buildings

Article

Effective Factors for Implementing Building Information Modeling Using Fuzzy Method to Manage Buildings on Mars

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Abstract: Ever since mankind has known the world around him and space, he has been trying to find a suitable alternative for his current residence, the Earth. In this research, two main criteria for buildings on Mars and their information management were extracted by checking the library of studies on Mars. These two main criteria are the components of the building and the internal components of the building. The criteria for building components include the health of walls, the health of roofs, meteor protection, the health of facilities, and the health of windows (air exchange), and the internal components of the building, including air temperature, air pressure, ambient oxygen, ambient carbon dioxide, humidity, and the amount of light. These criteria, which were extracted from the library materials, were screened using the fuzzy Delphi method, which is one of the most accurate criteria screening methods and is completed by experts. After the opinions of experts, the criteria of health of walls, health of roofs, health of facilities, rejection, air exchange, ambient temperature, and oxygen content were extracted as final criteria. The results of the experts' paired questionnaire were analyzed using the fuzzy AHP method, and the health criteria of the walls, the health of the ceilings, and air exchange have the first priority; the criteria of the ambient temperature and oxygen level are the second priority; and the criteria of the facilities are the last priority. These were placed as a suggestion, and it can be stated to the researchers that these priorities should be implemented in the blockchain platform so that the building information management system (BIM) works well in buildings on Mars and against any intrusion or damage. Being resistant, but it seems that the experts considered the components of the building separately from its protective components and put components such as the health of the window as a guarantee of the architecture of Martian buildings and did not include them as part of the main criteria of the research. Also, this research can be used as background for other research in this field.

Keywords: Mars; Earth; BIM; blockchain; expert analysis

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1. Introduction

Mars is the fourth planet in the solar system. It has a diameter that is only half that of the Earth. But the Earth has numerous qualities, and these characteristics lead us to conclude that there is life on Mars. It is even plausible that intelligent life exists on Mars. These hypotheses were confirmed after unmanned space probes traveled past Mars and transmitted data to Earth. These space travelers discovered that Mars is a frigid and dry planet, similar to the Moon rather than the Earth [1]. Large portions of Mars's surface are riddled with holes. The density of the Martian atmosphere is extremely low, comparable to that of the Earth's atmosphere about 50 km above sea level. This atmosphere is largely made up of carbon dioxide and a trace of water [2]. It does not include oxygen or nitrogen; however, they are most likely present in trace amounts. Because the air on Mars is so thin, UV light, which is harmful to most living organisms, can quickly reach the surface from space [3]. Large areas of Mars's surface were once covered with water, and the polar caps are made of frozen water. The explorers' samples of Martian soil were returned once the water warmed up [4]. Mars has piqued the interest of astronomers more than any other planet. There are two basic causes behind this.

- Among the planets that are far from the sun, Mars is the closest to Earth. In its orbit, Mars sometimes comes relatively close to the Earth, is located at a distance of about 56 million kilometers from it, and is one of the brightest objects in our night sky. The color of this planet is orange-red, and it can be seen easily with the naked eye. Mars is called the red planet.
- Mars and Earth are similar to each other in several ways. The duration of a Martian day is only about 40 min shorter than ours. Mars has an atmosphere. Like the Earth, it has seasons and a cap of ice on its poles. At one time, many scientists believed that there might be a yard on this planet [5].

Since then, a number of robotic space explorers have visited Mars, and reports have returned many images to Earth. These texts almost convince us that there is no life on this planet, although perhaps Mars's past climate was more conducive to life. Unfortunately, the Martian atmosphere is not breathable for humans, consisting primarily of carbon dioxide and a trace of water vapor. It should also be noted that Mars's atmosphere is extremely thin, with an average atmospheric pressure one hundredth that of Earth [6].

These features of Mars and its unique topography and landforms have sparked intense interest in Mars exploration and the possibility of future Martian migration. In the future, the Mars exploration missions of various countries around the world will continue to advance with the aim of further investigating the external environmental conditions and internal structure of Mars and laying the foundation for the further realization of the human mission to Mars [7]. Therefore, Martian buildings are extremely important for building information management. Because these researchers are at the beginning of their journey, therefore, building information management in these buildings will be different. Building Information Modeling (BIM) is a set of interrelated policies, processes, and technologies that provide a method for managing building design and initial project data throughout the life cycle of a building [8] and is a framework for safety managers that enables them to actively address the safety risks caused by construction activities and ultimately reduce the safety risks of the building [9]. Blockchain is a public, digital, decentralized document of data, assets, and all related transactions that is executed and shared among network participants. Although most associated with digital cryptocurrencies such as Bitcoin, blockchain is considered an emerging technology that could transform the current digital operational landscape and business practices of finance, computing, government services, and virtually every industry in existence [10].

Therefore, in this research, by examining the environmental conditions on the surface of Mars, we are trying to present and identify the factors that must be observed in Martian buildings for the continuation of life. Therefore, the management of these factors requires an impenetrable and secure system, for which blockchain is considered an emerging and reliable technology. But to what extent these factors should be controlled and which factors can be dangerous for humans need further investigation. In fact, the current technology available to mankind suggests Mars as the best option to replace the Earth for humans, but it still does not have the technology it needs to fully observe space, and it has limited humans to Mars or the Moon, which, due to the reasons, it can be said that the conditions on Mars are slightly better than on the Moon. Also, the Earth still has favorable conditions for the continuation of human life, but it is not known how long these conditions will remain stable, so until the study is completed, the issue of the continuation of life on other planets should be addressed. In this research, with a library approach, we are trying to find studies for the continuation of life as well as construction on the surface of Mars, and we have extracted the main and vital criteria with the help of specialists and experts and ranked these factors for the convenience of future researchers. We recommend reading this article to learn about blockchain-based frameworks for building information management on the surface of Mars. In fact, the main question of this research is: What criteria should be considered in Martian structures so that human lives are safe in Martian conditions?

In order to continue the research, the following assumptions are considered:

- Mars is considered the current option for the migration of humans from Earth.
- The atmosphere of Mars is different from the atmosphere of Earth, and it is not possible to continue life there as easily as on Earth.
- Taking care of human life against the dangers on Mars, such as lack of oxygen, ultraviolet rays of the sun, etc., is the most important challenge of life on Mars.

According to the assumptions of the research, it can be concluded that the study of Mars and the settlement on Mars can be a point of hope for mankind to continue their lives. Therefore, identifying the problems on Mars is of particular importance for the continuation of human life on this planet and trying to provide a solution to solve these problems can give researchers a vision of what features the structures on Mars should have and what criteria should be controlled. Therefore, this research has the following objectives:

- Identification of dangerous factors for life and survival on Mars.
- Ranking the dangerous factors to deal with them.
- Creating BIM guidelines for Martian buildings.

2. History

The fact that Mars is so similar to Earth piques researchers' interest in obtaining more solid answers about the existence of life on this planet. The sighting of ice pieces was one of the first discoveries of similarities between Mars and Earth in the mid-17th century. William Herschel highlighted in a report in the 18th century the variation in the volume of ice owing to changes in the atmosphere of each hemisphere of the globe throughout the summer and winter seasons [11]. By the mid-18th century, astronomers were confidently discussing the similarities between Earth and Mars, such as the length of the day on Mars being about the same as on Earth. They also recognized that Mars's similarity to the Earth's axial angle predicts a variety of seasons, exactly like on Earth, but twice as long. These observations raised confidence in the existence of water and land on this planet, and hence the possibility of living beings climbed dramatically [12]. Several speculations about life on Mars were published at the end of the 19th century based on telescopic sightings. In 1854, Cambridge University's William Whewell publicly offered the notion that Mars had land, sea, and, most likely, life. Percival Lowell, an American astronomer, released a book called *Mars* in 1895 concerning this planet and the water channels seen in it, claiming that these channels prove the existence of a very ancient civilization on Mars. This viewpoint motivated the English writer H. G. Wells to produce *The War of the Worlds* in 1897 in response to the unknown and weird beings living on Mars who were forced to leave. Clearer and more comprehensive photographs taken by the Mariner 4 spacecraft in 1965 revealed a Mars devoid of rivers, lakes, or evidence of life. The Viking projects' investigations to image and test the presence of bacteria on Mars were likewise inconclusive [13]. Finally, in 1990, it was demonstrated during a project dubbed "Mars Global Surveyor" that Mars, unlike Earth, lacks a magnetic field, allowing radiation to reach the planet's surface. Furthermore, scientists underlined that the lack of a magnetic field caused solar winds to destroy most of Mars's air over billions of years [14]. In recent years, following the studies conducted on the celestial rock ALH84001 and the discovery of fossilized microbes in it, various discussions about the existence of life on Mars have again been discussed and caused disagreements in the scientific community [15].

2.1. Atmosphere

In comparison to Earth, the oxygen content of Mars's atmosphere is quite low. This gas makes up only 0.13% of Mars's entire atmosphere, whereas oxygen makes up 21% of our planet's atmosphere. Carbon dioxide makes up 95.3% of the Earth's atmosphere. Nitrogen is 2.7%, argon is 1.6%, carbon monoxide is 0.7%, and water vapor is 0.3% [16].

2.2. Clouds

Clouds of frozen carbon dioxide particles form at great elevations in the Martian atmosphere. Furthermore, cloud and fog creation with water ice particles is fairly prevalent. Early dawn is the foggiest hour. Because the air is at its coldest at that time, the water vapor becomes dense [17].

2.3. Wind

The atmosphere of Mars, like that of Earth, has a basic cycle and wind pattern that sweeps across the planet. Carbon dioxide gas concentration and evaporation near Mars's poles have a substantial impact on the whole cycle. The carbon dioxide in the atmosphere is concentrated at the two poles as winter approaches. As a result, to fill the hole created by this gas, additional carbon dioxide travels toward the poles. When spring arrives, the frozen carbon dioxide evaporates, causing this gas to move away from the poles. The winds on Mars's surface are typically calm, with speeds of around 10 km per hour [18].

2.4. Dust Storm

The blowing of winds accompanied by dust is one of the most visible aspects of Mars's weather. Small tornadoes can lift soil off the planet's surface for a brief period of time. These minor winds resemble terrestrial tornadoes. Severe dust storms form when wind lifts dust into the atmosphere. Because of the absorption of sunlight, the air around the soil particles is heated at this time. When warm air rises, the wind blows stronger and picks up more dust. As a result, the storm intensifies. On a larger scale, the dust storm can cover an area larger than 320 km^2 or perhaps several thousand km^2. Larger storms can cover the entire planet's surface. Such storms are rare, but they can linger for months. The most powerful storms can render the entire globe invisible [19]. Such storms occurred once in 1971 and once in 2001. Sandstorms occur most frequently when Mars is close to the sun. The reason for this is that the sun heats the atmosphere more at those times [20].

2.5. Mass and Density

Mars has a mass of 42.6 $\times$ 1020 tons, which can be written as 642 followed by 18 zeros. The mass of Earth is around ten times that of Mars. Mars has a density of 3.933 g per cubic centimeter, which is around 70% of the density of Earth [21,22].

2.6. Force of Gravity

Because Mars is much smaller and lighter than Earth, its gravity is much lower. It accounts for only 38% of the Earth's total. As a result, a person standing on the surface of Mars will believe he has lost 62% of his body weight. Similarly, if a rock is dropped on Mars, it will arrive at the planet's surface much slower than it would on Earth [23].

2.7. Shell

Mars's crust is around 50 km thick on average. Because the southern hemisphere has greater elevations, the northern hemisphere's crust is thinner. The majority of the crust is most likely composed of basalt volcanic rocks. Basalt can also be found on the surfaces of the Earth and Moon, as well as Mars. Andesite rocks are found on Mars's surface, particularly in the northern hemisphere. Andesite is a type of volcanic rock that can be found on Earth. This stone contains more silica than basalt [24]. Silica is a silicon-oxygen molecule.

2.8. Plains

Many areas of Mars are plains. Most of these areas are located in the northern hemisphere. In the northern parts of the northern hemisphere, the flattest and smoothest regions of the solar system are located. The smoothness of these areas is most likely due to the sediments that created them. There are many reasons why water once flowed on the surface of Mars. The presence of water has caused the formation and accumulation of sediments [25].

2.9. The Valleys

On Mars, there is a remarkable emblem along the equator. The Martian valleys are a wide group of valleys. In 1971, the Mariner 9 spacecraft detected this occurrence on the surface of Mars. The valley runs from east to west and is approximately 4000 km long, which is the width of Australia or the distance between Philadelphia and San Diego. Scientists believe that this system was formed as a result of a fissure in the crust. The unusual valleys of the Martian valleys span 100 km. The valleys connect in the center section, which is 600 km broad. In certain areas, the valleys reach a depth of 8 to 10 km [26].

2.10. Volcanoes

Mars features the solar system's greatest volcanic mountains. The tallest of them, Olympus, has a diameter of 600 km and a height of 27 km. It is bordered by low plains. Arsia, Askreus, and Paonis are the other three major volcanoes of Mars, and they are located in a high terrain known as Tharsis. All of these volcanoes, like the volcanoes of Hawaii, have a steadily increasing slope. There are numerous additional types of volcanoes on Mars, from little conical hills to frozen molten material plains. Scientists do not know when the last volcanic eruption on Mars happened, but tiny eruptions may still occur [27].

2.11. Pits and Impact Areas

Many heavenly rocks that have collided with Mars over the course of its history have formed holes in its surface. These impact pits are extremely uncommon in the ground for two reasons: (1) The previously built trenches have been lost owing to erosion. (2) The dense atmosphere of the Earth stops rocks from colliding and generating holes. The holes on Mars's surface are extremely similar to the holes on the Moon, Mercury, and other solar system objects. The pits are bowl-shaped and deep. The core peaks of larger craters can be created by post-impact crustal rebound. The number of craters on Mars varies substantially from location to location. Because the surface of Mars in the southern hemisphere is quite old, it has many craters. Other locations, particularly those in the northern hemisphere, are younger and contain fewer craters. Some volcanic mountains include craters, indicating that they were formed very recently. Volcanic molten material can fill all existing holes. So, there has not been much time since the last eruptions, or else the number of craters on the volcanic mountains would be larger [28].

2.12. Polar Sediments

Thick volumes of sedimentary debris are the most intriguing occurrences in Mars's polar regions. A combination of water, ice, and soil particles forms these layers. These sediments have been found to stretch up to 80 degrees from each pole. The atmosphere has resulted in the deposition of layers over time. These layers are records of the activities and seasonal changes in the weather over very lengthy time periods. One possibility for temperature change on Mars is a shift in the planet's longitudinal axis. These fluctuations affect the amount of sunlight reaching different sections of the planet, resulting in general changes in the weather on Mars. The amount of sediment produced by the atmosphere is closely related to prior climate variations. Water ice caps exist in the form of ice on top of the sedimentary strata in both hemispheres throughout the year. These layers, as well as the cap on top of them, are many kilometers thick [29]. Seasonal caps produced from frozen layers also develop in the winter. Telescopes on the ground can clearly see these caps. Seasonal caps are made of frozen carbon dioxide or dry ice, which is generated from atmospheric carbon dioxide. These layers can reach up to 45 degrees toward the equator on the coldest days of winter [29].

2.13. Formation of Rock on Mars

Viking landers landed on Mars in 1976. They photographed a dry surface with large boulders located among gravel, sand, and mud. These were basalt stones. Some contained small holes from which gas was apparently released. On Earth, such basalts originate from volcanic lava filled with foamy gas. The rocks of Mars also probably had such a source. The soil of Mars is similar to the hardened soil of Earth's deserts [29].

So far, different types of rocks and sediments have been discovered on the planet Mars. Most of these stones are similar to the stones of the Earth, and some of them are discussed below.

Mudstone

Figure 1 shows the sedimentary rocks of the Kimberley Formation in the Gale Crater, which was recorded by the NASA probe on Mars in 2015. This crater has thick and flaky deposits of mudstone, which indicates fine-grained particles that have been in stagnant water for a very long time and were able to leave such a large thickness of sediments after settling.

Figure 1. Mudstone.

Sandstone

Figure 2 shows an outcrop of layered sandstones that can be seen on a part of Sharp Mountain. This was also photographed by NASA on the surface of Mars in 2015. This type of layering is very similar to the outcrops of windy sands that are abundant in the American Southwest.

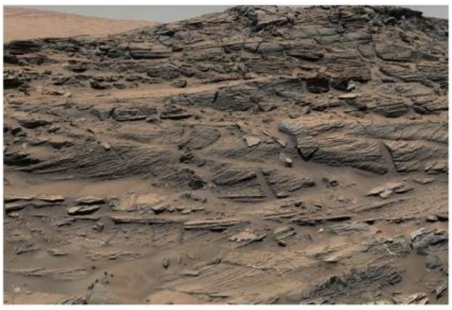

Figure 2. Sandstone.

Shale

Figure 3 shows a view of shales on the surface of Mars. This photo was taken in 2012 and is actually part of an outcrop inside the Gale Crater. The color of the image has been balanced to make it more similar to the surface of the planet Earth. These shales are fine-grained and flaky and are easily broken into thinner sheets. On Earth, the rocks that break down in this way are usually clay or mica grains that form through suspension and sedimentation in water. Since the rocks on Mars are generally made of clay, it is likely that these shales are also composed of clay minerals.

Figure 3. Shale.

Conlagomera

Conlagomera pebbles are detrital type and the result of water erosion. The presence of sandstone and conglomerate on Mars indicates the movement of water on the surface of this planet. The wind current is not strong enough to move the piles (pebbles) with a diameter of more than 1 mm. The piles that can be seen in this picture are highly rounded, which means that they have traveled a lot and had enough time to become rounded. The red color of this conglomerate is also the iron oxide that makes Mars known as the Red Planet. The cement that binds the piles together is probably a sulfate mineral.

Meteorite

Meteorites are not only alien to the planet Earth, but are the same for Mars. The first meteorite discovered on the surface of Mars in 2005 is about the size of a baseball.

Scoria

Figure 4 shows a volcanic rock that is very similar to mineral debris or scoria. The stone seen in the figure has an uneven surface and holes similar to scoria holes.

Figure 4. Scoria.

2.14. The Cause of Red Mars

This entire planet of Mars is a vast desert. There is no water flowing on its surface, nor is there any water in its atmosphere. The color photos show a completely dry and barren landscape covered with scattered rocks. The red color of this planet is due to the rocks that have iron oxide (iron rust). Some of these stones are also found on the ground. Only the surface of Mars has this color because the Viking ships excavated it and showed that there are dark-colored rocks under the red dust. Due to the presence of red dust, even the sky of Mars can be seen in this color. Sometimes, big dust storms appear, and almost every ten years, a huge tornado occurs that engulfs the entire planet [30].

3. Buildings of Mars

3.1. Steel

Steel, with a history of thousands of years of technological evolution, is almost the ideal building material and basic structural element for discovering military equipment on Earth. Steel has a fairly short learning curve. Steel is one of the most essential economic construction materials on the planet. The world produced 1.1 billion tons of steel in

2005. (This much outnumbers aluminum production, which is estimated to be around 30 million metric tonnes). It is found in everything from automobile engines to bulldozers and skyscrapers. Steel will also play an important role in space construction. Stoker et al., for example, proposed purifying metallic iron from Martian iron oxides by first concentrating the iron oxides with acidic leeches and then hydrogen reduction [31]. Iron and steel are collected on Earth from oxide sources ("iron ore"), most commonly hematite (Fe_2O_3) or magnetite (Fe_3O_4). Minerals are concentrated on Earth by geochemical processes that typically involve water and, in some cases, microbes (e.g., banded iron formations). Carbothermal reduction is commonly used to convert ores from oxide to metal.

3.2. Iron Ore on Mars

Iron ore can also be found on Mars. The MER-B (Opportunity) rover discovered significant hematite in the form of small (4–6 mm) spherules or "concretes" [32], colloquially known as "cranberries" (Figure 5). These contain roughly 50% hematite by weight [33]. Martian ores, like Earth's rock deposits, were concentrated and created early in Mars's history by water diagenesis. If a place as vast as the landing site on Earth was rich in hematite, it would be classified as an iron mine. It is a mineral that is easily accessible. Hematite clasts are found in the soil and can be easily collected. It is also embedded in soft sedimentary rock, which is easily mined.

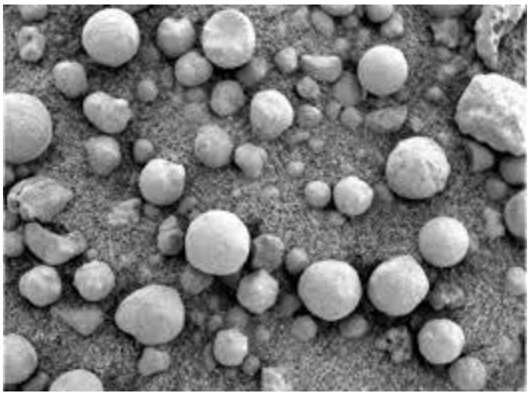

Figure 5. Iron ore on Mars. The hematite plumes found at the Meridiani landing site of the MER-B (Opportunity) mission contain approximately 50% hematite by weight [34].

3.3. Meteorites on the Surface of Mars

While the atmosphere on Mars is thick enough to reduce small- to medium-mass meteorites enough to survive an impact, the carbon dioxide atmosphere and the absence of liquid water allow nickel-iron meteorites to avoid oxidation, and iron remains in the reduced state for long periods of time, potentially millions of years [34].

3.4. Iron-Nickel as a Resource on Mars

The finding of reduced iron and nickel, an element found on Mars's surface, will alter our perspective on the question of internal resources for construction. Because of the potential to create iron without using energy-intensive procedures and reduction, creating steel on Mars would be far easier and less energy-intensive than producing steel on Earth. They virtually have complete recirculation [34].

3.5. Steel Processing Technology

The production of steel, rather than simple iron, requires the addition of carbon in controlled amounts. There are various means of reducing carbon dioxide to elemental carbon. One simple technology proposed for other applications is to use the Sabatier reaction of carbon dioxide with hydrogen to form water and methane, followed by the pyrolysis of methane to produce elemental carbon and hydrogen. The water produced in the Sabatier process can be electrolyzed to regenerate the original hydrogen reactant. There are also solutions for processing siderophiles and carbonyl elements. So far, we have found that, based on observations, the structural characteristics of Earth and Mars are relatively similar [34]. Mars colonization is a rapidly growing area of study and interest. NASA is preparing to launch the 2020 Mars rover [35] as part of a larger push to establish a human presence on the Red Planet, while SpaceX expects to begin manned missions in 2024 [36]. The construction of safe and durable structures using locally produced materials is one of the fundamental needs of a Martian community [37]. Concrete, for example, has been constantly advocated as an important structural material, with a wide range of formulations and procedures presented [38]. A comparative assessment of several choices and an analysis of their compatibility with the particular circumstances of the Martian environment are required for the successful use of concrete on the Red Planet.

3.6. Binders

In its most basic form, "concrete" is defined as a mixture of a binder and an aggregate (filler). Most binders necessitate the addition of water to the concrete formulation (ES is an exception). Additionally, though not necessarily essential, additives or admixtures may be added to affect the qualities of the concrete. On Earth, the use of OPC as a binder is so common that it is simply referred to as "cement". A binder, on the other hand, is any ingredient that causes the components of a mixture to cohere [18], and alternative binders to OPC may be appropriate for Martian concrete. An important point is that various methods have been presented for making concrete on Mars, all of which have been tested in laboratory conditions. All these methods have been implemented using a 3D printer in laboratory conditions. All buildings on Mars are designed and built using 3D printers, which is proof that the buildings on Mars and Earth are different. Therefore, different materials and tests must be conducted to reach a final model. But the point that should be noted is that all the structures must be constantly checked [39]. The research [40] shows the first manned mission to Mars. In this mission, in the first phase, robots and devices will be deployed on Mars to build structures, and in the second phase, these devices and robots will be used as a practical base to advance the goals of human habitation. They are on Mars, and they start working. In this research, suggestions for the concrete used in buildings on Mars using a 3D printer have been presented. Also, other equipment to be used on Mars for the continuation of human life, including the facilities required for structures, how to enter and exit, air conditioning, how to lay cables, how to use water, etc., have been stated, and finally, other methods. The proposed methods have been compared. An important point in these articles is the use of a 3D printer for designing structures. Also, the type of utility structure is of special importance. The research project [41] shows how performance-based design tools can be implemented as an architectural design method that proposes an innovative approach to designing housing shells in extreme environmental conditions without human assistance. This research study attempts to use the environmental data disclosed by NASA and its habitat design requirements to develop a conceptual design for an innovative habitat form and then simulate it under Martian conditions to determine the structural behavior of the habitat shell according to finite element analysis. As a result of these analyses, two established typologies of proposed habitation forms are presented in terms of their structural performance under the extreme loads of the Martian environment. Internal radiation analysis is important to assess the cross-sectional thickness of the habitable crust and the amount of thickness needed to provide maximum radiation protection. Wind is also a major concern on Mars. In fact, the thickness of the housing shell section should be designed in such a way as to prevent the exchange of air inside and outside the housing, and this should be controlled with regard to ventilation. Also, this thickness should be such that it is resistant to the wind. Also, the location of windows and their resistance to settlement is something that should be taken into consideration. It is stated in the research [42] that Mars provides plenty of the raw materials needed to establish a lasting, self-sufficient human colony on its surface. Due to the planet's vast distance from Earth, it is neither possible nor economically reasonable to provide a permanent, interplanetary supply. In situ resource utilization (ISRU) will be necessary to keep the Earth launch burden and mission costs as low as possible and to provide, apart from propellant and life support, a variety of construction materials. However, including outposts on other planets in the scope of human spaceflight also opens up new psychological and sociological challenges. Crews will live in extreme environments under isolated and confined conditions for much longer periods of time than ever before. Therefore, the design of a Mars habitat requires careful consideration of the physiological as well as psychosocial conditions of living in space. In this research, it is suggested to use bags of Martian rock that are not usable for shielding against the impact of meteorites. In fact, it can be said that according to the atmosphere of Mars, there is a possibility of meteorites hitting Mars, but according to the atmosphere prevailing on Mars, these meteorites do not have large dimensions [43]. According to the contents stated in this section, in fact, the criteria that can be extracted from these articles are criteria such as checking the walls, roofs, meteor protection, facilities required for the building, installing windows, and the amount of air exchange. Due to the Martian winds, it is in a suitable location.

4. Life on Mars

Every human being has basic needs to continue living. To some extent, these needs exist on Earth in a God-given form. These needs, such as thirst and breathing, are easily available to humans due to the Earth's atmosphere, and access to the climate for breathing is easier than anything else. Even the Earth, due to the ozone layer, has protected humans from the ultraviolet rays of the sun, which are very harmful and dangerous for humans. The energy needed by humans through renewable energies and how to store them on Mars is in a state of ambiguity [44,45]. But in order to continue living on Mars, humans must appreciate these basic needs and not try to maintain them because Mars does not provide these facilities easily to humans. The extraction of water from Mars and its frozen waters at the poles of Mars is itself an issue that is still at the center of discussion among scientists in this field. The atmosphere of Mars does not absorb ultraviolet rays like the atmosphere of the Earth, and the atmosphere of Mars does not easily provide oxygen to humans. The fact that one day humans will migrate from Earth to Mars is shrouded in uncertainty. But research to investigate the conditions and create living conditions on Mars can help mankind know more about this planet and also hope to have a new habitat. Humans' irrational actions at the beginning of the industrial revolution, which is still ongoing, have faced the danger of destroying the Earth. Of course, it is still too early to use the term destruction of the Earth, and this may not happen for hundreds of years. But finally, one should search and do research about the replacement of the land so that with the emergence of emergency conditions for the land, one can easily migrate to the new destination. Many studies and solutions have been conducted for the way of life and the shape and structure of buildings on Mars, but a final and reliable model has not been reached yet. But the important point is that the air temperature, air pressure, ambient oxygen, ambient carbon dioxide, ambient humidity, and ambient light should be measured [46]. In general, we have two types of data that were extracted from the articles. The first type is about the components of the building that provide living conditions. Table 1 shows these variables.

In fact, these studies show that paying attention to basic issues and challenges that do not exist on the ground is of particular importance. The criteria extracted from this review are completely different from the criteria for BIM in land buildings.

Table 1. Extracted variables from the articles.

Building components	Walls [35]
	The ceilings [31–33]
	Meteor protector [34]
	Facilities required for the building [39]
	Window (Air exchanges) [18,20]
The indoor environment of the building	Air pressure [21,22]
	The air temperature [16]
	Ambient oxygen [16]
	Ambient carbon dioxide [16]
	Ambient humidity [16]
	Amount of light [16,17]

5. Fuzzy Delphi

The predecessor of Delphi was a temple dedicated to Apollo, the god of the sun, music, and poetry, in the ancient city of Delphi. The Pythia was greatly credited for his prophesies, which were inspired by Apollo, and he was consulted before every major decision. Delphi, the old city, has since been turned into a contemporary city and is still standing. Pythian oracles have also been superseded by the Delphic procedure, a modern alternative. Delphi was used for the first time in the late 1950s in research by the US RAND Corporation to systematically investigate the opinions of specialists on the military defense project. The Delphi method's main purpose is to achieve the most trustworthy consensus of opinion from a group of experts via a series of rigorous surveys with controlled feedback. By establishing the consensus of a group of specialists, researchers can identify and prioritize problems as well as develop a framework for their diagnosis. The Delphi approach was defined by Lynnstone and Turoff [47] as a method of structuring a group communication process so that it is effective in helping a group of individuals to deal with a difficult problem as a whole. Several researchers have accepted this definition. According to Hasson et al. [48], there are various varieties of Delphi methodologies. Delphi modifications, policy Delphi, and real-time Delphi have all been employed. Delphi is utilized in three ways: classic Delphi, policy Delphi, and decision Delphi. The Delphi methodology is a tool and method for creating consensus that uses a series of questions to obtain data from a panel of selected individuals. The fuzzy Delphi technique has been used in a number of research. Kaufman and Gupta [49] invented the fuzzy Delphi forecasting approach. Ishikawa [50] created the Delphi technique using triangular fuzzy numbers as well. The Delphi method is a structured method for gathering data in successive rounds and eventually obtaining group consensus. Despite the fact that the Delphi technique has been used in scientific and academic study for more than 50 years, there are still many unknowns regarding it [51].

Fuzzy Delphi Technique Algorithm for Screening

The Delphi technique with a fuzzy approach can be used to determine the importance of criteria and to screen key criteria. One of the major advantages of the fuzzy Delphi technique compared to the traditional Delphi technique for screening criteria is that it can be used remotely to summarize and sort items.

The fuzzy Delphi technique algorithm includes the following steps:

- Identifying a suitable spectrum for fuzzification of linguistic expressions.
- Fuzzy accumulation of fuzzified values.
- De-fuzzification.
- Choice of threshold and screening criteria.

In the fuzzy Delphi technique algorithm for screening, first, a suitable fuzzy spectrum should be created to fuzz the linguistic expressions of the respondents. For this purpose, it is possible to use the methods of developing fuzzy spectra or common fuzzy spectra. For example, the triangular fuzzy spectrum for a five-point Likert scale on the importance of criteria is as follows (Table 2):

Table 2. Triangular fuzzy numbers with a five-point Likert scale.

Very Unimportant	Unimportant	Medium	Important	Very Important
(0, 0, 0.25)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1,1)

In this research, the following method of evaluating criteria is used. After choosing or developing a suitable fuzzy spectrum, experts' opinions are collected and fuzzy. In the second stage, experts' opinions should be gathered. Several methods have been proposed for the fuzzy aggregation of experts' opinions. If an expert's opinion is represented as a triangular fuzzy number (l, m, u), the simplest way to calculate the fuzzy average of experts' opinions is:

$$F_{AVE} = \frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n} \tag{1}$$

After the fuzzy aggregation of experts' opinions, the values should be de-fuzzified. With the different methods that are used with the fuzzy approach, the researcher finally converts the final fuzzy values into a clear and understandable number. Typically, the sum of triangular and trapezoidal fuzzy numbers can be summarized by a clear value, which is the best mean. This operation is known as fuzzification. There are many and complex methods for fuzzification. One of the simplest fuzzification methods is average triangular fuzzy numbers:

$$\begin{aligned}
&F_{ave} = (L, M, U)\\
&x_m^1 = \tfrac{L+M+U}{3}\\
&x_m^2 = \tfrac{L+2M+U}{4}\\
&x_m^3 = \tfrac{L+4M+U}{6}\\
&crisp \quad number = Z^* = \max(x^1_{\max}, x^2_{\max}, x^3_{\max})
\end{aligned} \tag{2}$$

The values do not vary much and are constantly close to M. M is the average obtained by summing the possible values of m from different triangular fuzzy numbers. However, the clear value is considered the maximum.

After choosing the appropriate method and unfuzzifying the values for screening, a threshold should be calculated. This threshold is usually 0.7, but it varies according to the opinion of the researcher in different studies. If the clear value of the unfuzzification of the collected expert opinions is greater than the threshold, the criterion is met. If the criterion is less than the threshold, it is removed.

6. Fuzzy AHP

The necessity of the fuzzy hierarchical analysis process: The AHP method has been widely used in choosing one option among other options, but in this method, pairwise comparisons are made for each level according to the purpose of choosing the best option using a nine-point scale. Therefore, the application of hourly AHP has some shortcomings, such as the fact that the AHP method (1) is mainly used for crisp decisions; (2) it examines a very unbalanced scale of judgment; (3) the uncertainties in individual judgments are not considered; (4) the ranking of this method is almost imprecise; and (5) subjective judgments, choices, and performances of decision-makers have a lot of effects on AHP results. In addition, it is acceptable that people's evaluations of quality indicators are always subjective and therefore, imprecise. Therefore, conventional and classical AHP seem to be insufficient and inefficient in accurately achieving the needs of decision-makers. In order to model this type of uncertainty in human preferences, fuzzy set theory should be combined with pairwise comparisons as an extension of the AHP technique. This hybrid decision-making technique provides a more detailed understanding of the decision-making process.

AHP is a multi-criteria decision-making tool that can construct complex problems hierarchically, thereby simplifying the evaluation of all criteria relevant to the decision to be made [52]. All options are compared separately based on each criterion using a preference scale, and a priority list of options is obtained for each criterion. The most commonly used preference scale is the 1–9 scale. Fuzzy AHP enables the decision analyst to provide a more realistic score for alternatives in cases where there are many uncertainties. Chang et al. [53] development analysis model is one of them that depends on the probability of each criterion.

Triangular fuzzy numbers (l, m, and u) are used to create a pairwise comparison scale, and a pairwise comparison matrix is constructed for each level in the hierarchy. Then, the subsets of each row in the matrix are calculated to have a new set. The overall triangular fuzzy values for the Mi criterion are obtained by calculation. Membership functions, which mean the average weight of the options in the corresponding matrix, are calculated using these values for each criterion. They are normalized, and the final significance weight of each criterion is obtained. To apply the process depending on this hierarchy, according to Chang et al. [53] development analysis method, each criterion is considered, and for each criterion, the GI criterion is measured.

The fuzzy hierarchical process method is used for weighting and ranking criteria or research options. There are three methods for calculating the weights in the fuzzy AHP method: Chang's development analysis method, the improved fuzzy AHP method, and the Mykhailo fuzzy prioritization method.

In this section, we explain the fuzzy AHP method based on Chang's development analysis approach (Table 3).

Table 3. Scale of fuzzy numbers.

Scale of Fuzzy Numbers	Linguistic	Fuzzy Number
(8, 9, 10)	Perfect	9
(7, 8, 9)	Absolute	8
(6, 7, 8)	Very good	7
(5,6 , 7)	Fairly good	6
(4, 5, 6)	Good	5
(3, 4, 5)	Preferable	4
(2, 3, 4)	Not bad	3
(1, 2, 3)	Weak advantage	2
(1, 1, 1)	Equal	1

Step 1: Forming a hierarchical research model.

In this step, after identifying the criteria, sub-criteria, and research options, the hierarchical model of the research should be determined.

Step 2: Forming tables of paired comparisons and answering according to the following spectrum.

In this step, as in the AHP method, pairwise comparisons should be created, and based on the following fuzzy spectrum, answer these paired comparisons. This 9-band spectrum is a fuzzy AHP; of course, you can use 5- or 7-band spectrums as well, but this 9-band spectrum is a standard spectrum.

Step 3: Calculate the incompatibility rate of paired comparisons.

In this step, the inconsistency rate of pairwise comparisons should be checked, and if this rate is less than 0.1, it means that the pairwise comparison has proper stability and consistency. The inconsistency rate in fuzzy matrices can be calculated in two ways. First, the fuzzy pairwise comparison matrix is defuzzified, and then its inconsistency rate is calculated definitively, or it can be calculated using the Goss and Butcher inconsistency rate calculation method. Goose and Butcher's incompatibility rate is available on this site, which you can learn for free by searching.

Step 4: Integration of paired comparisons.

When multiple respondents answered the pairwise comparisons, the geometric mean method was used to combine them to obtain a merged pairwise comparison matrix. The integration of fuzzy matrices is such that the geometric mean of the first terms of all comparisons, the second terms, and the third terms are taken together.

Step 5: Calculation of weights by Chang's development analysis method.

First, based on the following relationship, we obtain Si values for each row of the fuzzy pairwise comparison matrix:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \tag{3}$$

where gi is the objective set and are triangular fuzzy numbers. Then, based on the following relationship, we obtain the magnitude (degree of preference) of each Si over Sk.

$$V(S_i > S_k) = \begin{cases} 1 & m_i \geq m_k \\ 0 & l_k \geq u_i \\ \frac{l_k - u_i}{(m_i - u_i) - (m_k - l_k)} & otherwise \end{cases} \tag{4}$$

In the last step, the raw weights are calculated using the following relationship, which is obtained by dividing each raw weight by the total raw weights, and the normal weight is obtained:

$$\begin{aligned} &V(S \geq S_1, S_2, \ldots, S_k) = (V((S \geq S_1), (S \geq S_2), \ldots, (S, S_k)) \\ &= \min(V((S \geq S_1), (S \geq S_2), \ldots, (S, S_k)) \\ &= \min V(S \geq S_i) \qquad\qquad i = 1, 2, \ldots, k \end{aligned} \tag{5}$$

Suggested Method

After extracting the criteria shown in the table, these factors should be validated by experts, and with their opinions, it should be determined which of the variables is most needed in this research, which is achieved using the fuzzy Delphi technique. For this purpose, two experts working at NASA were used: one expert in construction management and one expert in risk management. Then, these factors are ranked using fuzzy ranking, or fuzzy AHP, so that the warning level can be determined based on them. The results of this research can help us implement a blockchain-based BIM system.

As mentioned, the statistical population of this research is four experts in this field, and these experts were identified using the snowball method (Figure 6).

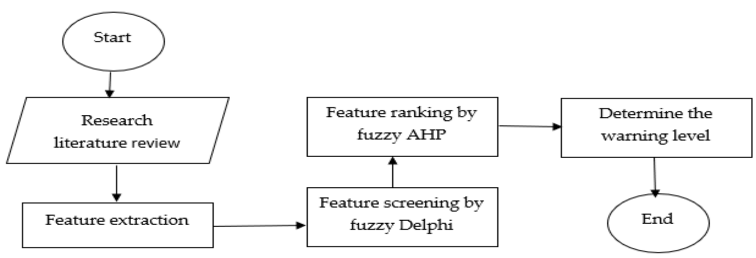

Figure 6. Flowchart of the proposed method.

7. Findings

The results of the fuzzy analysis performed on the expert results have been explored in this chapter, which is divided into two parts: fuzzy analysis and the results derived from blockchain. The fuzzy figures of each of the criteria against each other, as well as the ranking based on the final weight produced from the fuzzy AHP hierarchical analysis algorithm, are shown in this part. Following this stage, the outcomes of the blockchain and BIM integration will be discussed.

7.1. Suggested Method

In this phase of the research, experts' opinions were collected about the evaluated criteria. In the process of implementing this stage, the questionnaire was provided to the experts, and Table 4 shows the results obtained from this questionnaire.

Table 4. The results of the experts' answers.

The Main Criteria	Criteria	Expert 1	Expert 2	Expert 3	Expert 4
Building components	Walls	5	5	4	5
	The ceilings	5	4	5	5
	Meteor protector	1	2	1	2
	Facilities required for the building	1	3	3	2
	Window	4	5	3	4
	The air temperature	4	3	1	4
The indoor environment of the building	Air pressure	1	2	1	1
	Ambient oxygen	5	4	1	5
	Ambient carbon dioxide	1	1	1	1
	Ambient humidity	1	2	1	1
	Amount of light	1	1	1	1

After receiving the opinions of the experts, these opinions were analyzed in fuzzy-delphi-analysis-v2-01 software, and the results are as follows. The obtained threshold was equal to 0.169, which included six criteria, and the rest of the criteria were excluded from the analysis. Table 5 shows these criteria, along with their ranking and the points they obtained.

Table 5. Final criteria.

Criteria	Points	Rating
Walls	75/0	1
The ceilings	683/0	2
Facilities required for the building	267/0	6
Air exchange	6/0	3
Environment temperature	417/0	5
Ambient oxygen	567/0	4

Of course, it should be mentioned that, according to some experts, criteria such as dealing with meteorites can be seen in the walls or ceiling, or they have no function in BIM and cannot be addressed in the BIM of a building. All the extracted criteria can be evaluated and are important in their own right, but due to the increase in the number of calculations, it is obvious that some of these criteria will be left out of the research cycle. Now, after extracting the criteria, they can be ranked, and Table 6 shows the results.

Table 6. Rank of the results.

	Walls	The Ceilings	Facilities Required for the Building	Air Exchange	Environment Temperature	Ambient Oxygen
Walls	1	1.2	4.5	1.2	3.7	2.4
The ceilings	-	1	3.7	0.5	2.9	2.4
Facilities required for the building	-	-	1	0.2	0.4	0.3
Air exchange	-	-	-	1	4.5	2.4
Environment temperature	-	-	-	-	1	0.5
Ambient oxygen	-	-	-	-	-	1

7.2. Ranking Factors

In this section, the results and the results of the data collected from the questionnaires distributed to the experts will be discussed. In the first part, the data are reviewed, and then the other sections mentioned in the Introduction are discussed. In this analysis, according to the method described in the previous part, four pairs of questionnaires were distributed among the experts, which in this part are given to express the opinions of the experts involved in the research. In total, there are six main criteria that must be entered into BIM and stored on the blockchain for buildings on Mars. In the following, you can see the even matrix obtained.

In this matrix, each number represents the share of superiority or non-superiority of the criterion according to experts in comparison with other criteria. For example, the coefficient (1.5), which is equal to 3.7, shows that according to the experts involved in the design, the criterion parameter of the wall is superior to the ambient temperature by a ratio of 3.7.

The obtained pair matrix should be examined from two perspectives:

- Inconsistency rate.
- Being symmetrical.

One of the features of this matrix is that the columns are symmetrical; that is, for example, the columns (1, 2) and (2, 1) are inversely proportional to each other, and each is equal to the inverse of the other. In this matrix, this criterion has been met in all regions, which will be approved from this point of view.

Regarding the inconsistency rate, it should be stated that a program was written in MATLAB software (https://www.mathworks.com/products/matlab.html) (accessed on 20 August 2023) to calculate this value, and it is connected to the main fuzzy analysis code of this research. If the condition of the inconsistency rate is not satisfied, the analyses related to that inconsistency matrix will not be carried out until this inconsistency is resolved. Regarding this matrix, it should be stated that the algorithm for calculating the inconsistency rate has shown a number of 0.225, which shows a rate much lower than 10%. So, for this reason, and by observing the two stated conditions, we can be sure of the results obtained from this paired matrix.

It should be noted that there are two algorithms regarding the inconsistency rate in the fuzzy method: one is a common algorithm to calculate this rate, and the other is to calculate the inconsistency rate of the fuzzy matrix obtained from the paired matrix. The important point is that if there is an inconsistency in the even matrix, there is no need to check the inconsistency rate with the fuzzy algorithm, and if in some cases the inconsistency rate exceeds 10%, this method will also be examined, and then a decision will be made to resolve this inconsistency.

7.3. Fuzzy Distribution Charts

In this section, the analysis results and fuzzy matrices are discussed. Figure 7 shows the image of each of the fuzzy number graphs presented for the fuzzy matrix, which can be seen for each variable.

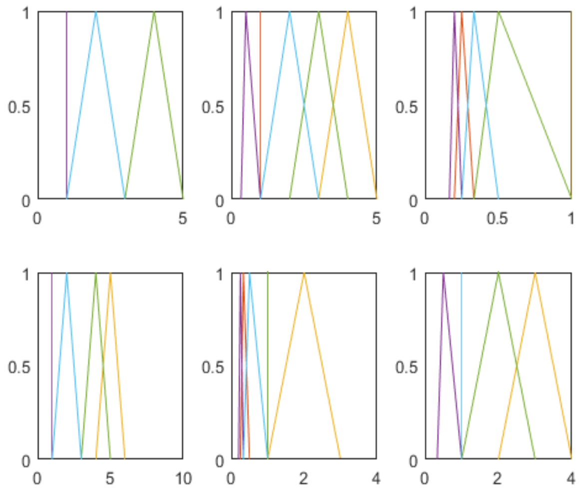

Figure 7. Main variables as fuzzy number diagrams.

In the given figure, there are as many main variables as fuzzy number diagrams, each of which is related to the measurement of the variable compared to other variables in a fuzzy manner, which is produced by the fuzzification function in the provided program. These charts are also like paired matrices, and the degree of superiority can be determined from them. Graphs that have compact and low values correspond to inverse phase values, which indicate a low variable superiority ratio, and graphs that are open and have larger numbers indicate superiority over others. It can be seen that the first variable, which has the advantage over all, has a completely open and uncompressed graph.

7.4. Fuzzy Final Ranking

In this part, Figure 8 shows the details of the final ranking of the criteria included in the research.

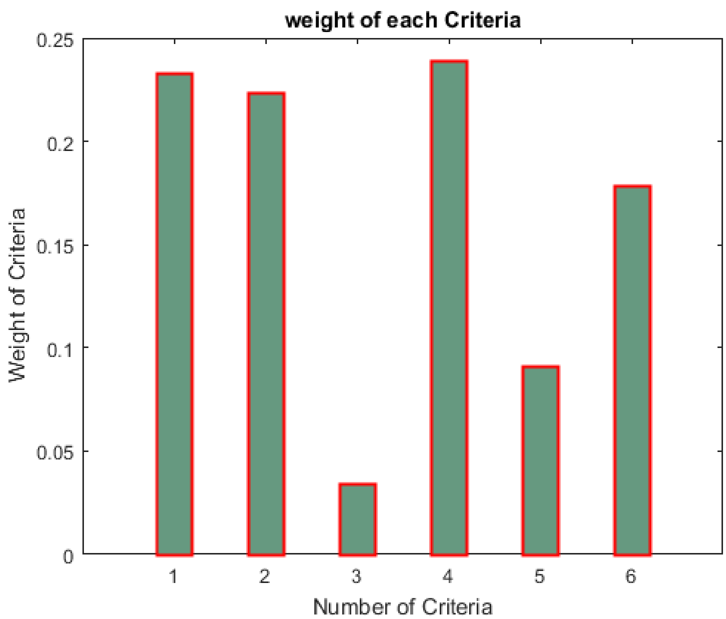

Figure 8. The final ranking of the criteria.

As it is clear in the figure, the first, second, and fourth criteria, which are the roof, wall, and air exchange, respectively, have the first rank and are of special importance from the experts' point of view. The fifth and sixth criteria are also in the next rank, which are the ambient temperature and the amount of oxygen in the environment. Finally, the last rank is assigned to the facilities, which have a lower degree of importance. Therefore, based on the opinions of our experts, we can now carry out our implementation.

8. Conclusions

During human life on Earth, man has caused the most damage to the environment and the Earth, his residence. Therefore, some of these damages are irreparable, and the Earth's ecosystem has undergone many changes. Therefore, some of these damages, such as ozone layer perforation, are irreparable. After people realized that they should be more concerned about their environment, they tried to compensate for the damages, but it was too late. After much research, the researchers came to the conclusion that they should choose a suitable alternative for Earth. According to its characteristics, Mars can be introduced as a substitute for Earth. Of course, considering current human technology, it seems that Mars is the only option. But Mars, in addition to its similarities with Earth, also has differences that affect human life on its surface. The atmosphere of Mars, the entry of ultraviolet rays, etc., are among these differences. In this research, two general criteria for building components and internal components of the building were extracted from a detailed study of Mars and library research. These criteria for building components include walls, roofs, meteor protection, facilities required for the building, air exchange, and internal components. The building includes air temperature, air pressure, ambient oxygen, ambient carbon dioxide, ambient humidity, and light. Using the fuzzy Delphi method, the criteria of wall, ceiling, building facilities, air exchange, ambient temperature, and ambient oxygen were extracted as the final criteria and provided to the experts in the form of a paired questionnaire. The results of the experts' paired questionnaire were analyzed using the fuzzy AHP method in MATLAB software, which showed that the criteria of roof, wall, and air exchange have high priority. The next priority included ambient temperature and ambient oxygen level, and finally, the criteria for facilities were ranked last. In fact, from the results, it can be argued that maintaining shelter and controlling oxygen in the environment, which is a critical element for the continuation of human life, is of great importance according to the opinions of experts and the analysis of the results. In reality, with the destruction of the wall or the roof of the building, or infiltration and creating a gap for the exchange of air in the environment, it is very dangerous and may endanger human lives. Therefore, these three options can be placed at the warning level of 3. Also, after this warning level, regarding the temperature of the environment and the amount of oxygen, the increase in temperature indicates the penetration of ultraviolet rays into the settlement, or the lack of oxygen indicates a defect in the production of oxygen, both of which can be dangerous for the continuation of human life, but they can be fixed, so they are placed at the level of warning 2, and finally, the inspection of the building's facilities, which cannot have much risk, is placed at the level of warning 1. Considering the fact that the buildings on Mars are of special importance and the slightest intrusion and failure in receiving information and processing may put human lives in danger, it is suggested that the results of this article be implemented in the form of a blockchain framework. The reason for using blockchain is that this technology is emerging and has very high security. Therefore, the information is fully protected, and less risk can threaten it and ultimately, human life.

Among the limitations of this research, we can point out that, considering that there is no similar case on Mars and the knowledge of Mars is not yet complete, this research can only be the beginning to continue the research in this research field. Also, considering that the results obtained in this research are based on the opinions of experts, it is possible that the experts have presented their opinions in a biased manner. Additionally, another limitation of the research is that it is very difficult to know experts in this field, and few people participated in this research. Moreover, a plan and a standard for the construction of settlements and shelters on Mars have not yet been presented, so the results of this research are only suitable for models in which the presented model can be implemented. Furthermore, considering the high security of blockchain as the final use of the results of this research, this technology has a low speed in extracting information, which is one of the problems and challenges of this work, which can perform poorly for the level of warnings provided. As another suggestion for future researchers, it can be suggested to use machine learning and reinforcement learning models as well as statistical data collected from the surface of Mars to provide a model to determine important criteria for the protection of humans on Mars.

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