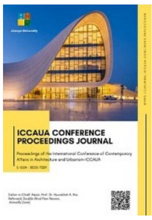

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Conditions of the Moon as Assessment Criteria: Turkish Moon Bases Competition Case

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Abstract

Sustainable human presence on the Moon is directly proportional to humanity's capacity to adapt to the Moon's environmental conditions. Designs on the lunar surface must be tailored to the physical conditions of the Moon. Within the scope of this study, a preliminary literature review identified atmosphere, pressure, wind, temperature, radiation, gravity, and dust as conditions that directly affect habitat design on the Moon, with each condition expressed as an evaluation criterion. As the sample area, five architectural design projects awarded in the Turkey Moon Bases National Idea Competition (Professional Category-2022) were analyzed. The main question of the study is to what extent these designs respond to the specified criteria. Based on the second literature review, which analyzed and clarified lunar conditions in depth, the projects were scored according to their compliance with the established criteria. Each project's site plan, plans, sections, 3D visuals, and project reports were evaluated on a scale of 100 points. In this context, a knowledge-based evaluation was conducted as an alternative to jury-based evaluation. Analyzing the projects from the Turkey Moon Base Competition is significant in providing a knowledge base for future studies in this field.

Keywords: Moon base habitat design;The Turkish Moon Bases National Idea Competition; Architectural Design Assessment; Knowledge-Based Design.

1. Introduction

The idea of establishing a permanent base on the Moon arose as a result of increased scientific research to explore space, collect more data about our universe and plan long-term studies of deep space. However, there is limited information about the design of living spaces on the Moon. This information is likely to undergo many changes in the future in terms of lunar habitat design. The universal priority for space architecture is to support sustainable user productivity through good design, while protecting the health and safety of the crew (Cohen and Houk, 2010). The architectural designer must adopt an interdisciplinary approach and develop a design model that can respond to the challenges posed by lunar conditions in the construction of a potential lunar habitat. The main challenges for short- or long-term missions in space should be identified and analysed in detail. The American Institute of Aeronautics and Astronautics has identified the main challenges to long-duration spaceflight as: spacecraft operations, communication difficulties, lack of adequate on-board resources, and crew presence in microgravity, which is airless and fraught with radiation and other hazards. (Dudley, Okushi, Gangale, Flores ve Diaz,2003). Many studies have been carried out in an attempt to create a suitable space mission roadmap for a long-term lunar habitat design. It is stated that the types of land on the Moon vary. New settlements will be exposed to the harsh environmental conditions of the Moon (Mueller,2022). Low gravity, extreme temperature variations, exposure to high-energy solar radiation, cosmic rays, micrometeorite impacts, corrosive electrostatic dust, zero atmosphere and limited human habitats are conditions specific to the lunar environment and need to be considered in architectural design (Inocente, Koop, Petrov, Hoffman, Sumini et la., 2019). Although no settlement has yet been established on the surface of the Moon, studies in this area are being carried out by a number of public and private institutions and organisations. Design proposals and competitions for lunar habitats submitted by various architectural firms and public/private organisations provide a knowledge base and inspire future lunar habitat design studies. The Artemis programme, announced by NASA in 2020 and carried out in partnership with various space agencies (ESA, CSA, JAXA), aims to develop the necessary operations and systems for a long-term scientific exploration mission to the Moon and Mars (The Artemis Accords, 2020). The Artemis programme is made up of four different categories, covering various tests and steps to build the first lunar gateway, with the aim of launching crewed missions to Mars from the 2030s. The Artemis programme not only aims to establish a human presence on the surface of the Moon. It also plans future missions to Mars (Deel, 2024). This program, which was carried out by various companies and organizations for a common purpose, accelerated research in the field of space. At the same time, the programme played an important role in the development of various designs for lunar habitats. In this context, it is important to have architectural design competitions that allow participation from different levels and disciplines in the development of design proposals for extraterrestrial habitats. One of the large-scale competitions, the 3D Printer Habitat Competition, which was held as part of the Centennial Challenges program launched by NASA (National Aeronautics and Space Administration) in 2015, was concluded in 2019. This competition has been a pioneer for current studies to be carried out in this field (Mueller, Prater, Roman, Edmunson, Fiske and Carrato, 2019). In our country, the Turkey Space Agency established in 2018 played an active role in carrying out studies in this field. For the first time in 2019, the 'Mars 2050: Habitat National Idea Competition' for the design of an extra-planetary habitat. In 2022, the "Türkiye Lunar Bases National Idea Competition" was organised in three different categories. This allowed participants from different levels in our country to be involved in studies in this field. The aim of the Moon Base Design Competition, which has been organised to promote space technology and awareness in Turkey, is the development of ideas that address the themes of 'extraterrestrial urbanism and space architecture' (Turkey Moon Bases National Idea Competition Specification,2022). In this study, the "Turkey Lunar Bases National Idea Competition" was selected as the sample area because it is the first competition organised in Turkey for designing lunar bases and the most recent architectural design competition for designing lunar bases. The Artemis programme, which is one of the most important space base studies being carried out in the world today, has identified the Moon as the first station to be established and is concentrating its studies in this area. Therefore, this study focuses on the architectural projects that have been awarded in the professional category of the Turkey Lunar Bases National Ideas Competition, in order to be able to analyse similar studies in our country. In this context, the physical conditions of the Moon, which have a direct impact on the design of the habitat, have been studied in detail. Mars habitat design studies conducted in our country and around the world, and not included in the scope of this study, should be considered as a separate study topic.

2. Physical Conditions of The Moon

The Moon's environment consists of a combination of radiation, atmospheric, thermal, meteoroid, magnetic field, and gravitational field mechanisms (Lindsey, 2003). Ay'da atmosfer olmaması ve çok az jeolojik aktivite olması nedeniyle Ay yüzeyi zaman içerisinde çok fazla bozulmamıştır. Ay yüzeyinde milyarlarca yıllık asteroit çarpmaları yüzeyde belirgin izler halinde korunmuştur. Bu kraterler, Dünya da dahil olmak üzere iç güneş sisteminin zaman içinde asteroitler tarafından ne kadar sık ve yoğun bir şekilde vurulduğunun kaydını tutmaktadır (Ruess, Schaenzlin ve Benaroya, 2006; 134). Satellite pictures and other data have revealed the following things on the Moon's surface: (1)there are many different minerals on the floor and peaks, (2) the impact melt deposits are different in different places, and the minerals in them are different too, (3) there is a lot of evidence of special windows (craters, cracks, pits) into these units (Schreiner, Setterfield, Roberson, Putbrese, Kotowick and Vanegas et la. 2015). The Moon's physical environment is significantly different from that of the Earth. As a consequence, lunar construction techniques differ from those employed on Earth. (Benaroya, 2002; Benaroya, 2018) It is not known exactly how these physical conditions, which differ from the world, have a long-term impact on human health, technologies, building components and materials. It is clear that structures need to be designed with a good understanding of how their materials behave and age in the low gravity of the Moon (Benaroya, 2018).

Table 1. A comparison of the properties of Earth and the Moon (Benaroya, 2018; Naser, Redmond, Chen ve Rangaraju, 2023).

Properties	Earth	Moon
Surface area (km²)	510.1 $\times 10^6$	37.9 $\times 10^6$
Radius (m/s^2)	6371	1738
Gravity at Equator	9.81	1.62
Surface temperature range (°C)	−89 ile 58	−173 ile 127
Magnetic vector field (A/m)	24–56	0
Surface atm pressure (kPa, psi, mbar)	101.3, 14.7, 1000	Negligible, 0, 3×10^{-12}
Day length (Earth days)	1	29.5
Diurnal length((hrs)	23.9	656
Main composition in the atmosphere*	N2, O2	He, Ar

*N2: Nitrogen, O2: Oxygen, He: Helium, Ar: Argon

Temperatures vary from very hot to very cold. One lunar day is about 29.5 Earth days. This means that extreme temperatures last longer. The atmosphere of the Moon is very thin, which results in an almost pressureless environment and a high level of radiation. The radiation and vacuum conditions pose significant challenges in the selection of suitable materials and equipment for the habitat. The Moon's gravity is about one/sixth that of the Earth's. This can affect adhesion and other gravity-related processes. Moon dust is made up of abrasive particles. It affects the operation of all systems (Azami, Kazemi, Moazen, Dubé, Potvin et la., 2024; 2-3). A detailed analysis of the lunar conditions is given below.

Atmosphere/Pressure/Wind: Our atmosphere is mostly made up of nitrogen (78%) and oxygen (21%). This gives it an adequate pressure level of 101.387 kilopascals (kPa) and protects us from extreme radiation (Naser et la., 2023). In contrast to Earth, the Moon lacks an atmosphere to prevent or mitigate heat exchange with deep space. The absence of atmosphere is also causing significant diurnal temperature variations and extreme radiation exposure (Duke,1998). The lack of a protective atmosphere on the Moon makes it necessary to protect habitats from cosmic rays and solar radiation. The Moon is surrounded by a harsh vacuum. Therefore, materials and structures that emit gas, such as hydraulic systems, should be avoided. There is no wind load on a lunar structure (Ruess et la., 2006; 135). The moon's axis of rotation is only about 1.5 degrees inclined, so there are almost no seasons (European Space Agency Cdf Study Report,2020: 107).

Temperature: The Moon is exposed to extreme temperature fluctuations, largely due to its weak atmosphere and slow rotation. The Moon's surface temperature fluctuates drastically, with nighttime lows of -173°C and daytime highs reaching 127°C. Designing habitats that can endure such harsh temperature fluctuations is vital (Bajaj,2024). During the day, temperatures can reach as high as 123°C at the equator. At night, they can drop as low as -233°C in the shadowed polar craters. In this environment, structures can undergo substantial expansion, contraction, and fatigue stresses, which should be considered during the design phase. Incorporating sufficient shielding methods is also necessary to mitigate the effects of the harsh lunar environment (Malla and Brown, 2015). To withstand the Moon's extreme temperatures, structures must be covered with a layer of compacted lunar regolith. The thickness of this layer should range between 1 and 4 meters, depending on the lunar environment's specific needs and construction factors (Zhou, Chen, Xu, Ding, Luo ve diğerleri, 2019).

Radiation: The design of building envelopes to protect against various types of radiation from the Sun and deep space is difficult because the Moon has no atmosphere and a very weak magnetic field. These types of radiation include: Galactic high-energy cosmic rays consisting of heavy nuclei, protons and alpha particles, and solar particle events resulting from solar flares (Nealy, Wilson ve Townsend, 1988). Different types of radiation have different effects on people, plants and buildings. Solar particle events are associated with solar activity. These events pose little danger to life on the Moon. The only exception is solar storms, from which life on the Moon would need protection. (Benaroya, 2018:17). Galactic cosmic radiation comes from stars. Although its short-term effects are not dangerous, long-term exposure can increase the risk of cancer. It is very difficult to protect against galactic cosmic rays because they are so penetrating (Straume, 2008). A third type of radiation is X-rays. These are produced by high-energy electron collisions (Benaroya, 2018:17). All these types of radiation will need to be considered when designing lunar habitats.

Gravity: Due to the Moon's low gravity, standard construction methods used on Earth are not suitable. (Zhang, Dai, Niu, Zhang, Liu ve diğerleri,2023:8). The Moon's gravitational force is 1/6 of the Earth's. This is an important factor that must be considered. The foundation design must consider the mechanical characteristics of the lunar regolith. Also, the operation of power machinery on the Moon is distinct from its operation on Earth (Zhou, Chen, Xu, Ding, Luo ve diğerleri, 2019). The Moon's low gravity affects the operation of all machinery, especially those involved in manufacturing and construction processes. In designing for a low-gravity environment, it's essential to consider how gravity-dependent mechanisms will function in such conditions. (Azami et la.,2024:3).

Lunar Dust: The pervasive lunar dust, with its tiny and abrasive particles, influences the performance of all systems. (Azami et la.,2024:2). Dust on the lunar surface can be easily lifted into the air as a result of possible human activities on the lunar surface. However, some of the fine dust particles are electrostatically charged. They are transported naturally under the influence of electric fields near the surface. Observations of dust on Apollo astronauts' spacesuits after short-term extravehicular activities demonstrate the importance of dust pollution control (Grün, Horanyi ve Sternovsky, 2011:1676)

2.1. Turkey Moon Bases National Idea Competition Professional Category

The Turkey Moon Bases National Idea Competition was prepared in cooperation with the Bursa Metropolitan Municipality, Bursa Technical University, the Provincial Directorate of National Education and Gökmen Space and Aviation Centre(GUHEM), was completed in 2022. The competition was organised into three distinct categories: high school, university, and professional. A total of 19 teams participated in the competition, 13 person in the 'high school student category' , 9 person in the 'university student category' and 41 person in the 'professional category'. In the context of the competition, it was tried to produce ideas about ''Bases That Can Be Established On The Lunar Surface'' within the framework of Turkey's National Space Programmes developed and carried out by the Turkey Space Agency. The Turkey Moon Bases National Idea Competition is an event at which young people's proposals on the architecture of the future are presented and discussed, with a particular focus on space architecture and extraterrestrial urbanism (URL 1).In the context of this study, the analysis was limited to projects that were awarded in the professional category of the Turkey Moon Base National Idea Competition (Turkey Moon Bases National Idea Competition Specification,2022). In the professional category, the participants were expected to answer five different questions as defined in the specification and to deal with two defined stages. The first phase, "Moon 2023-2028", involves building the spaces, volumes and infrastructure required for hard and soft landings and subsequent activities. There was a specification for a "protected volume" for at least 20 crew members and at least 1000 m3 per person. Architectural and engineering programme, material, production technique, form, design theme, philosophy, protected and durable against extreme external conditions, are left to the contestants with no restrictions. In the projects, answers to the questions listed in Table 2 were requested and evaluated according to the given criteria.

Table 2. Assessment criteria and points for the professional category (Turkey Moon Bases National Idea Competition Specification,2022).

Assessment Criteria: 100 total points
• Design Approach And Philosophy: Sustainability, Living Space Creation And Growth Model (30/100 Points) • Compliance And Competence With The Programme Of The Competition: Responding To The Needs Of 2023 And 2028 Targets And Beyond (30/100 Points) • Ideas For Construction And Production Techniques In Extreme Conditions: Materials And Fictional Or Theoretical Contributions On Production Technology... Etc. (20/100 Points) • Competence In Graphic Presentation, Representation And Expression - Diversity Of Visual Expression (20/100 Points)
Questions Of The National Idea Competition
1. In terms of the goals of creating a place, a space and a city on the Moon, how should we evaluate what we have done on Earth? **2.** How can we develop the technology, plan, vision and design process for the Moon's extreme environmental conditions? **3.** How can a lunar base be designed to ensure the psychological and sociological well-being of humans? **4.** With what kind of design and vision approach can the Moon Projects of Turkey's National Space Programme be sustainable and successful? **5.** In order to build a sustainable life, to produce appropriate spaces, related engineering & architecture How can the new generation of current developments in technology be evaluated under lunar conditions?

In the second stage, participants were asked to develop visions, plans, projects and spatial designs for the 'Moon 2030-2040-2050: Base Settlements Planning and Design' with a crew of 200 and the first architectural-engineering units for 1000 m3 / human, a settlement concept and the establishment of a sustainable Earth-Moon ecosystem for humans and other life forms. The location of the project on the lunar surface and the choice of site, the population of humans and other living things, the structure and balance of the ecosystem, the external and internal conditions of the area, the scenario components etc. are left to the participants (Turkey Moon Bases National Idea Competition Specification,2022).

3. Material and Methods

The sample area of this study has been defined as the architectural projects that have received awards in the professional category of the "Türkiye Moon Base National Idea Competition" to be held in Turkey in 2022.

Five architectural competition projects have been awarded in the professional category of the ideas competition, which will be held between March 2022 and November 2022 in partnership and cooperation with Bursa Technical University Rectorate, Bursa Metropolitan Municipality Science and Technology Center, Bursa Province National Education Directorate and GUHEM (Gökmen Space Aviation Education Center).

Within the framework of this study, five different architectural design projects were examined that were awarded the first prize, the second prize, the first honourable mention, the second honourable mention and the jury encouragement award. In the professional category, Keremcan Kirilmaz and Erdem Batirbek's project was awarded first prize, while Furkan Erdem Sözer, Cagatay Toprak, Alpcan Balci and Hazal Ozkan's project was awarded second prize. Levent Aridag and Emrah Ozcicek, Günay Erdem, Serpil Öztekin Erdem and Kerem Aydin's project was awarded an honourable mention. The work of Mustafa Haki Eraslan, Omer Ozeren, Edibe Begüm Ozeren and Hilal Eraslan was awarded the jury encouragement award (Turkey Moon Bases National Idea Competition Specification,2022).

The competition specifications, the final reports, the competition reports and the project layout plans, floor plans, sections and 3D models of the relevant projects were examined.

In the technical specifications, the expectations of the competitors were categorised according to the following criteria: scenario, habitat location, building material, building form/shell, structural elements, accessibility and production technique, which were used as evaluation parameters in the study. The projects examined whether or not the lunar environment was taken into account under specified parameters. In the review of the literature, five different basic conditions have been identified as design inputs in the design process of the lunar base habitat. These lunar environmental conditions that differ from Earth are: atmosphere, radiation, temperature, gravity and lunar dust. Out of 100 points, the extent to which the parameters determined from the relevant projects were in accordance with the criteria for lunar environment conditions determined from the literature and the extent to which these conditions were taken into account in the projects were assessed. Each lunar environmental condition criterion was considered equally important in the projects and was given a score of 20. The 100 points were divided equallyIn Table 3; if the horizontal parameters contain data in relation to the lunar environment criteria in the vertical plane, the corresponding box is marked. Three different scoring levels were used for marking. If there is no data in the table for the five conditions identified in the project, the corresponding box was left blank. If the identified criteria were considered under more than one parameter in the projects, the arithmetic average of the relevant values was taken. The projects were re-examined using a knowledge-based rather than a jury-based evaluation methodology.

4. Results

The project that won the first prize chose the North Pole as the habitat location because of its characteristics. The region receives sunlight for most of the day, has water ice reserves, and has lower temperature differences. Extreme fluctuations in temperature cause thermal expansion/contraction and thermal cycling problems in surface structures. If a structure is to be directly exposed to these extreme temperatures on the lunar surface, the structure must be of highly elastic materials and preference should be given to materials with different thermal expansion coefficients. The fatigue of the material caused by thermal cycling over time is a situation that needs to be dealt with (Benaroya, 2018:16-17). In the project, the dusty surface of the Moon and the 1/6 gravity were considered to be a positive environment for mining activities on the lunar surface, but no details were given. Lunar dust can pose a wide range of hazards to habitats, including inaccurate device readings for mining operations, visual blurring, thermal control problems, operational system failures, communication problems, and human health risks (Hubbard, 2023:123). Although the development of the habitat throughout the process has been comprehensively explained in the project, the resistance of the selected material to high temperatures, the erosive properties of the lunar dust on surfaces, the effect of 1/6 gravity on the shape of the structure and the vacuum environment existing on the Moon have not been mentioned. Openings such as doors and windows on module facades must be able to withstand high temperatures. They must also prevent further radiation from entering the building. Structural opening data for the project were not available. Information on relevant projects and evaluations of this information are presented in Table 3.

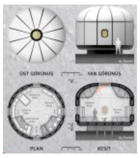
In the project that won the second prize, the effect of gravity, the abundance of hydrogen to be used for energy, the hardness of the surface for settlement and construction, the slope of the surface, the height factors and the choice of the Atatürk crater, which was found to be far from the meteors, show that atmospheric properties were taken into account in the design. Extreme temperatures, lunar dust and gravity were not taken into account in the design of the new-generation rail system. There was no data available for these difficulties in the project. Although the choice of materials and the building envelope took account of the need to protect against high levels of radiation and pressure, the project was unable to obtain data on the temperature factor of the materials. Windows were not included in the project as there is no atmosphere on the Moon. The project report largely ignored lunar dust and gravity information in the design criteria. High radiation levels, surface temperature and pressure were the focus of analysis during the design process.

Table 3. Data from related projects. Data evaluation and analysis (Bursa Metropolitan Municipality,2022; URL 2; URL 3;URL 4; URL 5)

Project Information

Layout plan/Floor Plans/Sections/Project Report

First Project:Keremcan Kirilmaz/Erdem Batirbek



Evaluation criteria		Scenario	Habitat location	Building material	Building form	Building shell	Structural elements (Structural opening)	Accessibility	Production Technique	**Project score**
Atmosphere	20	Good		Very good						
Temperature	20	Very good	Very good	Good						
Radiation	20					Very good				
Gravity	20									
Lunar dust	20									
Max. 100 p		Very good (black)		Good (dark grey)			Average (light grey)			
Undefined	Not marked									**56**

The information contained in the project

***Scenario:** In the first phase, robots will be used to extract raw materials, store resources on the lunar surface and build the first structures. The settlement system is designed to be modular
***Location:** Moon North Pole
***Material:** The module structure is made of high-strength steel and aluminium
***Building form/shell**: The building shell is made of high-strength steel, aluminium panels and a protective layer of regolith. The upper surfaces of the settlement modules will be manufactured from lunar regolith in modular pieces using 3D printer modules. These modules will be assembled and installed by construction robots.
***Accessibility:** Transport between residential areas can be provided by shuttles, magnetic levitation (maglev) trains or wheeled land vehicles. The choice depends on factors such as distance, speed and mass to be transported.
***Production Technique:** Construction robots sent to the surface ahead of the crew will build the first settlement, which will be manufactured and pre-assembled on Earth. Some of the construction materials will be supplied by mining and construction robots from Earth, while others will be extracted from the lunar regolith.
***Structural elements:** How the modules relate to the floor and door/window dimensions is not explained

Project Information

Layout plan/Floor Plans/Sections/Project Report

Second Project: Furkan Erdem Sözeri/Cagatay Toprak/Alpcan Balci/Hazal Ozkan

Evaluation criteria		Scenario	Habitat location	Building material	Building form	Building shell	Structural elements (Structural opening)	Accessibility	Production Technique	**Project score**
										55

The information contained in the project

***Scenario:** Robots with various tasks will provide a suitable environment for the first humans to arrive. The planned infrastructure circle will be covered with solar panels and will provide the habitat with energy, water and electricity
***Location:** Ataturk Crater
***Material:** The 3D printed material of regolith + sand + silicon is the main material of the walls and floors. Three-layer glass resistant to radiation from the Earth was used for transparent surfaces. Special impact-resistant glass materials were used to protect against radiation
***Building form/shell:** It is planned as three layers. In order to be resistant to impacts, tempered glass is used in the inner and outer layers of the shell. Radiation-resistant glass is used in the middle layer. Panels produced from regolith are used as the upper covering element of the building shell. Most of the living units are buried in the ground.
***Accessibility:** The new generation beyond-rail system is a transport system between units and around new units

Evaluation criteria	Points	Scenario	Habitat location	Building material	Building form	Building shell	Structural elements (Structural opening)	Accessibility	Production Technique	Project score
Atmosphere	20									
Temperature	20									
Radiation	20									
Gravity	20									
Lunar dust	20									
Max. 100 p		Very good		Good		Average				
Undefined	Not marked									

*Production Technique:** Excavators, workers, transporters, assistants, miners and UAVs (unmanned aerial vehicles) are responsible for various tasks
***Structural elements:** There are no windows in the project. No data could be found for other openings in the project

Project Information

Layout plan/Floor Plans/Sections/Project Report

First Honorable Mention:
Levent Aridag/Emrah Ozcicek

Evaluation criteria	Points	Scenario	Habitat location	Building material	Building form	Building shell	Structural elements (Structural opening)	Accessibility	Production Technique	Project score
Atmosphere	20									
Temperature	20									
Radiation	20									
Gravity	20									
Lunar dust	20									
Max. 100 p		Very good		Good		Average				
Undefined	Not marked									68

The information contained in the project

***Scenario:** Habitat units are suspended from the valley wall where the lava tube opens. The vertically placed core includes transportation between units, the necessary equipment to extract water from the valley floor, robotic arms, and a construction crane for habitat construction.This core is used to build the first unit, which includes the hangar where the lunar vehicles are parked at the top of the valley. The surface of the hangar contains solar panels
***Location:** Sinious Rille Valley
***Material:** Steel and ETFE
***Building form/shell:** The shell of the building is designed as two layers as the main carrier steel structure and the ETFE structure. A triangular surface concept was used in the design of the building. This minimised heat loss and reduced the surface area exposed to radiation and meteorites
***Accessibility:** Circulation between the units is provided by the service core, which includes the crane, installation and lift
***Production Technique:** Solar panels for mining and hydrogen production will be installed in the first settlements.Prefabricated structural elements such as construction cranes, lifts and water extraction systems are in place
***Structural elements:** Information on structural elements (doors, windows) is not included in the project

Project Information

Layout plan/Floor Plans/Sections/Project Report

Second Honorable Mention:
Günay Erdem/Serpil Öztekin
Erdem/Kerem Aydın

Evaluation criteria	Points	Scenario	Habitat location	Building material	Building form	Building shell	Structural elements (Structural opening)	Accessibility	Production Technique	Project score
Atmosphere	20									
Temperature	20									
Radiation	20									
Gravity	20									
Lunar dust	20									
Max. 100 p		Very good		Good		Average				
Undefined	Not marked									77

The information contained in the project

***Scenario:** Four different types of robot will be sent to the Moon to perform different functions.These categories are; Raw Material Preparation Robots, Assistant Rovers, 3D Printer Robots and Exploration Robots. Exploration robots will explore the lunar surface and lava tubes and create detailed maps. Assistant rovers will deposit resources at the location where the base will be built. In the first phase, the raw material preparation robot and the 3D printer robots will work together on the construction of the base's infrastructure and units
***Location:** The area around Shackelton and Cabeus craters on the lunar south pole
***Material:** The structures will be built using 3D printing robots. The concrete dough will be made from regolith found on the lunar surface
***Building form/shell:** A cylindrical shape has been chosen because it provides the greatest amount of usable space with the least amount of surface area. It is stated that the atmospheric pressure differential is taken into account when calculating the building envelope. The building material to be used for the building envelope will be closed porous. This will minimise heat transfer. It was decided to exploit the behaviour of sunlight in water in order to make the high levels of solar radiation contained in the building shell suitable for living in.
***Accessibility:** Transportation between units in the habitat (city centre, industrial area, lunar habitat hotel) could not be determined
***Production Technique:** Rovers will travel the lunar surface and carry out mining activities to provide for the need for raw materials. The raw materials will be processed in the industrial zone. They will be used for the needs of the base
***Structural elements:** Project contains no information on structural elements (doors, windows).

Project Information

Layout plan/Floor Plans/Sections/Project Report

Jury's Special Award: Mustafa Haki Eraslan/Ömer Özeren/Edibe Begüm Özeren/Hilal Eraslan

Evaluation criteria	Points	Scenario	Habitat location	Building material	Building form	Building shell	Structural elements (Structural opening)	Accessibility	Production Technique	Project score
Atmosphere	20									
Temperature	20									
Radiation	20									
Gravity	20									30

The information contained in the project

***Scenario:** The unmanned vehicles sent remotely create a protection layer in accordance with the conditions of the Moon.With the completion of the cocoon, the structural base is complete. Then, through metamorphosis, the desired forms are created according to different needs.
***Location:** Moon South Pole
***Material:** The shells of the structures will use the silk sericin protein found in the structure of the cocoon. Silk Sericin Protein has UV protecting and water binding properties. A material will be used to provide protection against meteorites and radiation. This will be made from reinforced silk sericin protein and regoliths and polymers from the lunar surface
***Building form/shell:** For the structures to be built, spherical and cylindrical shapes were chosen. This means any pressure is distributed over the whole surface.
***Accessibility:** No data could be accessed in the project
***Production Technique:** Mining robots will be used to convert products into sources of energy, to extract water and to extract oxygen from the regolith.
***Structural elements:** No data could be accessed in the project

Lunar dust	20					
Max. 100 p	Very good	Good	Average			
Undefined	Not marked					

In the first honourable mention project, high temperatures and the risk of meteorite impact were priorities in the choice of habitat location. The structure is suspended from the valley wall. It is located on the surface of the valley. Hanging the units on the valley wall was made easier by the fact that gravity on the lunar surface is 1/6In comparison to Earth, the gravitational load on the unit's support system is lower. Within hanging units, spatial organisations are usually constructed. Shelters have been built inside the cave in potential danger situations. In the design of the habitat, the radiation sensitivity of the ETFE material has been increased. The material has been inflated with air to provide thermal insulation. The Moon has very low atmospheric pressure. This creates vacuum conditions. It is not explained how the materials chosen in the project will react in a vacuum environment. The project was not able to obtain any data on how to protect the vertical core, which is directly exposed to lunar dust, high temperature variations and radiation, against these conditions. The properties of lunar dust, the vacuum environment and radiation were largely ignored in the project. The second honourable mention project's scenario addressed lunar environmental features such as atmosphere, temperature, gravity, radiation and dust, and these features partially influenced the design decision. The project mentioned that lunar dust would pose a danger to humans and robots due to its electrical charge. However, no information could be obtained about precautions against lunar dust on the structure. The habitat will be constructed by using 3D printers to make concrete dough from regolith, and the building shell will be covered with at least 2 meters of regolith. Data on the building shell load-bearing system and the regolith layer load-bearing system are not given in the project. There is no mention of the materials of the openings (windows) in the project models and how these openings will be protected against radiation, heat and moon dust. In the project visuals, there are transport tunnels between the units in the habitat. However, the materials of these tunnels are not mentioned. In order to balance the temperature difference between the inside and outside, a system was developed that uses sunlight in the building envelope. In this system, sunlight passes through the water solution. The sunlight is cleaned from radiation and heats the interior. Data on the material of this system could not be obtained.
In the project that won the Jury's special prize, it was noted that meteorite impacts, radiation effects and pressure were taken into account when determining the structural form. The building materials used in the project were basalt glass and reinforced silk sericin protein. It was stated that the materials selected for the project took into account the risk of radiation and meteorite impact. However, the effects of high temperatures, gravity and lunar dust on the material of the building envelope were not considered. Similarly, the project scenario did not take into account high temperatures, gravity and lunar dust properties. On low resolution project sheets, detailed plan and section readings could not be performed.

4. Discussions

The Moonbase 2124/Artemis Centennial Competition (2020), organized by X-Plor, asked participants to design a lunar colony capable of housing at least 160 people. The competition was held closely following the Turkey Moon Base National Idea Competition. It is open to participants of all levels. The competition is open to students, architects, engineers, designers and scientists. Information on the two competitions for the design of habitats in the lunar environment is given in Table 4. The Turkey Lunar Base National Idea Competition did not share any information about the lunar environment conditions with the participants. The specifications of the Turkey Lunar Base National Idea Competition contain the approximate number of crew members and spatial volume calculations for the project scenarios. All the features such as the architectural/engineering programme, the production techniques and the technologies to be used, etc. are left to the participant. This situation allowed the participants to develop different solutions and scenarios for their lunar base designs. At the same time, this situation has made it easier for extreme environmental conditions to be ignored, especially in some of the projects. In addition, the lack of sharing of data with participants that could be used as a guide was seen as a factor that limited the development of realistic design proposals. The Moon Base 2124 competition is a detailed description of the lunar environment that is different from Earth and the limitations of the competitors.

Table 4. Comparison of the information presented in the specifications of the Turkey Moon Base National Idea Competition and Moon Base 2124/Artemis Centenary Design Competition (Turkey Moon Bases National Idea Competition Specification,2022; URL 6).

Competition specification information	***Turkey Moon Bases Competition***	***Moon Base 2124/Artemis Centenary Design Competition***
Competition year	2019	2020
Habitat location	Moon	Moon
Number of crew	First stage: 20 person Second stage: 200 person	160 person
Habitat atmosphere	Undefined	101.35k Pascal (Earth-normal gas mix at sea level)
Probable habitat location	Undefined	• South pole craters • Underground lava tubes ***Competitors are free to choose areas other than the suggested settlement areas.**
Construction Methods	Undefined	• A hybrid method between: 3D printing technology, pre-integrated modules and inflatable structures
Spatial Volume	at least 1000 m3/person	Undefined
	Left to competitors	Self-sufficient, Self-sustaining lunar settlement with a closed-loop system and a modular design

Information given about the habitat		Recommended energy sources: • Solar satellite • Solar sail • Nuclear batteries • Fusion reactor
Information given about the Moon	Undefined	• 1 moon day lasts 29 earth days • Temperatures varies from 127 to -173 degree centigrade • Moon has an electrostatic surface due to continuous exposure to cosmic radiation. • There is a danger of meteor impact on the lunar surface • The Moon regolith is a fine hazardous dust • The moon gravity is 16.8 % of Earth gravity
Recommended technologies	Left to competitors	• 4D printing and memory shaped alloys • Thermoluminescence materials, • Bio-molecular 3D printing ***Competitors are free to use alternatives to proposed technologies**
Program Outlinşe	Architecture-engineering programme, material, production technique, form and design theme are left to the competitor.	•The contestants were given a program outline: • Moon mining facility • Research labs(for hazard biological experiments) • Spaceport (to other celestial bodies like Mars) • Space safe time capsule • Lunar tourism facility • Living areas including sleeping pods, exercising areas etc. • Aeroponics and/or hydroponics farms with 4 types of plants (Medical, Oxygen bomb, Vegetables and fruits for nutrition, Construction wood trees) • Communication center • Power station • Surface Access Unit (including airlock system,lunar terrain vehicles)
Evaluation criteria	• Presentation • Design approach • Compliance and competence with the competition programme • Suggestions for construction and production techniques	• Presentation • Concept/idea • Spatial volumes and design • Design Outputs

In the Moon Base 2124 Competition, the units that should be part of the habitat were defined in the programme outline. These units include research laboratories, mining facilities, spaceports, living quarters, exercise areas, a communications centre, a power station and surface access units. There were no restrictions on the units to be included in the habitat in the Turkey Lunar Base National Idea Competition. The specification stated that the habitat had to be able to withstand the environmental conditions on the Moon. They were expected to come up with a sustainable design proposal. The Moonbase 2124 competition suggested technologies that could be used on the moonbase, such as 4D printing and memory shaped alloys and thermoluminescent materials. It was also stated that participants could use alternative technologies. Suggested energy sources for the habitat include solar satellites, solar sails, nuclear batteries and fusion reactors. It is stated that participants may use one or more of the proposed options together. The region of the South Pole and areas with underground lava tubes have been suggested as locations for the habitat, but the participants can also choose other areas. In the 'Turkey Moon Base National Idea Competition', information on the energy sources to be used in the habitat, possible technologies, construction methods and information on the possible location of settlements was not shared with the competitors. The evaluation criteria for the two competitions are similar.

The specifications of the Turkey Lunar Base National Idea Competition did not include any information specific to lunar conditions. Therefore, the participants were able to respond to the criteria for lunar environmental conditions at different levels. Although the questions in the specifications were answered in the first selected project, the lunar environmental condition criteria were not fully answered and were not included in the project scenario. The second prize-winning project was also partly concerned with the atmospheric conditions of the moon. No data could be obtained on the ability of the triple-layered glass sent from Earth and used in the building envelope to withstand the high temperature differences between day and night. The response of the defined building form and envelope to gravitational conditions different from those on Earth was not considered in the project. Furthermore, the ability of lunar dust to adhere and penetrate surfaces due to its extremely fine structure was not considered at any stage of the design process. The project that was awarded an honorable mention noted that gravity and atmospheric conditions were taken into account in the positioning of structural units.

No information was found on how the vertical core providing circulation between units was protected from these atmospheric conditions. The environmental characteristics of the Moon such as atmosphere, temperature, gravity, radiation and dust partially influenced the design decision of the project that was awarded the second honorable mention. However, the properties of the lunar dust did not play an active role in the design of the project. This situation was neglected in the design of structural spaces or in the design of structural voids. In the scenario of the project that won the Special Jury Prize, only meteorite impacts and radiation conditions were taken into account. No data on the temperature, gravity and properties of lunar dust could be obtained from the project.

5. Conclusions

The competition specifications do not specify any limitations or mandatory spaces in the architectural and engineering programs. For this reason, leaving important principles such as the Moon's environmental conditions directly affecting the material to be selected in the structural design and material selection entirely to the competitor was not considered a correct approach. In fact, not all roles belong to the designer in the design of the lunar base habitat, which is expected to take an interdisciplinary approach and the designer (architect, interior designer, etc.) should not make all the decisions regarding the design. For this reason, it is inevitable that there will be secondary spaces that are integrated into the main spaces in the Moon Base designs, depending on the environmental conditions. The specification of subsystem architectural components to competitors can play an active role in producing better structural solutions, such as environmental control and life support systems, thermal control systems, waste management systems, energy conversion systems, extra-vehicular activities, etc. At the same time, the environmental conditions of the Moon, which must be taken into account in every project, can be defined in the competition specifications. Within these mandatory constraints, design scenarios can be developed in line with real information. The lack of definition of these limits has caused competitors to look for solutions to many questions in the discipline of space architecture, which has a diverse knowledge base and a broad pool of information. However, the answers to these problems should be developed in cooperation with various disciplines at different levels. For this reason, the competitors were unable to respond adequately to the design solutions. They created their scenarios by ignoring some aspects of the lunar environment that should not be ignored in the design. The answers given to these conditions were used throughout the process as a minimum input to the design, and the competitors were mainly looking for answers to five different questions in the specifications. As a result of the evaluation of the project images examined in the framework of the study, the low resolution of some images was identified as one of the limitations of the examination process. In this competition, which is in line with the study of space architecture, a new and current topic in our country, it is very important that the data is shared clearly and openly. This will be a source of inspiration for future research.

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Conflict of Interests
The Authors declare that there is no conflict of interest.

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