TERRA LUNARIS: Assessment of a Lunar Habitat for Scientific Astronauts, Space Miners, or Space Tourists

WORKING PAPER

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Highlights

- Development of an innovative habitat concept—Terra Lunaris, designed by Schumann—including a physical 1:25 scale model.
- Comprehensive qualitative and quantitative analysis of the Terra Lunaris model in comparison with existing habitat types.
- Detailed characterization of three key user groups—space tourists, space miners, and scientific astronauts—including their specific behaviors, functional needs, and roles within simulated scenario contexts.

Abstract

This conceptual paper explores ground-based habitable space modules for various applications. The Terra Lunaris concept serves as the baseline and is evaluated in comparison to existing and theoretical studies in this field. *Terra Lunaris* is a compact hybrid habitat that expands to offer nearly four times its transport volume by combining rigid modules with an inflatable shell. With most interior elements pre-installed and foldable, setup time and complexity are minimized. The design integrates technical zones, living quarters, and shared spaces, while also supporting psychological well-being under extreme conditions. The paper provides both qualitative and quantitative analyses of lunar habitation scenarios from different perspectives, offering recommendations tailored to each characteristic group. The findings indicate that the hybrid design of the Terra Lunaris concept—combining fixed and inflatable components—is particularly advantageous for the lunar scenario considered. Additionally, the study suggests that the concept is also a viable option for Mars, although a fully fixed habitat may be slightly preferable in that context.

Keywords: Mars base, Moon base, scientific astronauts, space architecture, space commercialization, space miners, space tourists

JEL Classification: F64, L91, O18, P48, R41

Introduction

The idea of lunar habitats dates back a long time: “The first discussion in print about a lunar colony is attributed to Bishop John Wilkins. In his 1638 book, *A Discourse Concerning a New World and Another Planet*, he voiced the opinions that man would one day learn to fly and would plant a colony on the Moon.” (Johnson & Leonard, 1985, p. 48)

Since the founding of Bigelow Aerospace in 1999, entrepreneur Robert Bigelow has introduced various inflatable concepts and prototypes, offering the advantage of providing larger volumes than rigid structures (David, 2015). However, a disadvantage of fully inflatable habitats is that, after inflation, the interior space is empty, requiring interior elements to be assembled afterward. This process increases the amount of work and, consequently, costs in space. On the other hand, fixed habitats are limited by the size of the carrier launcher's cargo bay, restricting their maximum external dimensions.

The authors propose that a hybrid solution—combining fixed and inflatable components—is superior to either a purely inflatable or purely fixed habitat. This assumption is based on the advantage that interior structures can be pre-installed using a foldable design, avoiding the drawbacks of large size and bulky exterior dimensions.

Thus, the research question (RQ) to be explored is: *For which locations and user groups does the mixture of fixed and inflatable elements for a lunar habitat make sense?*

In the next section, we provide background information on space habitats. Section three offers a qualitative assessment of expected operational scenarios involving scientific astronauts, space tourists, and space miners. Section four outlines the methodological framework of the study, focusing on a quantitative evaluation of the various scenarios using a five-step approach, and presents implications and recommendations for specific applications on the Moon and Mars. Finally, section five concludes with our closing remarks.

Background

In general, the definition of habitats encompasses various types of space stations, space hotels, Moon bases, and Mars bases. Table 1 presents a list of typical space habitats.

For fixed habitats, the well-known International Space Station (ISS) and the Apollo Lunar Module (LM) serve as typical examples of assembled solid components, which generally have limited degrees of freedom due to their rigidity. Newer designs, such as the Bigelow modules, primarily utilize soft components that are inflated in space. The hybrid approach, which combines both types mentioned above, is realized in the Terra Lunaris concept by Schumann (2022) (see Figure 1), aiming to provide a broader range of usage options. Additionally, an in-situ approach would involve 3D printing a habitat on the Moon or Mars using existing raw materials from the surface along with a binder agent transported via a launcher.

Table 1

Typical Types of Space Habitable Modules

Types	Characteristics	Examples
Fixed	Solid components	ISS, LM
Inflatable	Soft components	Bigelow module
Hybrid (baseline)	*Soft and solid components combined*	*Terra Lunaris concept*
In-situ	Individual components	In development

A literature search revealed several recent papers on this subject. Denisov et al. (2023) discuss the design and deployment of a lunar habitable modular base that incorporates both soft and solid components, focusing on aspects such as design, radiation protection, power generation, and storage systems. Deleo et al. (2020) introduce origami-based deployable solid structures made from carbon fiber reinforced polymer (CFRP) composites.

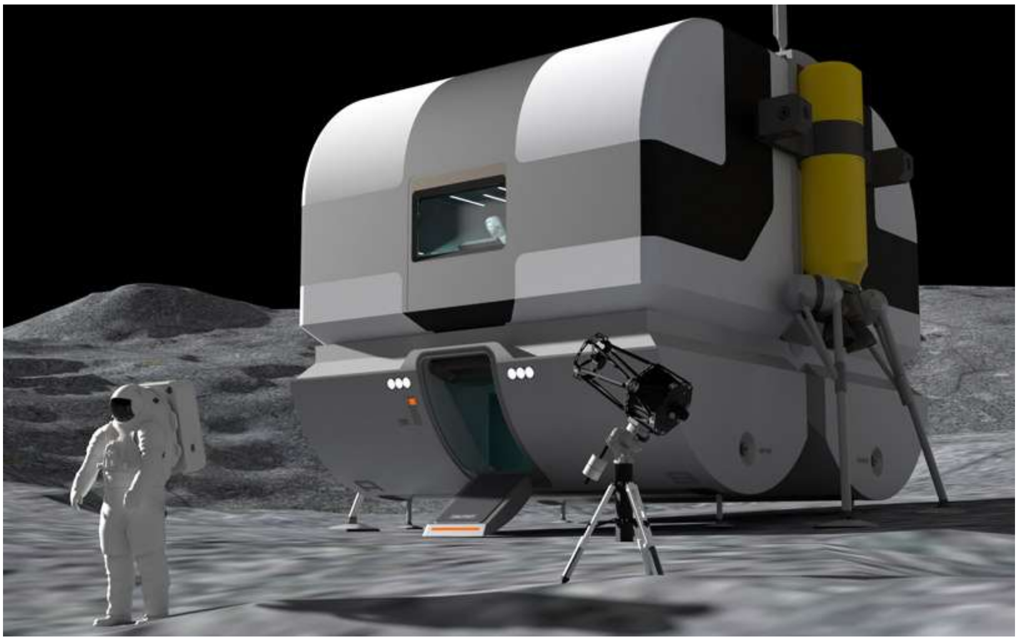
Herzig et al. (2022) focus on site selection for inflatable lunar habitats. Pernigoni and Grande (2020) study a self-healing multilayer system designed for inflatable habitats. Frulla et al. (2023) investigate sandwich materials used in the structural components of lunar and Martian habitats, specifically in deployable and foldable configurations.

Wang et al. (2022) provide an overview of additive manufacturing technologies applicable for the in-situ utilization of regolith for lunar and Martian habitats. In addition to the design of in-situ habitats, Pilehvar et al. (2021) investigate the material characteristics of lunar regolith in relation to 3D printing. Caluk and Azizinamini (2023) present their concept for lunar infrastructure construction, which involves first 3D printing modular blocks that are assembled in a subsequent step.

In contrast to the habitat types described in recent and past literature, Terra Lunaris features a novel hybrid design principle: the habitat is configured as a solid and robust structure during the transport and landing phases. This is followed by an automatic inflation and assembly procedure that incorporates both primary and secondary structures made from a combination of soft and solid components (see Figure 2 and 3). The result is an enhanced interior habitat experience that leverages the material characteristics of soft components (e.g., the potential for large spaces) and solid components (e.g., the potential for rigidity), while avoiding the drawbacks of each—such as the flabbiness of soft components and the confinement of solid components (see Figure 4).

Figure 1

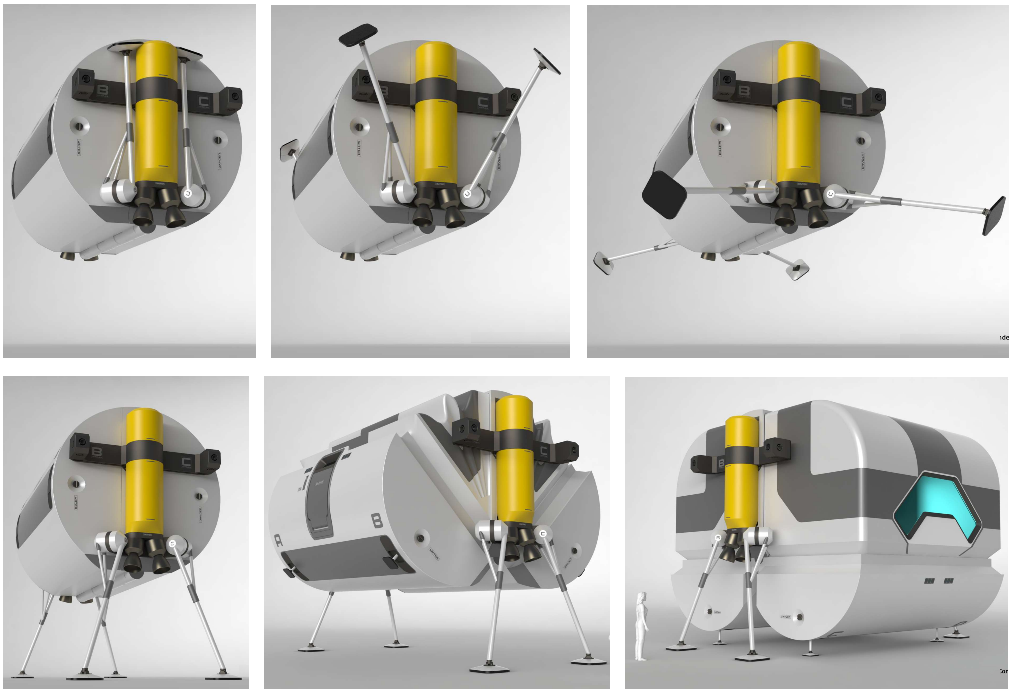
Terra Lunaris Concept



Source: Schumanndesign

Figure 2

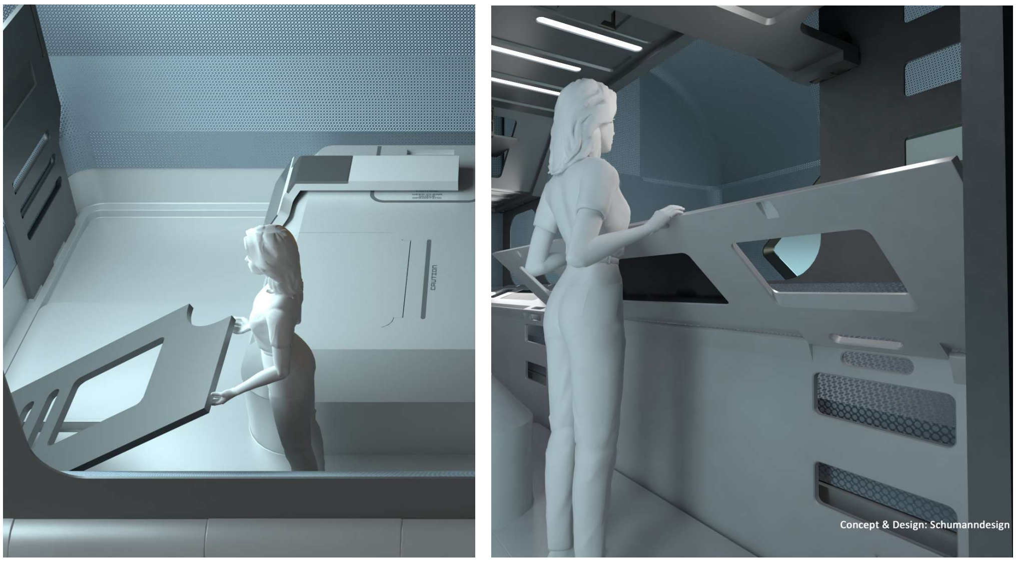
Terra Lunaris Landing (upper images) and Assembly (lower images) Procedure



Source: Schumanndesign

Figure 3

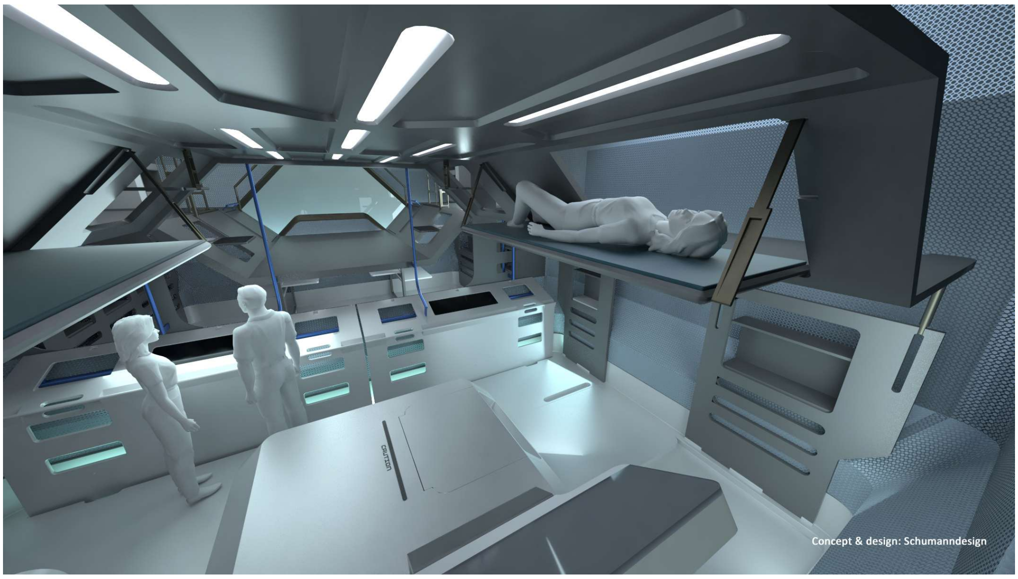
Terra Lunaris Interior Assembly Procedure



Source: Schumanndesign

Figure 4

Terra Lunaris Interior Arrangement



Source: Schumanndesign

Qualitative Assessment

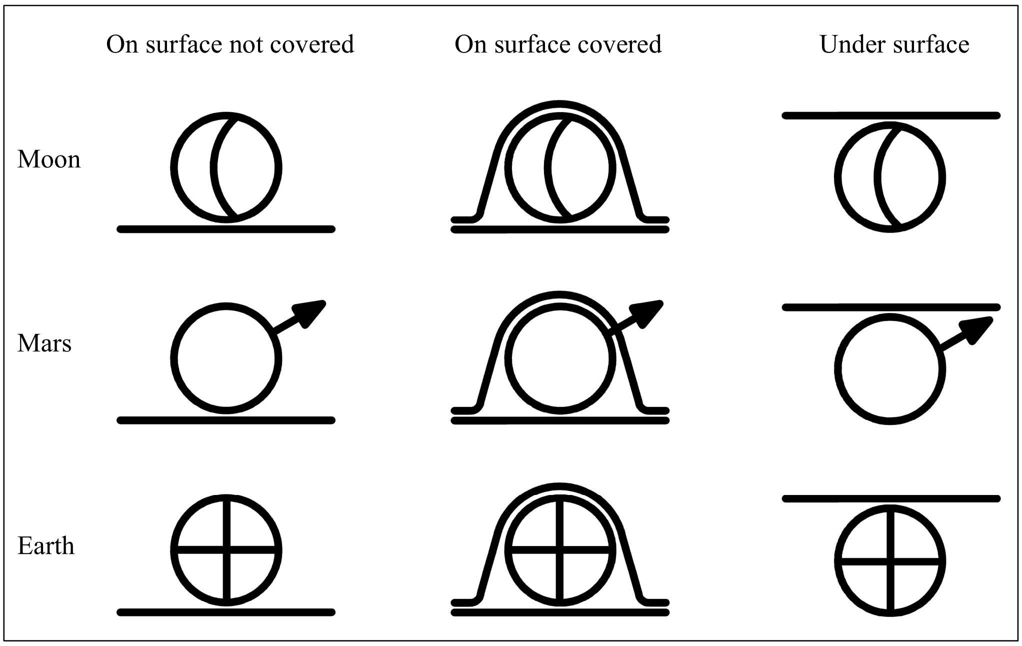
This section aims to divide the overall complex theme into smaller components (such as types of locations and types of users) that can be assessed independently, ultimately allowing for the combination of the separate findings into a comprehensive result matrix.

Type of Location

Typical placements of habitats include those that are uncovered on the surface, covered on the surface, and located below the surface (see Figure 5). Table 2 outlines these placements in relation to applications on the Moon, Mars, and Earth.

Figure 5

Possible Locations



Source: Schumanndesign

Table 2

Type of Location

Type	Details	Example	Advantages	Disadvantages
Moon				
On surface not covered	Placed directly on the surface	Apollo Lunar Module	Easy placement	Exposed to naturel influences (e.g., UV light, radiation, meteorites)
On surface covered	Habitat filled with surrounding regolith material	Not realized	Protected against natural influences	Extensive preparation required
Under surface	Placed in natural caves	Not realized	Protected against natural influences	Limited to existing cave locations
Mars				
On surface not covered	Placed directly on the surface	Not realized	Easy placement	Exposed to naturel influences (e.g., UV light, radiation, meteorites)
On surface covered	Habitat filled with surrounding regolith material	Not realized	Protected against natural influences	Extensive preparation required
Under surface	Placed in natural caves	Not realized	Protected against natural influences	Limited to existing cave locations
Earth				
On surface not covered	Placed directly on the surface	Polar stations	Easy placement	Exposed to natural influences (e.g., temperature, wind)
On surface covered	Habitat filled with surrounding material	Bunker	Protected against natural influences	Extensive preparation required
Under surface	Placed in natural caves	Research labs	Protected against natural influences	Limited to existing cave locations

For the uncovered surface type, the primary advantage is ease of placement, while the main disadvantage is exposure to natural influences. Regarding radiation on the surface of Mars, Timoshenko and Gordeev (2020) summarized that the dose will be approximately half of that experienced during the flight, based on their assumed scenario of a fast transit and long stay mission. This suggests that the impact of radiation is of lesser concern in this context.

For the covered surface type, the primary advantage is protection against natural influences; however, this comes with the drawback of significant effort required to prepare the surrounding material.

For the under-surface type, a key benefit is the ability to utilize existing caves, which require minimal preparation and provide natural protection. However, this option is limited to the availability of suitable locations.

Type of Users

Assumed typical users for future space habitats include scientific astronauts, space tourists, and space miners, as outlined in Figure 6 and Table 3.

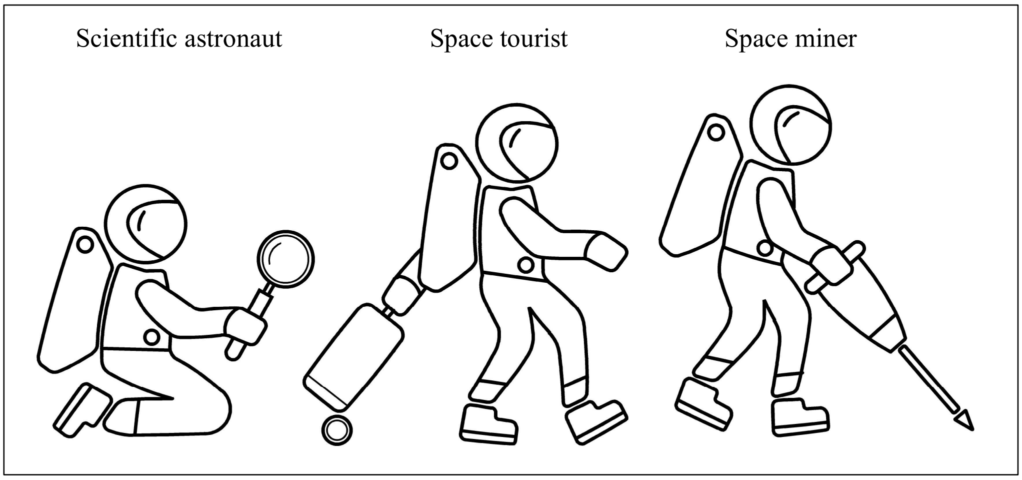
Scientific astronauts are defined in our study as professional astronauts specialized in fields such as geology, astronomy, biology, physics, and chemistry, with the aim of conducting experiments.

Space tourists visit habitats out of curiosity, adventure, self-realization, and awareness enhancement, often with little to no experience in space conditions.

Space miners are experts in maintaining mining equipment, and their presence is primarily driven by economic factors.

Figure 6

Possible Users



Source: Schumanndesign

Table 3

Type of Users

Type	Details	Example	Advantages	Disadvantages
Scientific astronaut	Professionals trained to execute experiments	Alexander Gerst	Skilled at solving complex problems	Funded by taxpayers
Space tourist	Tourists seeking leisure and personal experiences	Dennis Tito	Paying customer	Requires guidance
Space miner	Professionals trained in mining and maintenance	Concept only	Commercial purpose	Requires crew infrastructure

Quantitative Assessment

As shown in Tables 4 and 5, we evaluated the different types of space habitats against user types and locations. Our qualitative findings were translated into a five-point Likert scale, ranging from 1 (very poor) to 5 (very promising). This is intended as a preliminary, best-guess approach from us and serves as a starting point for more in-depth analysis in future work. Further research could involve gathering data from experts and potential users through questionnaires. To ensure a transparent and traceable methodology, our assessment is structured into five steps.

Step 1. Assess combinations of habitat–location types

The driving question for Table 4 is: *Which habitat type is the best match for each location from a technical feasibility standpoint?* We assume that the budget required to realize each habitat type varies by location, with a relatively low budget for Earth, a high budget for the Moon, and a very high budget for Mars.

Moon. For the Moon, an uncovered habitat is simple for all types. However, a covered habitat may pose challenges for inflatable and hybrid types due to the risk of damage to the sensitive habitat skin. The in-situ habitat type presents a slightly higher technical challenge, as the manufacturing and qualification processes must take place on the Moon. An under-surface habitat is straightforward for the inflatable type, as it can be easily lowered into small-diameter holes. For the hybrid type, this is neutral, but for the fixed type, it becomes more challenging due to its larger dimensions. The in-situ type is less feasible under-surface, as transporting a robot into a cave is a particularly difficult task.

Mars. For Mars, compared to the Moon, an additional challenge for any habitat approach and landing is the presence of an atmosphere. This adds complexity, particularly for larger habitats, as larger heat protection shields are required. Furthermore, Mars' sandstorms present a significant challenge for under-surface habitats, as entrance doors may become blocked by unwanted regolith.

Earth. For Earth, any habitat type that is assembled, inhabited, and maintained is relatively unproblematic compared to those on the Moon or Mars. However, natural forces such as storms, floods, and earthquakes pose significant challenges for all habitat types—challenges that are less prevalent or nonexistent on the Moon or Mars.

Table 4

Assessment of Habitat–Location Type Combinations

Habitat type	Moon			Mars			Earth		
	NC	C	US	NC	C	US	NC	C	US
Fixed	5	4	2	4	3	1	*5*	4	3
Inflatable	5	2	4	4	2	2	*5*	4	4
Hybrid (baseline)	5	2	3	3	2	1	5	4	4
In-situ	4	4	1	4	3	1	*5*	*4*	2

Note. NC = not covered, C = covered, US = under surface; Technical feasibility is: 5 = very likely, 4 = likely, 3 = neutral, 2 = unlikely, 1 = very unlikely

Step 2. Assess combinations of habitat–user types

The driving question for Table 5 is: *Which habitat type is the best match for each user type, based on convenience needs such as ambience, usefulness, and safety?*

We distinguish between the "importance/weight of needs" for different users and their "perception of needs." For example, we assume that safety and ambience are more important for space tourists than for scientific astronauts, which we reflect in the table with a higher weight factor. Additionally, we consider that perceptions of these needs can vary.

For instance, while a scientific astronaut may perceive a wobbling structure as equally safe as a fixed one—due to their knowledge of high qualification standards, trust in processes, and experience with space materials—a space tourist might perceive the same wobbling structure as stressful and unsafe, perhaps associating it with past unpleasant experiences (e.g., a punctured bicycle tire or air mattress). As a result, the inflatable habitat type is represented with a lower fulfillment rate for space tourists compared to astronauts. Similar considerations were applied to the evaluation of ambience and usefulness.

Scientific Astronauts. The assumed priority for scientific astronauts is the usefulness of a habitat, with ambience and safety being of secondary importance. The hybrid type offers the highest benefit, combining fixed elements within a spacious interior, which optimizes workflows among the team. The fixed type, while having smaller interior space and furniture, is still useful. In contrast, the in-situ type, and especially the inflatable type, present initially "empty" rooms due to their inherent characteristics, making them less immediately practical.

Space Tourists. For space tourists, ambience and safety are of equal priority, while usefulness is secondary. The hybrid type is the best option for fulfilling the needs of space tourists, offering features such as privacy (e.g., separated sanitary facilities, private spaces, and sleeping areas), comfort (e.g., spacious movement areas and common rooms), and a sense of safety (e.g., stable walls and ample space). The fixed type is less effective in providing a comfortable ambience, while both the in-situ and inflatable types fall short in meeting tourists' expectations. For example, it is likely that space tourists would feel uneasy about living in a wobbling inflatable structure or might have concerns about the safety and quality of a 3D-printed wall in an in-situ habitat, especially considering the hazardous vacuum environment outside.

Space Miners. For space miners, usefulness and safety are of equal priority, while ambience is a secondary psychological consideration. The hybrid type is assessed as the most advantageous option compared to the others. The narrow space of a fixed habitat provides less utility for efficient workflows among miners. Additionally, relatively sensitive materials, particularly those of in-situ and inflatable types, are unsuitable for the harsh conditions required to economically operate a habitat for space mining.

Table 5

Assessment of Combinations Habitat–User Types

Habitat type	Scientific Astronauts				Space Tourists				Space Miners			
	A	U	S	Sum	A	U	S	Sum	A	U	S	Sum
Weight of needs	0.1	0.7	0.2	1.0	0.4	0.2	0.4	1.0	0.2	0.5	0.3	1.0
Fixed	4	4	5	**4.2**	4	4	*5*	**4.4**	4	4	*5*	**4.3**
Inflatable	2	1	3	**1.5**	1	2	1	**1.2**	2	1	2	**1.5**
Hybrid (baseline)	5	5	4	**4.8**	5	5	4	**4.6**	5	5	4	**4.7**
In-situ	2	2	3	**2.2**	2	2	1	**1.6**	2	2	2	**2.0**

Note. A = perceived ambience; U = perceived usefulness; = S = perceived safety; fulfillment is: 5 = very likely, 4 = likely, 3 = neutral, 2 = unlikely, 1 = very unlikely

Step 3. Merge assessments of habitat–location types (step 1) with habitat–user types (step 2)

The driving question for Table 6 is: *Which habitat type is the best match for both, location types as well as user types.*

By merging the technical feasibility assessments of location types related to the Moon, Mars, and Earth with the convenience needs assessments for scientific astronauts, space tourists, and space miners—each given equal weight (0.5)—we derive the following scenario outcomes (see Table 6). If an overall score exceeds 3.0 in Table 6, we highlight the value in bold for easier recognition. While we fully acknowledge that the terms and user groups—scientific astronauts, space tourists, and space miners—are not applicable to Earth, we retain them for the sake of transparency and comparability.

Table 6

Detailed Results of Habitat Types Dependent on Locations and Users

Habitat type	Moon			Mars			Earth		
	NC	C	US	NC	C	US	NC	C	US
Fixed	5	4	2	4	3	1	5	4	3
Sci.Astronauts 4.2	**4.6**	4.1	3.1	**4.1**	3.6	2.6	**4.6**	4.1	3.6
Space Tourists 4.4	**4.7**	4.2	3.2	**4.2**	3.7	2.7	**4.7**	4.2	3.7
Space Miners 4.3	**4.7**	4.2	3.2	**4.2**	3.7	2.7	**4.7**	4.2	3.7
Inflatable	5	2	4	4	2	2	5	4	4
Sci.Astronauts 1.5	**3.3**	1.8	2.8	2.8	1.8	1.8	**3.3**	2.8	**3.3**
Space Tourists 1.2	**3.1**	1.6	2.6	2.6	1.6	1.6	**3.1**	2.6	3.1
Space Miners 1.5	**3.3**	1.8	2.8	2.8	1.8	1.8	**3.3**	2.8	2.8
Hybrid (baseline)	5	2	3	3	2	1	5	4	4
Sci.Astronauts 4.8	**4.9**	3.4	3.9	**3.9**	3.4	2.9	**4.9**	4.4	4.4
Space Tourists 4.6	**4.8**	3.3	3.8	**3.8**	3.3	2.8	**4.8**	4.3	4.3
Space Miners 4.7	**4.9**	3.4	3.9	**3.9**	3.4	2.9	**4.9**	4.4	4.4
In-situ	4	4	1	4	3	1	5	4	2
Sci.Astronauts 2.2	**3.1**	**3.1**	1.6	**3.1**	2.6	1.6	**3.6**	3.1	2.1
Space Tourists 1.6	2.8	2.8	1.3	2.8	2.3	1.3	**3.3**	2.8	1.8
Space Miners 2.0	3.0	3.0	1.5	3.0	2.5	1.5	**3.5**	3.0	2.0

Note. NC = not covered, C = covered, US = under surface; Technical feasibility and convenient needs are: 5 = very likely, 4 = likely, 3 = neutral, 2 = unlikely, 1 = very unlikely; bold = suitable combinations

Step 4. Identify suitable (i.e., best fit) combinations

The driving question for Table 7 is: *What are the best fit combinations for each habitat type?*

Our approach is: If a score in Table 6 exceeds 3.0 we define the location and user combinations as suitable. If a score in Table 6 is less than or equal to 3.0, we define the location and user combination as unsuitable and omit the corresponding term from Table 7 and the user icon from Figure 7.

Table 7

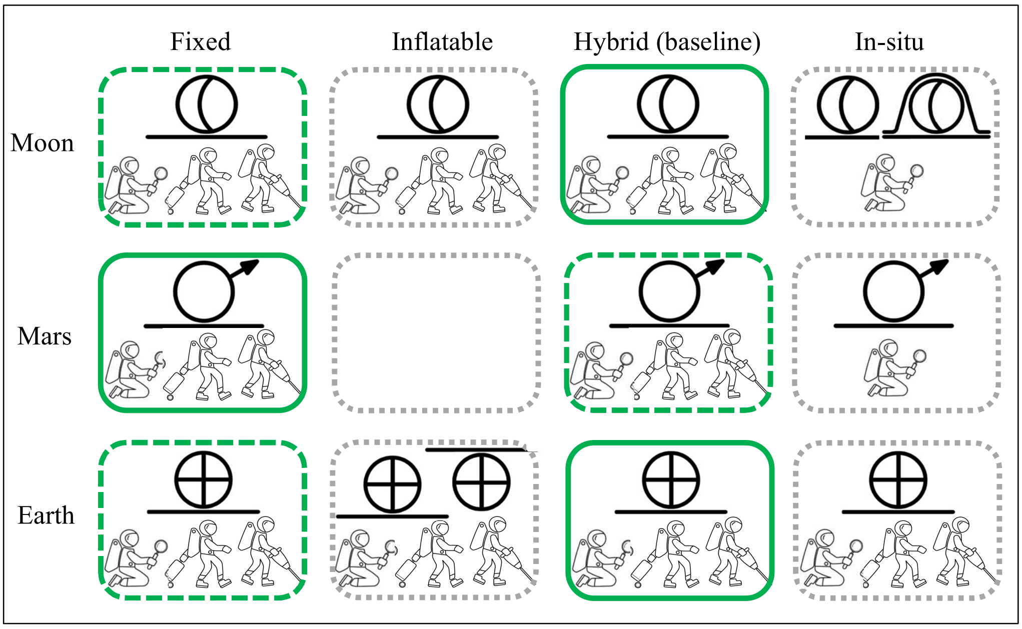
Best Fit Results of Habitat Types Dependent on Locations and Users

Habitat type	Moon	Mars	Earth
Fixed	***NC*** ***- Astronauts*** ***- Tourists*** ***- Miners***	**NC** **- Astronauts** **- Tourists** **- Miners**	***NC*** ***- Astronauts*** ***- Tourists*** ***- Miners***
Inflatable	NC - Astronauts - Tourists - Miners	(unsuitable)	NC & US - Astronauts NC - Tourists - Miners
Hybrid (baseline)	**NC** **- Astronauts** **- Tourists** **- Miners**	***NC*** ***- Astronauts*** ***- Tourists*** ***- Miners***	**NC** **- Astronauts** **- Tourists** **- Miners**
In-situ	NC & C - Astronauts	NC - Astronauts	NC - Astronauts - Tourists - Miners

Note. NC = not covered, C = covered, US = under surface; bold = first choice; bold and cursive = second choice

Figure 7

Best Fit Results



Note. Green solid line = first choice; green dashed line = second choice; gray dotted line = less relevant options

Step 5. Implications and recommendations

The driving question for step 5 is: *What are the implications and applications for each habitat type?*

Fixed. Applicable to all three user groups at all destinations (Moon, Mars, or Earth). The best fit for technical feasibility and convenience needs for scientific astronauts, space tourists, and space miners is to use a fixed habitat that is uncovered on the Moon, Mars, and Earth.

Inflatable. Partially applicable to all three user groups, but only at Moon and Earth destinations. There is limited demand for inflatable habitats, especially among space tourists. The best fit for scientific astronauts and space miners is an inflatable habitat that is uncovered on the Moon and/or either uncovered or under-surface on Earth.

Hybrid. Applicable to all three user groups at all destinations (Moon, Mars, or Earth). The best fit for technical feasibility and convenience needs for scientific astronauts, space tourists, and space miners is to use a hybrid habitat that is uncovered on the Moon, Mars, or Earth. The hybrid habitat type effectively meets the needs of most users.

In-situ. Partially applicable to two user groups and particularly less suitable for space tourists at Moon and Mars destinations. Currently, there is little demand for in-situ habitats, as technical feasibility and convenience needs do not align well. However, advancements in technology could potentially make this a game changer in the future.

Table 6 further indicates that, based on overall lower ratings, Mars is the most challenging location for settlement. The hybrid and fixed habitats, however, are superior for most applications. The hybrid habitat is slightly the better option for the Moon, while the fixed habitat is preferable for Mars. Since the numbers are so close, the difference is not significant. In contrast, inflatable and in-situ habitats are less recommended as primary options for settlements on the Moon and Mars, visualized in Table 7 and Figure 7.

Conclusion

In answering our initial research question—*For which locations and user groups does the mixture of fixed and inflatable elements for a lunar habitat make sense?*—we conclude that the driving factors are the types of users and locations. Specifically, we found that the hybrid habitat, Terra Lunaris, is a very good fit for the combination of scientific astronauts, space tourists, and space miners in uncovered habitats on the Moon (and Earth). It also remains an acceptable option for Mars.

Further, our results indicate that Mars presents the greatest challenges for settlement, with hybrid and fixed habitats emerging as the most suitable options overall. While the hybrid type is slightly favored for the Moon and the fixed type for Mars, the difference is marginal; inflatable and in-situ habitats are generally less recommended for either location based on the current state of the art, though future technological advances could change this assessment.

Limitations

To conduct this initial assessment, we—the authors—relied solely on our own experiences and knowledge to arrive at a best-guess evaluation. We acknowledge that this approach is preliminary and lacks empirical validation. Therefore, future research should include statistically sound methods, such as surveys or structured interviews with a broad range of experts, to verify and refine our findings. Nonetheless, this process allowed us to demonstrate our line of reasoning and provide readers with transparent insight into our research methodology.

Declaration of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authorship Contribution

Schumann: Conceptualization, Design, Methodology, Investigation, Analyzing, Visualization, Writing. Goehlich: Methodology, Investigation, Analyzing, Visualization, Writing.

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The views expressed in this paper are those of the authors alone and do not reflect those of any institution. The authors are solely responsible for any errors or omissions that remain.

OpenAI's ChatGPT (GPT-4.5, July 2025 version) was used exclusively to support grammar correction and minor language refinement during the preparation of this manuscript.

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