ISSN: 2634 - 8853

Journal of Engineering and Applied Sciences Technology

SCIENTIFIC
Research and Community

Research Article

Open Access

Design and Feasibility of Tourism Habitation in Space Using AR and Sustainable Systems

Arnold Folarin

College of Engineering, West Lafayette, USA

ABSTRACT

This paper investigates the feasibility of sustaining planetary habitation while supporting space tourism through advancements in technology, environmental systems, and in-situ resource utilization (ISRU). By utilizing resources like lunar regolith and Martian soil, as demonstrated in recent research, in-situ resource utilization (ISRU) has the potential to minimize dependency on Earth for constructing habitats and producing essential resources like oxygen and water. Technologies such as closed-loop life-support systems, as exemplified by ESA's MELiSSA project, highlight innovative solutions for long-term sustainability. However, environmental challenges such as radiation shielding, energy reliability, and extreme temperatures remain unresolved, presenting obstacles to accommodating tourists in extraterrestrial settings. Augmented reality (AR)-based tools, as discussed in the Purdue RASCAL Report, provide intuitive solutions for resource management and task guidance, offering ways to enhance experiences for both astronauts and tourists. By integrating sustainable technologies, intuitive interfaces, and scalable solutions, space tourism can play a pivotal role in advancing sustainable planetary life while opening new frontiers for human exploration and commercial ventures. However, as commercial space operations expand, new threat vectors such as cyberattacks, kinetic assaults, and orbital terrorism pose significant risks, drawing parallels to potential "Space 9/11" scenarios. This study proposes a hybrid economic and security framework, advocating for international regulatory oversight, AI-driven cybersecurity measures, and radiation-shielded habitat designs to ensure both financial sustainability and operational safety. These findings contribute to the growing discourse on space tourism viability, regulatory challenges, and technological innovations necessary for sustained human habitation in extraterrestrial environments.

***Corresponding author**
Arnold Folarin, College of Engineering, West Lafayette, USA.

Received: January 10, 2025; **Accepted:** February 12, 2025; **Published:** February 24, 2025

Keywords: Space Tourism, Economic Feasibility, Lunar Habitation, Space Security, Augmented Reality, Orbital Threats

Introduction

The growing interest in space tourism has transitioned from speculative science fiction to a tangible, emerging industry [1]. With private enterprises like SpaceX, Blue Origin, and Virgin Galactic spearheading commercial spaceflight, the potential for ordinary civilians to experience extraterrestrial environments has never been closer to reality [2]. Space tourism, however, introduces challenges fundamentally different from traditional crewed space missions [3]. Unlike trained astronauts who undergo rigorous preparation and are accustomed to highly technical and task-specific interfaces, space tourists are largely untrained civilians who require intuitive, user-friendly systems to ensure both their safety and enjoyment. This necessitates a paradigm shift in the design of extraterrestrial habitats, one that focuses on accessibility, sustainability and user experience.

Central to this challenge is the development of tourism-specific habitation systems that cater to the unique needs of non-professional astronauts. Traditional space habitats, equipped with augmented reality (AR)-based interfaces, have emerged as promising solutions for creating user-friendly environments. These AR technologies offer tourists an intuitive means of managing resources, such as air, water, and food supplies, while also enhancing safety through real-time task guidance and environmental monitoring [3]. For instance, NASA's Sidekick project demonstrates how AR can assist in navigating unfamiliar terrains, maintaining habitat systems, and improving cognitive engagement during isolation [3]. By integrating AR tools, habitats can empower tourists to interact with their surroundings effectively, reducing dependency on centralized systems and ensuring a more immersive and autonomous experience.

While designing for user experience is critical, sustainability remains a cornerstone of long-term space habitation. Effective resource management systems are essential for supporting tourism habitats without depleting vital supplies or relying excessively on Earth-based resupply missions. Technologies such as in-situ resource utilization (ISRU) play a vital role in achieving this balance. ISRU technologies leverage local materials, such as lunar regolith or Martian soil, to produce construction materials, oxygen, and water [1]. For example, lunar regolith can be processed into bricks for constructing traditional space habitats-like habitats, while Martian soil contains compounds like silica and iron oxide, which are suitable for cementitious applications. These approaches drastically reduce the logistical challenges associated with transporting materials from Earth and contribute to the economic feasibility of space tourism.

Energy systems also form a critical component of sustainable tourism habitats. Solar energy, due to its abundance on the Moon and Mars, offers a reliable and renewable energy source for powering habitats, life-support systems, and AR technologies. Hybrid energy systems, which combine solar, thermal, and nuclear power, have also been proposed to address the limitations of solar energy during lunar nights or Martian dust storms [2]. Additionally, closed-loop life-support systems, such as ESA's MELiSSA project, demonstrate the potential for recycling over 98% of water and generating oxygen from carbon dioxide, creating a self-sustaining ecosystem that can support tourists and crew members alike [2].

Another critical factor in space tourism is the psychological well-being of participants. Unlike professional astronauts who are trained to endure extended isolation and confinement, tourists are likely to experience heightened psychological stress in extraterrestrial environments. Augmented reality tools and immersive technologies offer a means to mitigate these challenges by simulating Earth-like environments, providing entertainment, and fostering a sense of connection to home. For example, AR can be used to create virtual windows with views of Earth or simulated natural landscapes, offering psychological comfort during prolonged stays in isolated habitats [3]. This combination of technology and design is essential for ensuring the safety, comfort, and satisfaction of tourists in space.

Environmental challenges further complicate the development of space tourism habitats. As shown in Table 1, celestial bodies like the Moon and Mars present extreme environmental conditions that must be addressed through innovative habitat designs. The Moon's lack of atmosphere and extreme temperature fluctuations necessitate habitats with advanced radiation shielding and thermal regulation systems. Mars, with its thin carbon dioxide atmosphere and slightly higher gravity, offers a more habitable environment but still requires substantial adaptations to support human life [1,2]. In contrast, planets like Venus, despite their Earth-like gravity, are rendered inhospitable by extreme atmospheric pressures and surface temperatures [4].

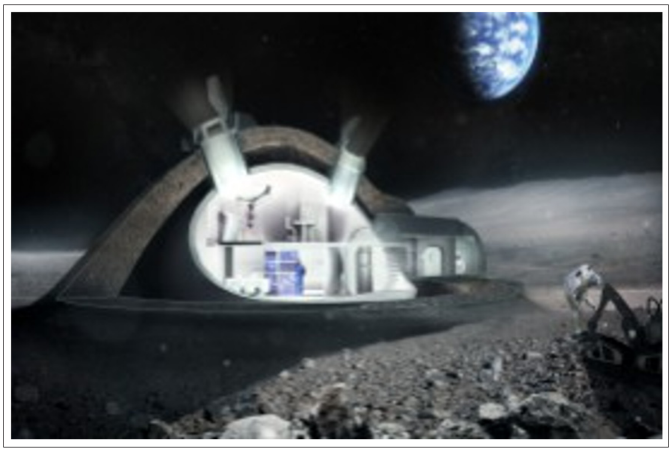


Figure 1: Conceptual design of traditional space habitats for space tourism, showcasing modular construction and integrated solar panels [5]

Table 1: Comparative characteristics of Earth, Moon, Mars, and Venus. Adapted from NASA, ESA, and other sources [1,2]

Parameter	Earth	Moon	Mars	Venus
Diurnal length (hrs)	23.9	656	24.7	2802
Surface temperature (ºC)	-89.2 to 56.9	-143 to 117	-125 to 35	462
Gravity (m/s^2)	9.81	1.62	3.71	8.87
Surface area (km^2)	196.9×10^6	37.9×10^6	144.8×10^6	460×10^6
Atmospheric pressure (kPa)	101.3	Negligible	0.7	9,200
Escape velocity (km/s)	11.1	2.38	5.03	10.4
Main atmospheic composition	N_2, O_2	He, Ar	CO_2, Ar, N_2	CO_2, N_2

Economic feasibility also plays a critical role in the advancement of space tourism. The cost of developing, launching, and maintaining extraterrestrial habitats is significant, requiring innovative solutions to make space tourism accessible to the broader public. Modular and reusable designs, such as inflatable habitats or mobile living spaces, have been proposed as cost-effective alternatives to traditional rigid structures. These designs can be deployed efficiently and adapted to different planetary conditions, reducing overall costs while increasing flexibility.

While space tourism represents a significant opportunity for technological and economic advancement, it also serves as a testing ground for broader space exploration initiatives. The development of sustainable tourism habitats contributes to the advancement of technologies that can support scientific missions, deep-space exploration, and eventually, permanent human settlements. By addressing the unique challenges of tourism-focused habitats, this research lays the groundwork for creating user-friendly, sustainable, and economically viable solutions that bridge the gap between Earth and extraterrestrial environments.

Related Work and Background

The rapid advancements in space exploration and tourism have spurred numerous studies and collaborative projects aimed at designing sustainable and user-friendly habitation systems. Notable among these efforts is the collaborative research conducted as part of the Purdue University RASCAL 2023-2024 NASA Challenge, where I contributed to the exploration of tourism-specific habitation systems. This challenge focused on developing innovative solutions for extraterrestrial tourism, with a particular emphasis on sustainability, usability, and safety in planetary habitats [3]. One critical aspect of space tourism is the development of intuitive interfaces for resource management and task guidance. Augmented reality (AR)-based systems, such as those discussed by Unity Technologies and the Purdue RASCAL Report, provide promising solutions for ensuring tourists can safely navigate and interact with their environment [3,6]. NASA's Sidekick project has demonstrated the use of AR for astronaut assistance, highlighting its potential for enhancing situational awareness, task performance, and cognitive engagement during space missions [3]. These technologies are particularly relevant for space tourism, where tourists may lack the extensive training provided to professional astronauts.

Another area of significant research is the integration of in-situ resource utilization (ISRU) technologies. Studies such as those conducted by Naser et al. (2023) demonstrate the feasibility of utilizing local resources, such as lunar regolith and Martian soil, for constructing habitats and producing essential resources like oxygen and water [1]. This approach drastically reduces the dependency on Earth-based resupply missions, aligning with the goals of sustainable space tourism and habitation. The European Space Agency's MELiSSA project also provides a model for closed-loop life-support systems, capable of recycling water and generating oxygen for long-term habitation [2]. These systems not only ensure sustainability but also significantly enhance the feasibility of supporting non-astronaut tourists.

In addition to technical challenges, research has also explored the psychological impacts of space habitation on untrained individuals. Augmented reality tools have shown potential to mitigate the effects of isolation and stress by providing interactive and immersive experiences. Technologies such as Unity's AR Development Tools and NASA's augmented reality interfaces have been proposed to simulate Earth-like environments, offering tourists psychological comfort and reducing the cognitive strain associated with extraterrestrial confinement [6].

While these studies and projects have laid a strong foundation, gaps remain in the development of tourism-specific habitation systems. Most existing research focuses on professional astronaut missions rather than the unique needs of space tourists. For example, tourist-centric habitation designs must prioritize intuitive usability, recreational experiences, and scalable solutions for larger groups. Furthermore, limited large-scale experimental validation of these technologies in analog or real-world settings underscores the need for further research in this area. This study builds on the innovations of previous works by exploring the technical, operational, and economic feasibility of traditional space habitats habitats equipped with AR technologies for sustainable space tourism.

Figure 2: Example lunar habitat concept, highlighting lightweight construction and efficient deployment for space environments [5]

Methodology

The research methodology focuses on developing sustainable planetary habitation systems, with a specific emphasis on mobile habitats, AR system integration, and sustainability strategies. These elements address the technical, operational, and environmental challenges of supporting tourism and long-term habitation on celestial bodies like the Moon and Mars.

Habitat Design

For the purpose of this research paper we will explore traditional space habitats that have historically relied on prefabricated structural components fabricated on Earth, shipped to extraterrestrial destinations, and assembled to form permanent bases [7]. Effective for fixed missions, this serves as a viable form of habitation to a fixed radius. To overcome these challenges, mobile habitats have emerged as a viable solution.

Such innovations align with the goals of space tourism by enabling predetermined exploration to otherwise unpopular locations offering variety of choice. For instance, tourists could participate in guided mobility tours on lunar or Martian surfaces, experiencing a broader range of environments and landmarks.

Future advancements may include mobile habitat designs to circumvent the natural limitations of a fixed lunar base, further enhancing the operational efficiency of habitats on the moon [8].

Augmented Reality (AR) Systems Integration

AR technologies play a pivotal role in enabling safe and intuitive interaction with extraterrestrial environments, especially for untrained space tourists. While astronauts undergo extensive training for managing habitat operations, tourists require simplified, user-friendly systems to enhance their experience and ensure safety.

AR tools are integrated into habitats through hardware like Microsoft HoloLens and software platforms such as Unity [6]. These systems provide:

Figure 3: Augmented reality interface demonstrating real-time monitoring of oxygen, energy, and waste metrics for tourists [5]

Real-Time Resource Management: AR interfaces display critical metrics, including energy consumption, oxygen generation, and water recycling efficiency, enabling users to make informed decisions [3].

Navigation and Terrain Mapping: AR-based guidance systems assist users in navigating the habitat and its surroundings, offering interactive maps and overlaid instructions for efficient movement.

Emergency Protocols: In high-risk scenarios, such as habitat depressurization or exposure to radiation, AR systems deliver real-time instructions to mitigate risks and ensure safety [3].

For example, NASA's Sidekick project demonstrated the use of AR for astronaut assistance, showing how it improves task performance and operational efficiency during missions. Expanding these applications to space tourism ensures that technology remains accessible, reducing the cognitive load for tourists while enhancing their overall experience [2,3].

Sustainability Strategies

Sustainability is a cornerstone of extraterrestrial habitation systems, ensuring that operations remain viable over extended periods. This study integrates advanced sustainability strategies inspired by ESA's MELiSSA initiative, which focuses on closed-loop life-support systems for recycling resources efficiently [2].

Key sustainability components include:

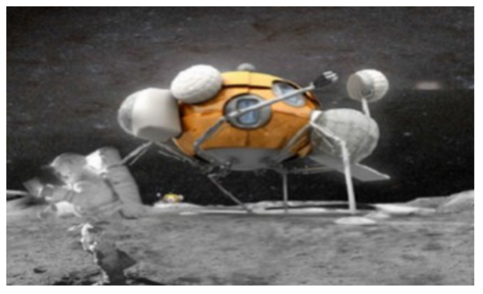
- **Energy Systems:** Solar panels are the primary energy source, capitalizing on the abundant solar radiation on the Moon and Mars. Hybrid systems combining solar and thermal energy address challenges such as lunar nights and Martian dust storms [2].
- **Water Recycling:** Advanced filtration systems recycle over 85% of water within the habitat, significantly reducing the reliance on Earth-based resupply missions (Table 1).
- **Oxygen Generation:** Electrolysis-based oxygen generation systems convert water into breathable air, leveraging local water resources such as lunar ice or Martian soil [1].
- **Waste Management:** Closed-loop recycling systems achieve up to 95% efficiency in converting organic waste into reusable resources, minimizing the environmental footprint of the habitat [2].

Sustainability is a cornerstone of the design. Solar panels are incorporated for renewable energy, while closed-loop water and waste recycling systems minimize environmental impact as seen in Table 1.

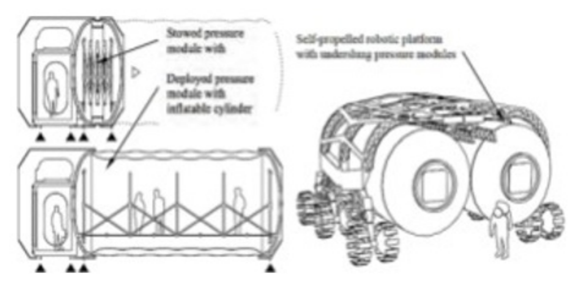
Table 2: Sustainability Metrics for Space Habitats [3].

Parameter	Value	Units	Description
Energy Consumption	100	kW	Daily energy consumption
Water Recycling Efficiency	85	%	Percentage of recycled water
Oxygen Generation	90	%	Efficiency in oxygen production
Waste Management	95	%	Effectivenes s in recycling waste materials

These strategies ensure that habitats can operate autonomously for extended periods, catering to the needs of both scientific missions and tourism. By reducing dependence on Earth-based resources, such systems enhance the economic feasibility and reliability of extraterrestrial operations.



a) Lunar habitat concept with Augmented reality interface demonstrating real-time monitoring of oxygen, energy, and waste metrics for tourists [9].



b) Planetary surface robotic with parametric hybrid inflatable module(left), and robotic platform (right) [Howe & Howe (2000)]

Figure 4: Lunar base on the surface of Moon or Mars (Courtesy of NASA)

Figures

The research methodology is supported by visual concepts of mobile habitats, including the Mobitat, Moonwalker, and hybrid inflatable-rover designs. These visuals demonstrate how structural innovation supports mobility, adaptability, and user-centric design (see Figure 4).

Integration with Space Tourism Goals

The methodology outlined above directly addresses the needs of space tourism, where intuitive systems, sustainability, and dynamic exploration capabilities are essential. Mobile habitats enable tourists to explore diverse landscapes, while AR systems ensure their safety and engagement. Sustainability strategies, such as renewable energy and waste recycling, make these operations economically viable for commercial ventures.

Future work will focus on refining these systems through large-scale testing in analog environments and interdisciplinary collaboration, bridging the gap between conceptual designs and real-world applications.

Results and Discussion

The results of this study present a comprehensive evaluation of the feasibility of planetary habitats, emphasizing technical, economic, physiological, and psychological aspects of supporting space tourism. By integrating data from simulations, previous research, and real-world analog studies, the findings demonstrate a path forward for sustainable extraterrestrial habitation.

Structural Viability and Load Actions

Reduced Gravity and Its Implications

The Moon's gravity at 1.62 m/s^2 and Mars' gravity at 3.71 m/s^2 significantly affect the structural requirements for habitats:

Load Optimization: The reduced weight of equipment and personnel minimizes stress on structural components. For example:

An 80-kg individual would weigh only 13 kg on the Moon and 30 kg on Mars thus lightweight materials such as composites and alloys are ideal due to the lower gravitational.

Radiation Protection and Meteorite Impacts

Radiation and meteoroid impacts are also critical challenges for extraterrestrial habitats:

Regolith-based shields, with thicknesses of 4–6 meters, effectively block cosmic radiation. Other materials, such as polyethylene and hydrogen-rich composites, offer lightweight alternatives [1,2,7].

Impact Resistance in the form of layered Kevlar and advanced composites improve durability against meteoroid impacts, ensuring long-term safety [7]. Alternative materials include polyethylene, which offers a high hydrogen content for effective radiation blocking. Meteoroid Resistance such as layers of Kevlar or similar composites enhance resistance to micro-meteoroid impacts, ensuring long-term durability [7]. forces, reducing transportation costs [1].

Thermal and Vacuum Effects
Habitat structures face challenges from extreme temperatures and vacuum-induced material degradation:

Thermal Fluctuations: On the Moon, temperatures range from -143°C to 117°C, while Mars experiences -125°C to 35°C. Materials must withstand these fluctuations to prevent cracking or fatigue [1,2].

Vacuum Deterioration: Polymers may off-gas in vacuum conditions, reducing structural integrity. Protective coatings and vacuum-compatible materials mitigate these issues [2].

Load Combinations
Extraterrestrial habitats encounter unique load conditions:

- Dead loads (structural weight and shielding).
- Live loads (crew, equipment).
- Pressurization (internal atmospheric pressure).
- Thermal loads (expansion/contraction due to temperature changes).
- Meteor impacts and seismic activity.

The design equation for expected loads:
Load (L) $= D + L \pm P \pm T + Q \pm M \pm W$

Habitat Design and Human-Centric Considerations
Geometric Optimization
Efficient habitat designs maximize usable space while maintaining structural efficiency:

Cylindrical and toroidal shapes distribute stress evenly. Spherical designs maximize volume-to-surface ratios but require stabilization against micro-meteoroids [2].

NASA guidelines recommend 25 m³ per person for missions exceeding 90 days, translating to 500 m² for a crew of 12 [10].

Modularity and Expandability
Modular habitat designs allow for scalability
Units can be expanded or reconfigured for diverse applications, such as laboratories, sleeping quarters, or recreational areas [7].

Privacy and Social Dynamics
Psychological well-being is critical for long-term stays should this be a viable form of tourism or for sustaining long term missions for miscellaneous purposes.

Privacy Features like soundproof partitions and visual dividers reduce interpersonal stress and shared spaces which allow for recreational and communal areas promote cohesion among diverse crews [8].

Sustainability and Resource Utilization
In-Situ Resource Utilization (ISRU)
ISRU technologies significantly reduce dependency on Earth-based resources:

Water: Polar ice deposits and advanced recycling systems recover 85% of water from waste [1].

Oxygen: Processes such as electrolysis and Sabatier conversion achieve 90% efficiency in oxygen production [2].

Regarding construction materials, regolith-based concrete and sulfur derivatives are cost-effective for habitat construction in lunar environments [2].

Biocement offers an eco-friendly alternative for Martian habitats [7].

Table 3: Construction Materials for Habitat Design

Materia l	Advant ages	Challenges	References
Regolith (Sintered)	Abundant, high radiation shielding	Requires sintering infrastructure	[1,2,4]
Sulfur Concrete	No water required, durable	Brittle in cold environments	[2,8]
Biocement	Eco-friendly, Martian soil compatible	Requires microbial cultivation setup	[7,10]
Lightweight Alloys	Strong, easy to transport	Expensive to manufacture	[1,2]

Energy Systems
Energy is a cornerstone of extraterrestrial sustainability and the maintenance of life on extra terrestrial life must support his:

Solar Arrays: Efficient at lunar poles and Martian equators but vulnerable to dust storms.

Nuclear Reactors: Small modular reactors (e.g., SP-100) provide consistent power for larger settlements, generating 100 kWe to 1 MWe [2,8].

Table 4: Energy Demands and Supply Options

Population	Energy Demand	Power Source	References
6–12	100 kWe	Solar/Nuclear Hybrid	[2]
100–1,000	~1 MWe	Nuclear Reactor	[1,10]
>10,000	>10 MWe	Complete Nuclear Cycle	[2,8]

Physiological and Psychological Needs
Physiological Requirements
Initially, water may be brought from Earth, followed by the recycling of drinkable water from waste and washing water. Analogous to water, oxygen will also be supplied from Earth, and with effective oxygen recovery, a space habitat will need around 1.5-2.05 kg of oxygen replenishment per person each day. Oxygen may subsequently be recovered from lunar and Martian soil and rocks, as well as carbon dioxide, using the Sabatier process [1].

Basic life support must address oxygen, water, and food needs (see Table 5):

Oxygen: 1.5–2.05 kg/person/day.
Water: 0.71–3.2 gallons/person/day.
Food: 2,000–3,000 kCal/person/day [1,2].

Table 5: Physiological and Life Support Needs

Factor	Input (Per Person)	Output (Per Person)	References
Oxygen (kg/day)	1.5–2.05	1.0 (CO_2)	[1,2,10]
Drinking Water (gal/day)	0.71–3.2	1.83 (perspiration loss)	[1,2,8]
Food (kCal/day)	2,000–3,000	1.9 kg (biological waste)	[1,7]
Factor	Input (Per Person)	Output (Per Person)	References

Psychological Well-Being

Long-term missions impose psychological challenges summarized as isolation and social dynamics caused by limiting the space potential tourists or astronauts have.

Isolation: AR/VR technologies alleviate stress through immersive recreational activities.

Design considerations include shared spaces and cultural sensitivity training to minimize interpersonal conflicts [2,8].

Table 6: Psychological Needs and Mitigation Strategies

Psychologic al Factor	Impact	Mitigation Strategies	References
Long-Term Isolation	Stress, depression	AR/VR for leisure, private space design	[1,10]
Social Conflicts	Strain on group dynamics	Cultural training, recreational activities	[2]
Lack of Natural Stimuli	Decline in mental health	Natural light simulation, AR environments	[7,8]

Economic Feasibility

While the initial costs of deploying habitats are high, long-term benefits such as helium-3 mining and resource utilization must offset the expenses. The economic feasibility of extraterrestrial habitats and space tourism rests on addressing high initial costs and ensuring sustainable revenue streams.

Funding Sources

Establishing extraterrestrial habitats involves substantial initial investments, ranging from $10 billion to $20 billion for medium-sized settlements. These costs include infrastructure development, transportation, and research. The transportation of materials alone, via rockets such as SpaceX's Starship, can cost $2,000 to $10,000 per kilogram [1,2].

Government Agencies

Government space agencies, such as NASA and the European Space Agency (ESA), are primary contributors to funding. NASA has committed $25 billion annually to the Artemis program, which aims to establish lunar outposts [2,5]. ESA's MELiSSA project, focusing on closed-loop life-support systems, further emphasizes the role of public funding in technological advancements [2].

Private Sector Contributions

Private companies, including SpaceX, Blue Origin, and Axiom Space, are key players in driving commercialization. SpaceX, for example, has developed reusable rockets to lower costs and facilitate access to the Moon and Mars.

Technology companies like Unity Technologies and Google contribute by developing AR systems and communication platforms that enhance usability in extraterrestrial environments [4,3,6].

Public-Private Partnerships

Collaborations between governments and private enterprises, such as NASA's contracts with SpaceX for lunar landers, enable cost-sharing while accelerating technological progress. These partnerships reduce financial burdens on individual stakeholders and allow for shared risk and innovation [1].

Revenue Streams

Extraterrestrial habitats present several promising avenues for generating revenue, offsetting the initial investment costs over time.

Space tourism is poised to become a major industry, with companies like Virgin Galactic and Blue Origin offering suborbital flights. Lunar habitats could offer short-term tourism packages, priced at approximately $50 million per person, targeting high-net-worth individuals [2,5]. The addition of luxury modules for extended stays could further enhance revenue potential.

Yet in spite of the financial barrier this undoubtedly poses to well over 90% of the current earths population resource extraction is a critical revenue driver. The Moon's surface is rich in helium-3, a valuable isotope for nuclear fusion.

Revenue from helium-3 mining is estimated at $1 billion per metric ton, making it a lucrative investment for energy markets on Earth [2,11]. Ice deposits on the Moon and Mars can be harvested for water and hydrogen-based rocket fuel. Mars also harbors rare metals, such as platinum, projected to generate $10 billion annually [2,11]. Scientific Research through extraterrestrial habitats provide unique opportunities for scientific innovation as universities and governments could lease laboratory space for low-gravity research [2,10] while pharmaceutical companies could conduct advanced drug testing in microgravity environments.

Outside formal research the media and entertainment industry would likely see a boom. The unique environment of space offers significant media and entertainment opportunities. Lunar or Martian landscapes could serve as filming locations for movies or documentaries and AR and VR platforms could enable millions of Earth-based users to virtually explore these habitats, generating subscription-based revenue [3,6].

In the event that despite its return on investment, space tourism's revenue streams dip unexpectedly or overtime, decreasing costs of space tourism, would make it accessible to high-net-worth individuals by 2035 supported by Table 7.

Table 7: Cost Breakdown of Space Tourism

Expense Category	Estimated Cost Per Tourist (USD)	Potential Cost Reduction (%) by 2040
Rocket Launch & Transport	$450,000	60% (reusable rockets)
Habitat & Life Support	$150,000	40% (closed-loop ISRU systems)
Food & Consumables	$20,000	35% (3D-printed food technology)
Insurance & Safety	$75,000	25% (advanced AI safety systems)
Total Estimated Cost (Current)	$695,000 per person	Projected to fall below $300,000 per person

References: [12,13,14]

Tourist Experience and Engagement

Space Security and Threat Prevention

As space commercialization accelerates, new security risks emerge, ranging from cyber-attacks on critical systems to kinetic threats against orbital and lunar infrastructure. The growth of private space enterprises, space tourism, and off-world settlements introduces vulnerabilities that could be exploited by rogue actors, state-sponsored entities, or ideological groups seeking to disrupt operations. The potential for a "Space 9/11" scenario has been raised by security analysts, where an attack on key orbital assets could cripple communication networks, disrupt financial transactions, or even endanger human lives in space [15].

Modern space habitats rely on networked systems for life support, navigation, and mission control. A targeted cyber-attack could disable habitat life support systems, cutting off oxygen and temperature regulation, manipulate spacecraft trajectories, potentially leading to collisions or mission failures or compromise financial transactions in space commerce, creating economic instability.

Previous analyses suggest that militarized cyber-warfare in space is a growing concern, particularly as private actors such as SpaceX and Blue Origin become integral to national security infrastructure [15].

The risk of kinetic attacks, such as anti-satellite (ASAT) weapons or debris-based sabotage, is no longer theoretical. Nations like China, Russia, and the U.S. have tested ASAT weapons, proving that satellites and orbital stations can be deliberately destroyed [15]. If a commercial space station housing tourists were targeted, it could trigger a catastrophic event akin to a "9/11" in orbit.

To prevent these risks, future space tourism hubs and orbital settlements must integrate AI-based intrusion detection systems for cybersecurity [15]. Radiation-shielded, impact-resistant habitat designs to withstand kinetic threats some form of international treaties restricting the militarization of lunar and orbital tourism zones and or private security collaboration with governmental space agencies for joint monitoring and rapid-response measures to name a few [16].

"As tourism expands beyond Earth, policymakers and commercial space entities must prepare for the reality of security risks in orbit, just as they do for air travel and maritime industries." – The Conversation [15].

Enhancing Space Tourism Experience and Motivations

Tourist Experience and Engagement

The success of space tourism depends not just on the journey but on the quality of the experience at the destination. Findings from terrestrial space tourism studies indicate that tourists seek interactive, hands-on experiences rather than passive observation [16]. In comparison to Antarctic tourism, which allows visitors to engage in research and exploration, future lunar and orbital tourists must also have opportunities for meaningful participation.

Rather than simply observing the Moon from within a habitat, tourists must have the chance to walk on the lunar surface, interact with regolith, and engage in guided exploration missions. Safe methods for achieving this include:

- Radiation-shielded tunnels with transparent enclosures for safe surface observation.
- Airlock-sealed rock enclosures where tourists can touch lunar material while remaining pressurized.
- EVAs (Extravehicular Activities) with trained astronaut escorts, similar to space station protocols.

Tourists strongly prefer hands-on experiences and research participation (consistent with Antarctic tourism models) supported by Table 7 [13].

These features aim to be comparable to Antarctic tourism, where visitors fund research missions and contribute to scientific discoveries [16].

Table 8: Psychological Needs and Mitigation Strategies

Tourist Motivation	% of Participants Indicating Strong Interest	Correlation with Actual Space Travel Intent
Interest in Space Exploration	82%	High (0.75)
Participation in Educational Tourism	74%	Medium (0.61)
Experience of Zero Gravity	69%	Very High (0.82)
Seeing Earth from Space	91%	Very High (0.89)
Interacting with Space Technology	68%	Medium (0.59)
Scientific Research Participation	53%	Medium-Low (0.47)

References: [17,18]

Augmented Reality for Immersive Exploration

Augmented Reality (AR) and Virtual Reality (VR) systems are critical in bridging the experience gap for tourists who may not have EVA access. The Purdue RASCAL Report suggests that AR-assisted helmets could provide virtual overlays of Apollo landing sites and historical missions [3]. This Interactive, gamified geological surveys, where tourists collect and analyze lunar samples using AI-driven astronaut guidance, could greatly reduce the reliance on ground control for navigation and safety.

These systems will enhance the sense of presence and engagement, making space tourism an active experience rather than a passive one.

Expanding the Economic Model for Space Tourism

Revenue Expansion Models

Economic feasibility remains one of the greatest barriers to mainstream space tourism. While the cost of a lunar vacation remains exorbitant, alternative revenue streams can support sustainable operations. Terrestrial space tourism findings indicate that research-driven tourism models—like those in Antarctica—can be applied to space tourism [16].

Research-Based Tourism

A viable business model involves allowing tourists to fund scientific research while participating in exploration.

Examples include:

- NASA and ESA partnerships with private space hotels to subsidize research through high-net-worth tourists.
- SpaceX's proposed commercial space station, where wealthy patrons offset costs for scientific endeavors.
- Lunar archaeological tourism, where visitors participate in preserving and studying historic landing sites.

"Tourists visiting Antarctica often engage in conservation work and data collection, proving that research-backed tourism can be both commercially viable and scientifically beneficial." – UiT Alta Study [16].

Media and Entertainment Revenue

In addition to scientific tourism, space can be monetized through media, live broadcasts, and VR tourism. Potential revenue streams include:

- Subscription-based AR/VR live tours of the Moon for Earth-bound users.
- Exclusive filming rights for movies/documentaries shot on-location in lunar habitats.
- Celebrity and influencer partnerships to generate mainstream appeal.

These strategies align with findings from terrestrial space tourism, which show that public fascination with space increases commercial viability when combined with educational outreach [16].

Practical Recommendations

Collaborations with space organizations and private companies are essential for advancing habitat designs. Future research should focus on material innovation and automation in habitat construction.

Future Work and Opportunities

Future work should explore the use of AI in habitat management, advanced autonomous systems for emergency handling, and scalable models for interplanetary tourism as well as the social.

Conclusion

This research highlights the potential of innovative designs and AR technologies to address the challenges of tourism habitation in space. By integrating sustainability, usability, and economic considerations, the proposed solutions offer a pathway toward making space tourism a reality. Future work will focus on applied research to validate these findings and develop prototypes for real-world testing.

Findings indicate that tourists are not only motivated by novelty but by immersive experiences, including EVAs, hands-on research participation, and AR-enhanced exploration. Lessons from Antarctic research tourism suggest that scientific participation models could serve as a viable funding mechanism, supporting both private and government-backed space missions.

Economically, space tourism remains a high-cost, low-accessibility industry, but projections indicate that by 2040, costs could decrease by over 60% due to reusable launch systems, ISRU, and advances in closed-loop life support. The transition from elite-only tourism to middle-class accessibility depends on continued investment in cost-reducing technologies and infrastructure.

However, as commercialization expands, new security risks emerge, including cyber threats to life-support systems, kinetic sabotage of orbital assets, and geopolitical tensions surrounding lunar resource claims. The potential for a "Space 9/11" scenario underscores the urgency of developing international space security frameworks, AI-based cybersecurity, and impact-resistant habitat structures. As a preventive measure, public-private collaborations should establish regulatory frameworks to mitigate risks while fostering sustainable economic growth in space tourism [19].

As humanity stands at the frontier of space commercialization, the intersection of economic viability, immersive tourism experiences, and security frameworks will determine the long-term success and sustainability of extraterrestrial tourism.

Acknowledgments

"This paper is inspired by the collaborative research conducted as part of the Purdue University RASCAL 2023-2024 NASA Challenge. The author acknowledges the invaluable contributions of the Purdue RASCAL team, whose collective efforts laid the foundation for this work. This work builds upon the shared knowledge and innovative spirit fostered by the RASCAL program and Purdue University."

This template was adapted from those provided by the IEEE on their own website.

References

1. Naser MZ, Redmond L, Chen Q, Rangaraju P (2023) Habitats for Space Exploration: Construction Materials, Design Concepts, and Future Directions. The Planning and Execution of Human Missions to the Moon and Mars. American Institute of Aeronautics and Astronautics 229-266.
2. (2023) MELiSSA: Micro-Ecological Life Support System Alternative. European Space Agency (ESA) https://www.esa.int/.
3. (2023) Designing Augmented Reality Interfaces for Space Tourism Habitats. Purdue RASCAL Report.
4. Google (2023) Speech-to-Text API Documentation. Google Cloud https://cloud.google.com/speech-to-text/docs.
5. Giraldo C (2023) Space Tourism and Habitation Systems. NASA https://www.nasa.gov/humans-in-space/astronauts/jasmin-moghbeli/nasas-2023-space-station-achievements/.
6. Reid J (2023) AR Development Tools. Unity Technologies https://www.mixyourreality.com/insights/augmented-reality-development-tools.
7. Schreiner SS, Setterfield TP, Roberson DR, Putbrese B, Kotowick K, et al. (2015) An overnight habitat for expanding lunar surface exploration. Acta Astronautica 112: 158-170.
8. Howe AS, Spexarth G, Toups L, Howard R, Rudisill J, et al. (2010) Constellation architecture team: Lunar outpost "Scenario 12.1" habitation concept. In Proceedings of the 12th International Conference on Engineering, Science, Construction, and Operations in Challenging

Environments – Earth and Space 2010 https://ascelibrary.org/doi/10.1061/41096%28366%2991.

9. Aguzzi M, Häuplik S (2005) Design strategies enabling evaluation on the lunar surface. Int. Astronaut. Fed - 56th Int. Astronaut. Congr. 2005 https://repositum.tuwien.at/handle/20.500.12708/63363.
10. Howe AS, Gibson T (2006) MOBITAT: A mobile habitat based on the trigon construction system. In Collected Technical Papers - Space 2006 Conference 3: 1643-1665.
11. Risley R (2012) Lunar resources utilization - An economic assessment<149>of manufacturing and construction of large structures in space. Arch. Set 175 https://arc.aiaa.org/doi/10.2514/6.1979-1412.
12. FAA (2022) The Commercial Space Transportation Industry: Economic Impact Analysis. Federal Aviation Administration https://www.faa.gov/space.
13. (2021) The Future of the Space Economy. Bank of America.
14. Musk E (2023) Starship and the Cost Revolution in Spaceflight. SpaceX Conference Talk.
15. Coleman N (2017) From tourism to terrorists: fast-moving space industries create new ethical challenges. The Conversation https://theconversation.com/from-tourism-to-terrorists-fast-moving-space-industries-create-new-ethical-challenges-84618.
16. C Le Dily (2020) Tourist Motivations & Terrestrial Space Tourism. UiT Alta, Master's Thesis https://munin.uit.no/bitstream/handle/10037/18687/thesis.pdf?sequence=2&isAllowed=y.
17. Harrison AA (2011) Spacefaring: The Human Dimension, University of California Press https://www.ucpress.edu/books/spacefaring/paper.
18. Cater CI (2010) Steps to Space: Opportunities for Astrotourism. Tourism Management 31: 838-845.
19. Tsiolkovsky K (2023) Exploration of the Universe with Reaction Machines. Scientific Review https://spacemedicineassociation.org/download/history/history_files_1920-1930/Tsiolkovsky%20Oberth%20Goddard.pdf.