Toward sustainable lunar base development: Comprehensive space environment platform

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The 759th Xiangshan Science Conference, held on December 7-8, 2024, in Beijing, focused on "Lunar-Based Comprehensive Space Environment Platform Construction" and brought together experts and scholars to discuss the future of lunar exploration and base development. With an emphasis on strategic visions for lunar research, the conference highlighted the critical role of research collaboration alongside recent advancements in energy systems and resource utilization, which are essential for sustainable lunar habitation. Recognizing the establishment of a lunar base as a pivotal step in humanity's exploration and utilization of space resources, participants exchanged ideas on the scientific, technological, and collaborative pathways necessary for its construction. Discussions further underscored the importance of multi-domain operations to support comprehensive and effective lunar exploration.

Key themes of the conference included lunar environmental monitoring and control, in-situ resource utilization technology, multi-domain transportation frameworks, and energy utilization on the Moon, reflecting a comprehensive and interdisciplinary approach to lunar base development. Recent research underscores the critical role of effective energy systems in sustaining lunar missions, emphasizing the need for efficient solar power systems and the exploration of alternative energy sources available on the lunar surface.[1] The integration of these advanced energy solutions is essential for enabling continuous operations, resource processing, and the long-term human presence on the lunar surface.

The Moon Exploration Engineering and Technology (MEET), proposes an integrated approach encompassing a regional mobile research station, a wide-area environmental observation station, and an outer lunar space surveillance station, aiming to enhance multi-dimensional sensing, energy resource utilization, efficient multi-terrain transportation, and precision in-situ resource processing. This initiative reflects a commitment to multi-domain exploration and establishes a foundation for comprehensive lunar research. These efforts focus on fostering innovation, interdisciplinary collaboration, and open exchange to explore new lunar frontiers and expand human spatial domains. Building on two decades of progress in lunar exploration, advancements in talent cultivation, scientific innovation, and research capabilities have created a strong foundation for future lunar-based research. Moving forward, the emphasis is on leveraging these achievements to push the boundaries of scientific understanding, drive technological breakthroughs, and advance human exploration of extraterrestrial life.[2]

The lunar extreme environment, characterized by significant temperature fluctuations, high radiation levels, and micrometeorite impacts, necessitates robust environmental monitoring systems.[3] Recent advancements in low-frequency electromagnetic detection technology were highlighted as essential for probing the lunar subsurface structure and resource distribution. These technologies also enable comprehensive environmental assessments, critical for site selection and long-term sustainability.

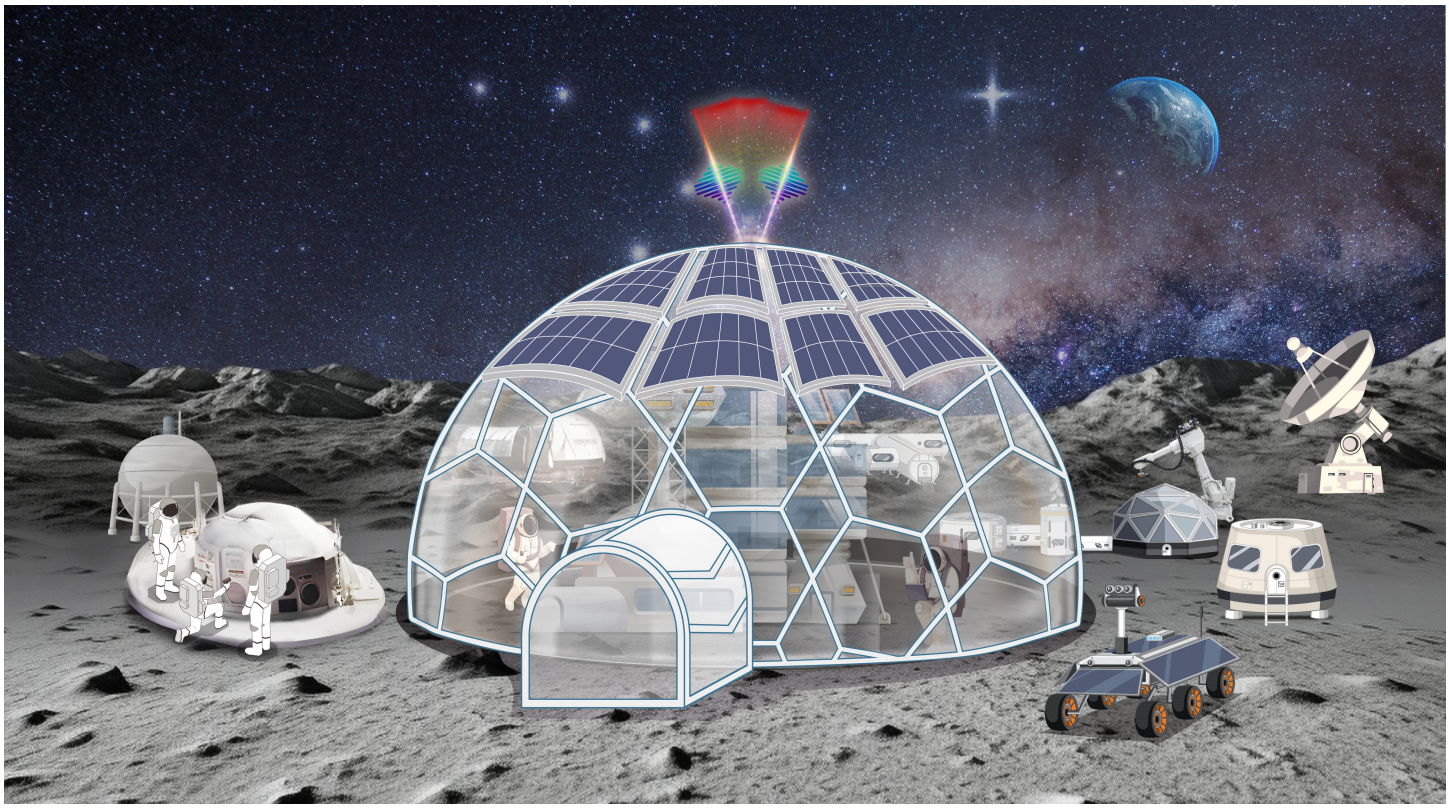

Figure 1. A conceptual diagram of lunar base.

Key technological challenges in lunar base construction, such as developing advanced materials to withstand extreme lunar conditions while ensuring

structural integrity, were highlighted. Innovations, including multimodal lunar science models enabled by cloud computing, were introduced to enhance geological analysis capabilities critical for lunar research. Breakthroughs in lightweight, high-strength construction materials for the Moon could revolutionize Earth-based industries, particularly in construction and transportation. Similarly, advancements in AI-driven autonomous systems for lunar exploration could be applied to disaster response and remote operations on Earth.

Efficient planetary transportation platforms are crucial for deploying equipment, materials, and personnel to the lunar surface. Proposals included the design of modular and multifunctional landing platforms capable of supporting high payload capacities. Additionally, mobility-enhancing technologies such as intelligent navigation systems and cooperative robotic networks were discussed as integral to ensuring operational efficiency and adaptability in dynamic lunar environments.

Energy sustainability remains a cornerstone of lunar base operations. Advanced solar power systems and energy storage systems were identified as key enablers of continuous functionality.[4] Strategies for integrating energy generation, storage, and utilization into a cohesive system were emphasized to maximize operational efficiency and ensure resilience against environmental fluctuations. Additionally, the integration of advanced energy systems was identified as crucial for efficient energy consumption and resource management, with recent studies suggesting that leveraging local resources, such as lunar regolith, can further optimize energy systems and support long-term lunar habitation.[5]

The complexity of lunar base construction offers an unparalleled opportunity to develop new frameworks for systems engineering, integrating robotics, artificial intelligence, and material science to address challenges such as extreme temperature fluctuations, radiation shielding, and remote operation. Furthermore, establishing a human presence on the Moon raises ethical and sociological questions regarding governance structures and equitable resource sharing, demanding theoretical exploration to guide international policies on space exploration.

The 759th Xiangshan Science Conference underscored the collaborative spirit required for significant advancements in lunar exploration. By addressing critical scientific challenges and promoting international partnerships, foundational ideas for future lunar missions were established. The continuous integration of advanced technologies will be pivotal for achieving sustainable lunar habitation, thereby expanding humanity's presence in space.

REFERENCES

1. Wu W., Shen J., Kong H., et al. (2024). Energy System and Resource Utilization in Space: A State-of-the-Art Review. *Innov. Energy* **1**:100029. DOI:10.59717/j.xinn-energy.2024.100029
2. Huijun L., Zhaojin R. and Yong W. (2023). Exploring the universe and protecting the Earth: Young Chinese scientists in action. *The Innovation* **4**:100466. DOI:10.1016/j.xinn.2024.100660
3. Mandt E. K.. (2024). The scientific importance of the lunar environment. *Science* **384**:9563. DOI:10.1126/science.ado9563
4. Byron R., Sophia H. and Katharina B. (2023). Assessment of the technological viability of photoelectrochemical devices for oxygen and fuel production on Moon and Mars. *Nat. Commun.* **14**:3141. DOI:10.1038/s41467-023-38676-2
5. JuanCarlos G., Miranda F., Tim S., et al. (2023). Material aspects of sintering of EAC-1A lunar regolith simulant. *Sci. Rep.* **13**:23053. DOI:10.1038/s41598-023-50391-y

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AUTHOR CONTRIBUTIONS

All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

Jun Shen and Peixue Jiang serve as Editorial Board Members for The Innovation Energy. The authors declare no other competing interests that could appear to have influenced the submitted work reported in this paper. Dr. Jun Shen and Dr. Peixue Jiang did not influence the objectivity, peer review process, or editorial decisions regarding this manuscript.