Domi Inter Astra (DIA) Moon Base: an interdisciplinary approach for cooperation to build a near-future Moonbase and how to use it as an educational tool

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Abstract

Permanent human settlements outside of low-earth orbit face technical and psycho-social challenges for the crew members and programmatic risks around funding and operating these missions, without clear public support and international involvement. A concept for the construction and operation of a lunar settlement named "Domi Inter Astra" (DIA), near the Shackleton Crater, was developed to understand the feasibility of a near-term permanent settlement crewed by international researchers and tourists. This project was created by a team under the Space Generation Advisory Council's auspices and a follow-on to our First Place design in the Moon Base Design Contest by The Moon Society. Technologies for infrastructure, life-support, environment control, and robotics were selected using high-level trade studies to balance resource requirements, safety, reliability, operability, and maintainability of the base over a long (20+ year) operating life with 10-30 inhabitants. Technology roadmaps were developed for gaps in existing technologies, considering opportunities with ISRU and methods of closing the environment control and life support system loops. A wider range of human factors pertaining to the social environment onboard the base is discussed to ensure long-term stability. Architectural design choices were made, keeping these factors in mind while also considering technical and economic viability. Large-scale space exploration projects must mitigate both public interest and funding risks throughout their life cycle. Economic roadmaps are introduced to diversify revenue streams throughout the settlement's design, deployment, and operation. Funding opportunities that evolve with the base design and functionality over time are identified for long-term economic sustainability. A polycentric model for international collaboration is explored to promote interest from current space-leading countries while providing opportunities for emerging space nations. The DIA lunar settlement case study showcases the interrelation between engineering, economics, architecture, science, social and management scopes. It highlights the interdisciplinary approach and inclusivity in the field of space sciences. This case study can help international and public-private partnerships to develop human space exploration capabilities further. The current DIA base plan could be used in many ways for educational activities, for any level of students and professionals. Two types of activities could be design and analysis based and mini analogue missions. Students could devise and perform small experiments that relate to the base's day-to-day activities as well as resources required, for example growing microgreens and plants in different conditions, geology surveys, 3D printing different objects and many such mini-projects. Graduate students and professionals could work on CAD modelling for structures, improving the architectural plan and the statistical analysis for the economical model.

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Keywords

Extra-terrestrial settlements, Moon Exploration, Human spaceflight

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Acronyms/Abbreviations

CAD	*Computer-Aided Design*
DIA	*Domi Inter Astra*
ECLSS	*Environment Control & Life Support Systems*
SEDS	*Students for Exploration and Development of Space*
SGAC	*Space Generation Advisory Council*
STEAM	*Science Technology Engineering Arts Mathematics*

1. Introduction to DIA

Domi Inter Astra (DIA, Latin for home among the stars) is a project that participated in the Moon Society's 2021 Moon Base Design Competition. This multidisciplinary and multicultural team was formed through the Space Generation Advisory Council (SGAC). After winning the competition, the team decided to share the project with the wider public to show them the wonder and excitement of space exploration. DIA's diverse team comprises 50 members from over ten countries, now working on writing an outreach book analysing lunar base building through the lenses of STEAM (Science, Technology, Engineering, Art, Mathematics). The entire lunar base is explored through the story of a young girl, Antariksha, from India, who is an integral member of the base. The combination of the creative aspects with technology highlights the values that DIA stands for: safety, collaboration, exploration, curiosity, and equality. The book is divided into three parts and starts by analysing the challenges that in 2022 do not allow us to start the construction of a Moon Base. The second part highlights how the base will overcome these challenges and establish itself before describing the operations and life on the base for the first ten years. The final part describes what the base will look like in 50 years and showcases future relations between Earth, the Moon and Mars. Once the book is published, the team will develop educational materials ranging from theory explanations to practical exercises and experiments related to the book's content. The current DIA base plan could be used in many ways for educational activities, both for school level and research-level professionals.

Figure 1. DIA Authors Technical Backgrounds

2. Thematic Areas of DIA

This section highlights the departments that play a key role in DIA.

2.1 Space Law, Politics and Policy

The DIA Moon Base is conceived in the spirit of international space projects like the ISS [1-3]. SGAC's Effective and Adaptive Governance for a Lunar Ecosystem (EAGLE) Manifesto will be followed to create a Lunar Governance Charter for peaceful and sustainable lunar exploration [5]. In this spirit, there is no claim of sovereignty, and space exploration is recognized as a benefit for all humankind [4]. DIA will rely on a polycentric governance system, where different structures and both public and private institutions will participate in rule creation in multiple and overlapping layers [6-7]. This will allow for an agile sustainable, accessible and intergenerational mindset. Decentralization and collaboration will be designed into the system. Decision-making will happen through a tiered system that ensures voting will be proportional to the investment made while ensuring no single block has excessive influence on voting (as seen in Figure 2).

An important area that should be addressed is the possible gap between social sciences and space exploration. Key professional fields like that of astropolitics [8], astrosociology [9] and the already burgeoning Space Law sector will need to be further developed going into the future. In order to initiate, operate and enhance activities in the competing jurisdictions of space and lunar exploration, significant capacity for establishing Space Law and Policy will be needed [10-11].

The UN Committee on Peaceful Uses of Outer Space (COPUOS) has explored the need to develop a specific corpus for Space Education to anticipate the needs of professionals that can build governance and regulatory systems [12]. The DIA base's extreme conditions can act as an excellent proving ground for these fields in the coming decades. Ideathons and moot court exercises could be a non-traditional way to educate lawyers and political scientists and introduce basic knowledge to technical specialists [13].

2.2 *Management*

The base management structure will be divided into Lunar and Earth segments, with the former taking care of day-to-day operations and the latter taking care of the broader project aspects (as seen in Figure 3). A rotating Managing Director will oversee both. In the spirit of decentralization and agility, a Lunar Base Operations Head is appointed on-board, equivalent to the commander on US/Russian spaceflight missions [14]. An overlapping shift rotation system will maintain continuous operation and monitoring while promoting crew interaction and unity.
There is a lot of scope for having roleplay situations, with semi-analogue astronaut exercises to help identify challenges involved and strategies that could be utilized.

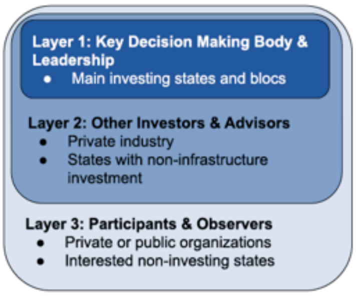

Figure 2. Polycentric Governance model of DIA

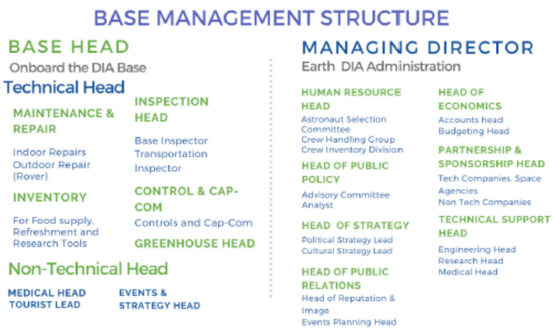

Figure 3 . DIA Base Management divided between Earth and Lunar Segments

2.3 *Society and Culture*

DIA honours multiculturalism and inclusivity by its very spirit and intends to have these act as core tenets of the base it will establish. The remote and challenging lunar environment means the base's culture will be key to ensuring its long-term survival. To that end, it is essential to establish a strong code of ethics and conduct and a culture of mutual trust and cooperation. Activities that could be done in this area could be surveys on cultural attitudes to space travel and exploration, audits of studies on work in remote and harsh environments, diversity studies (focusing on gender, race, disabilities and other markers), analogue astronaut experiments, as well as generating proposals for intercultural recreational activities.

2.4 *Health*

We hope to address inequity in information access via a comprehensive and accurate data set accessible to all on the Moonbase, regardless of gender, sexual orientation or identity. There are many extra considerations regarding the health of female astronauts in space [15]. The female menstrual cycle in space does not change in volume or character and does not impact a woman's ability to perform as an astronaut. A woman's fertility is not considered to be impacted by space. However, the ethical and practical considerations of having a child in space constrain research in this area. The unknown effects of space radiation and microgravity are risks simply too great to justify research in this area. [16]

2.5 *Economics*

A key aspect that will need to be addressed for the moon base will be the economic challenges with settling a remote outpost. At a high-level key question regarding the project's financing when it comes to its research, development, establishment and initial operation. Revenue generation is another aspect that can be tackled, with new models and sources of revenue that can be unearthed to help support the operation of the base. For example, lunar tourism is anticipated to be a key revenue source. However, ensuring sustainability and not overcommitting limited base resources will be a huge challenge.
Additionally, more specific challenges like evaluating the need for an internal economic system and establishing a system to enable commercial participation could be studied.

2.6 Architecture

The base architecture will take into key consideration the psychological as well as the material and operational needs of its residents. Over the long-term, space missions' provisions must be made not only for key life-support and mission-critical operations but also for mental well-being. Modularity is also a key aspect of the design to allow crew members to adapt and modify based on their own learning and experiences. Building upon terrestrial architectural knowledge, the lunar base will need a new class of architecture to take on the unique lunar conditions.

Not only do all these challenges lie at the intersection of multiple STEAM fields, but they could also be readily utilized as challenge topics for an ideathon or collective brainstorming exercises [17].

2.7 Technical Development and Engineering

This area forms the core competency that will dictate the success or failure of the DIA project. It will address diverse challenges like selecting and establishing a settlement site, ensuring that key services and resources are reliably provided, and ensuring smooth and robust operations. The key subsystems identified and their key aspects are highlighted in Table 1.

Table 1. Engineering: Key Aspects

Subsystems	Key aspects
Settlement Location	Geographical location, Surface Mapping
Base Construction	Radiation Shielding
Power	Power Distribution, Audit and Conservation
Environment Control & Life Support	Temperature, Climate Control, Dust Ingress
Surface Transportation	Long/Short-range Transportation
In-Situ Resource Utilization (ISRU)	Mining, Extraction, Manufacture
Waste Management	Circular Economy
Operation & Control	Maintenance, Software
Safety Hazards	Regulatory framework

Something common to all the areas identified in Table 1, is the need to go beyond a basic technical understanding. Expertise must be built to a stage that allows for scalability, sustainability and robustness in the solutions proposed, all with the mindset of enabling further utility and expansion to unlock lunar colonization.

2.9 Innovation Principles:

The inquisitive nature of resolving these challenges in new scenarios have led scientists and individuals to grow new ideas. These concepts rely on meeting the needs of expeditions at low costs and resources-expeditions often have poor infrastructure, insufficient workers, and challenging environments. In these constraints, individuals often craft innovative solutions to make the best of every situation [18]. Transdisciplinary innovations from other fields such as social anthropology can serve as conceptual guides for innovation, alongside learning from translational research [19].

3. Educational Deliverables

Having introduced the key knowledge areas, the following section will explore the educational outcomes and deliverables that could be derived and implemented.

3.1 Collaborative Learning Activities

DIA intends to educate participants on the identified themes and their associated challenges through collaborative activity platforms. These can take the form of moot court sessions, brainstorming workshops, ideathons, role-play situations and mock debates [20]. These can play a valuable role in strengthening core knowledge areas, introducing adjacent knowledge fields, strengthening soft skills and practical problem-solving. Some example activities can be seen in Table 2.

Table 2. Collaborative Activity Examples

Topic	Activities
Fire Safety Design Challenge	- Requirement Generation - Risk/Constraint Identification - Storyboarding/Digital Mock-ups - Solution Brainstorming - Design/CAD Modelling - Concept Evaluation
Resource Utilization	- Stakeholder Identification - Motivation Setting

	- Role Play Debates
Mock Crisis Response	- Learning Review - Plenary Sessions
Lunar Transport Challenge	- Traffic Estimation Study - Technology Audit -
Natural Design Challenge	- Biomimetic Principles Primer - Constraints Identification - Design Ideation

3.2 Open Learning Platform

A curriculum can be designed around the key technological and scientific knowledge required to enable effective lunar base design. The curriculum will utilize a pedagogical framework that relies on project-based tasks that can cater to all the VARK learning preference styles, with integrated assessment points to provide regular and constructive feedback. An online, open-source Learning Management System (LMS) can be used to not only provide access to learning material and resources but allow learners to practice autodidactism, giving them the license to motivate, regulate and evaluate their own learning.

3.4 Potential External Collaborators

DIA aims to partner with the largest student-led organization, Students for the Exploration and Development of Space (SEDS), SGAC, WoAA etc. The DIA moon base can serve as a common theme with various tracks that the students can take up; for example, there could be a logo design competition that focuses on spatial skills whilst the design of the base focuses on logical thinking. The main aim would be to explore the multiple intelligences, ensuring no child is left behind and develop various domains for the next generation in space that promote inclusivity, collaboration and advancing humanity through the peaceful uses of outer space.

4. Conclusion and Future Scope

The Domi Inter Astra project showcases the planning, development and operational directives of a Lunar base from a holistic and multi-thematic perspective. The project touches upon scientific research and engineering technologies employed , as well as the economic and management structure intertwined with architectural design aspects and societal significance of the human feature.
The study approach undertaken to develop this project has inspired a novel directive to research and analytical skills, which we have attempted to impart into students from the productive distributaries of this project. Real-life applications for the theories discussed in the project can aid a student's understanding by involving concepts from various subjects in tandem. This study showcased how the future book could be integrated into classes to educate the students of scientific, economic or engineering principles/theories by showing the real-life applications of those principles/theories. This is also done by worksheets and experiments that go together with the book. Additionally, the potential collaborators from NPO, NGOs, government organizations and universities could propagate STEAM for space technology. We aim to develop the integration of academia in space sector developments. The space-oriented companies are providing education as societal activity. A view from students and young professionals of space education. The continuous adaptation of the space education system to the evolution of sector needs The internationalization of space education train and attract world talents.

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