SpaceTech 2016

Central Case Project

Executive Summary

The Creative Leader in Lunar Mobility Experiences
Leave Your Mark on the Moon!

submitted to
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"Every revolutionary idea seems to evoke three stages of reaction [...]

1- It's completely impossible.
2- It's possible, but it's not worth doing.
3- I said it was a good idea all along..."

Arthur C. Clarke

Abstract

The SpaceTech Master Programme of the Technical University of Graz, Austria, is aimed at international, mid-career professionals seeking expertise in space systems and business engineering. The SpaceTech 2016 participants were invited by the European Space Agency (ESA)'s Director General to come forward with ideas to develop a viable and profitable business case, coherent with ESA's Moon Village vision. The team's objectives were to generate a series of business ideas, put in place a decision process based on stakeholders' needs and select the most appropriate business idea according to justified criteria. The business idea was then further developed into a business case, attractive to the general public and to private investors. The business case was subject to a thorough system engineering analysis, leading to a preliminary technical design.

It is in this context that the company LUNATIX was created by the eight participants of SpaceTech 2016. The market analysis, coupled with initial work done for the system design, has led LUNATIX to the definition of the following market need and opportunity statement: "An opportunity exists to provide mobile capability on the lunar surface." The ambition of LUNATIX is to become the creative leader in lunar mobility experiences, achieving this by means of unique mobile platforms on the lunar surface. "We intend to enable you to leave your mark on the Moon!"

In this initial phase, becoming the creative leader in lunar mobility, we propose two types of mobility platforms. First, we are designing a series of Small Mobile Platforms (SMPs also called Nanobots), equipped with video cameras, that will be mainly dedicated to entertainment and gaming purposes for the general public. The Nanobots can be thought of as the first "inhabitants" of the Moon Village. Humans will control them and will feel through their cameras the Moon experience in near-real-time; therefore providing the first step towards human telepresence on the lunar surface. In addition, a Main Mobile Platform (MMP) will carry different payload instruments for the scientific community. The MMP will also provide services to the Nanobots, ensuring their survival in the harsh Moon environment.

In order to fulfil the mission, the following additional elements are needed and will be obtained as external services or through strategic partnerships: the Earth launch element, the Moon descent element, the Earth antennas and associated Earth communications network, and a Data Centre.

The market addressed by LUNATIX is considered to have a significant potential, especially since there are no competitors already offering similar services. The time to enter the market is excellent. Technically, the mobile platforms proposed by LUNATIX are innovative and still only relying on mature technology. The business strategy is robust, giving credibility to investors. The project will raise public awareness and enthusiasm, allowing for further expansion with evolved mobility products on the Moon. No significant legal or regulatory issues have been identified. LUNATIX is ready to assist the space lawmakers into the clarification of international legal framework in view of increasing activities with multiple partners, on the Moon and beyond.

Chapter 1

Introduction

1.1 ESA and The Moon Village

In the coming decade, what has constituted the best example of international cooperation for space exploration - the International Space Station (ISS) - will come to an end. Our most distant outpost, which represented an overall investment of more than 150 billion USD, will crash back to Earth in a fireball above the ocean. We cannot wait for that moment to ask ourselves *"where next?"*. The question of the future of human space exploration has to be raised now! The Director General of ESA, Dr. Johann-Dietrich Wörner, sees the Moon as the obvious next venture. His vision of a Moon Village is not about "single houses, a school, a church, a swimming pool, a bakery, an undertaker". It is about the development of a diverse and international community of public and private organisations, who see the opportunity and choose to work together on the Moon. These collaborations could include building powerful telescopes, robotic and human exploration, extraction of resources (like hydrogen and oxygen), development of habitats on the surface, and lunar tourism.

The Moon Village is a vision with the power to grow over time. It is an open-ended, international and incremental venture which, from humble beginnings, will ultimately provide humans with the experience and the knowledge to embark on the next stage of deep space exploration, preparing them to travel further into the Solar System.

1.2 SpaceTech and LUNATIX

The SpaceTech Master Programme of the Technical University of Graz, Austria, is aimed at international, mid-career professionals seeking expertise in space systems and business engineering. The Master Programme integrates the acquisition of specific technical competences related to the space industry, together with the development of business management skills. SpaceTech also has a strong component on individuals' personal development, encouraging participants to reflect about their strengths, their development needs and supporting them in creating cohesive and highly efficient teams.

All these skills are brought together through the Central Case Project (CCP). The purpose of the CCP is the creation of a space business case, viable both technically and financially. The participants are organised in a group of knowledgeable individuals as founders of a space start-up.

The SpaceTech 2016 participants were invited by ESA's Director General to come forward with ideas to develop a viable and profitable business case coherent with the Moon Village vision. The team's objectives were to generate a series of business ideas, put in place a decision process based on stakeholders' needs, and select the most appropriate business idea according to justified criteria. The business idea was then further developed into a business case, attractive to the general public

and to private investors. The business case was supported by system engineering analysis, leading to a preliminary technical design. The followed roadmap is summarised in Figure 1.1.

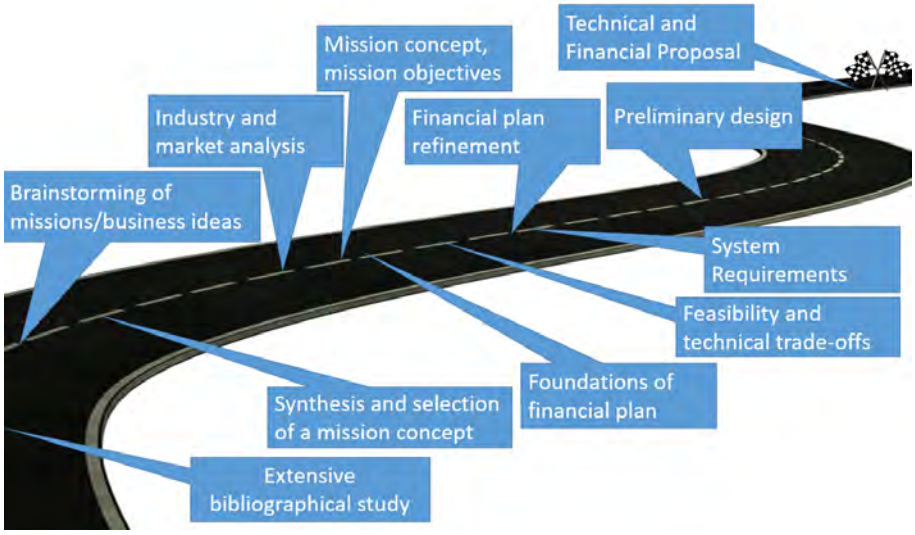

Figure 1.1: CCP Roadmap

It is in this context, and with the wide range of opportunities offered by the vision of the Moon Village, that LUNATIX was created by the eight participants of SpaceTech 2016. The formal establishment of the company is planned for 2018, once the Master Programme has been completed, driven by the personal interest of the participants.

Chapter 2

Market Opportunity

2.1 The Space Paradigm Shift

The 21st century has seen a shift in the paradigm of space exploration. The economic context (financial crisis of 2007) and the political will (US Former President Obama's Space Act in 2015) have produced a shift in the traditional lead and ownership of space programmes from governmental institutions such as ESA or NASA to private companies like SpaceX or Blue Origin.

This paradigm shift has different triggers. One of them is National Aeronautics and Space Administration (NASA)'s strategy to further empower the private space sector. NASA's Commercial Crew and Cargo Programme (C3PO) in 2006 closed several contracts with private companies, establishing the bases for new private players. NASA also evaluated the viability of a commercial lunar transportation market and associated business models. In 1998 ESA proposed a Moon Lander mission where all European national space agencies would participate. These initial triggers culminated to the "Moon Village" vision. It was presented by ESA in 2015 as an open Moon development programme. ESA encouraged the participation of different nations as well as different industries and partners.

In November 2016, Luxembourg created a draft law with the objective of granting rights to private companies to harvest resources in outer space. This new revolutionary legal and regulatory framework, established in Europe and respectful with the International Law, proves ideal context for LUNATIX to be established.

2.2 Opportunity Statement

Before selecting a specific business case for LUNATIX, dozens of business ideas were brainstormed, analysed and ranked. Examples include the establishment of an astronomy base on the far side of the Moon, the exploitation of lunar tourism or the possibility to offer services for the Moon Village such as communications, navigation or even electromagnetic spaceports.

The market analysis, coupled with initial work done for the system design, has led LUNATIX to the definition of the following market need and opportunity statement:

"An opportunity exists to provide mobile capability on the lunar surface."

Achieving such endeavour constitutes a stepping stone towards the Moon Village vision, as it meets the following criteria:

- It offers a framework for hosting innovative concepts.
- It is feasible, while remaining technically challenging.

- It provides evolving capabilities; it is scalable; and it is realistic to bring a first version to market within a few years.
- It targets the premium as well as the mid market segments.
- It fosters international cooperation.

This mobile system will be designed to satisfy modern societies' hunger for new experiences, to achieve individual self-definition and sense of purpose, to fulfil exploration objectives as well as scientific purposes and to support the materialisation of the Moon Village itself. The mobile system will address a wide variety of international users such as students, scientists, gamers, and "Moon Villagers" in general.

2.3 Competition Overview

Currently not a single company has a running business with mobile platforms on the Moon. However, there are considerable number of private space start-ups planning some ambitious milestones in the next years. The private investments in space start-ups in 2015 alone exceeded the total amount of investments recorded for the previous 15 years altogether (source http://space.taurigroup.com).

The companies identified as main competitors for LUNATIX are Astrobotic, Moon Express, Masten Space Systems and Hakuto (iSpace inc.). The panorama is very dynamic, with plenty of new companies being created and existing ones disappearing. It is a volatile sector. A common feature of most of the competitors is their enthusiasm for the Google Lunar X Prize. It is a competition to be won by the first company capable of landing a mobile platform on the Moon, travel 500 meters on the lunar surface and send video back to Earth. In addition to the cash reward, the winner is expected to enjoy significant future marketing advantages.

There is considerable competition for Moon mobility. At the same time, there will also be opportunities for collaborations. In any case, the "enabling roles" of space agencies such as ESA, NASA, Centre National d'Études Spatiales (CNES), and Deutsches Luft Und Raumfahrt (DLR) (creating the right business atmosphere and strategic Public-Private Partnerships) will be of the highest importance for the success of these endeavours.

Chapter 3

Value Proposition

The ambition of LUNATIX is to become the creative leader in lunar mobility experiences. LUNATIX invites its customers to leave their mark on the Moon.

In this initial phase, LUNATIX approaches both the general public and the scientific community, proposing versatile multi-purpose mobile platforms for entertainment and scientific purposes. The company's goal is to bring the Moon to its Earth-based customers, achieving this by means of unique mobile platforms on the lunar surface.

A series of Small Mobile Platforms (SMPs also called Nanobots), equipped with video cameras, will be mainly dedicated to entertainment and gaming purposes for the general public. LUNATIX aims to start attracting customers right from the beginning of the development phase of the Nanobots. For that reason, a virtual game will be brought online for the general public to first experience virtual lunar exploration.

In addition, a Main Mobile Platform (MMP) will carry different payload instruments for the scientific community. The MMP will also provide services to the Nanobots, ensuring their survival in the harsh Moon environment.

The LUNATIX company capitalises on the opportunity to combine different types of missions in order to address the two most promising and accessible segments of the Moon market: the scientific segment and the wide consumer segment of the gaming industry.

One of the main strengths of this business case is its wide appeal to a broad customer range. In addition, it contributes to the development of the Moon Village.

Artistic impressions of the MMP and the Nanobot are presented in Figures 3.1 and 3.2.

Figure 3.1: Artistic impression of the MMP

Figure 3.2: Artistic impression of the Nanobot

Chapter 4

System Description

This chapter presents the scope of the system, its concept of operations and architecture. The lunar environment is extremely harsh in terms of temperature, radiation, vacuum, micrometeorites, dust, low gravity and distance from Earth. The chapter gives special attention to the technical solutions proposed for the different subsystems of the mobile platforms in order to ensure their survival and the accomplishment of the mission.

4.1 System Boundaries

Before starting with the description of the system, this section explains how the system has been scoped and how its boundaries have been defined. The system is considered to be comprised of the mobile platforms on the Moon (the MMP and the Nanobots) and the Mission Operations Centre (MOC) on Earth.

In order to fulfil the mission, some additional elements are also required including the Earth launch element, the Moon descent element, the Earth antennas and associated Earth communications network, and a Data Centre used to store mission data. These additional elements are considered to be outside the scope of the system. They will be obtained as external services or through strategic partnerships.

The MMP is designed with the possibility for hosting several scientific instruments provided by space agencies such as ESA, NASA, CNES or DLR. Although these scientific payloads will interface with the system, they are considered to be outside its scope and they will be treated as Customer Furnished Items (CFIs).

4.2 Concept of Operations

The first launch of LUNATIX's mobile platforms will be comprised of one MMP (140 kg) and five Nanobots (5 x 1.5 kg), what accounts for a total mass of 147.5 kg. The launch is targeted for 2021, taking into consideration the time needed to formally establish the company, secure the funding and complete the design, production and verification activities.

The targeted landing point on the Moon is the Marius Hill region. This area contains large lava tubes, which are of interest for the scientific community as the potential area for the Moon Village development including human settlement. The terrain is relatively smooth, which will be an advantage for the landing and, since it is located on the near side of the Moon, the direct line of sight with Earth will simplify telecommunications.

The Marius Hill is located close to the Moon Equator, where periods of 14 days of sunlight are

alternated with 14 days of darkness. The operations of the mobile platforms will be restricted to the availability of solar energy. During the lunar night, the mobile platforms will hibernate to survive the very low temperatures.

Upon successful soft landing on the Moon, the MMP will deploy its solar panel array and will start communications with the Mission Operations Centre (MOC) on Earth. The scientific payload instruments onboard the MMP will become operational. The scientific customers will be able to receive data from their payloads and to submit specific telecommands to them through the MOC.

The Nanobots will also switch on their cameras, becoming ready to be controlled by the gaming customers by means of telecommands routed through the MOC. Given the small size and short communication range of the Nanobots, the MMP will serve as a gateway for all communications between the Nanobots and the MOC. The Nanobots will also rely on the MMP to charge their batteries and to seek the MMP's thermal protection to survive the long cold lunar nights.

The concept of operations is summarised in Figure 4.1. The concept is powerful because of its

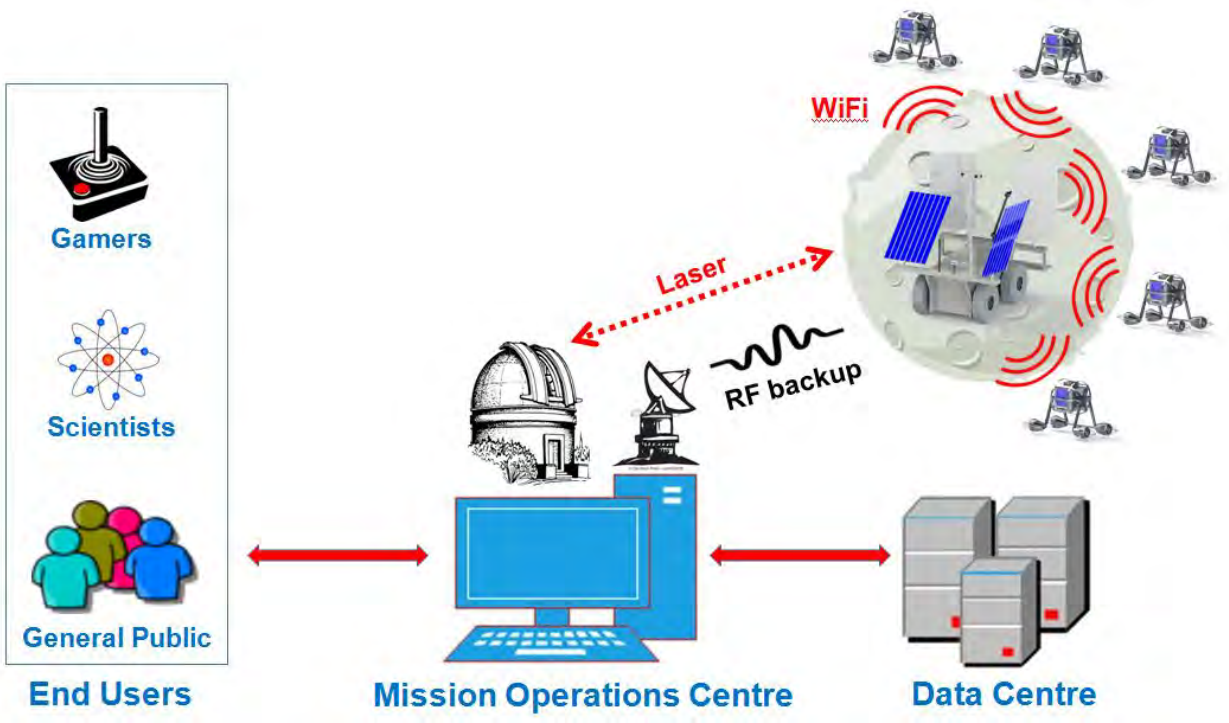

Figure 4.1: Concept of Operations (CONOPS)

versatility. The scientific mission can be adapted to evolving scientific objectives. As long as the mass and power envelopes are maintained, the instruments themselves can be modified in subsequent missions. The Nanobots can be thought of as the first "inhabitants" of the Moon Village. Humans will control them and through their cameras will feel the Moon experience in near-real-time; therefore providing the first step towards human telepresence on the lunar surface.

4.3 Architecture of the Mobile Platforms

Figures 4.2 and 4.3 present the architectures of the MMP and Nanobot, respectively. The rest of this chapter is dedicated to the description of the different subsystems.

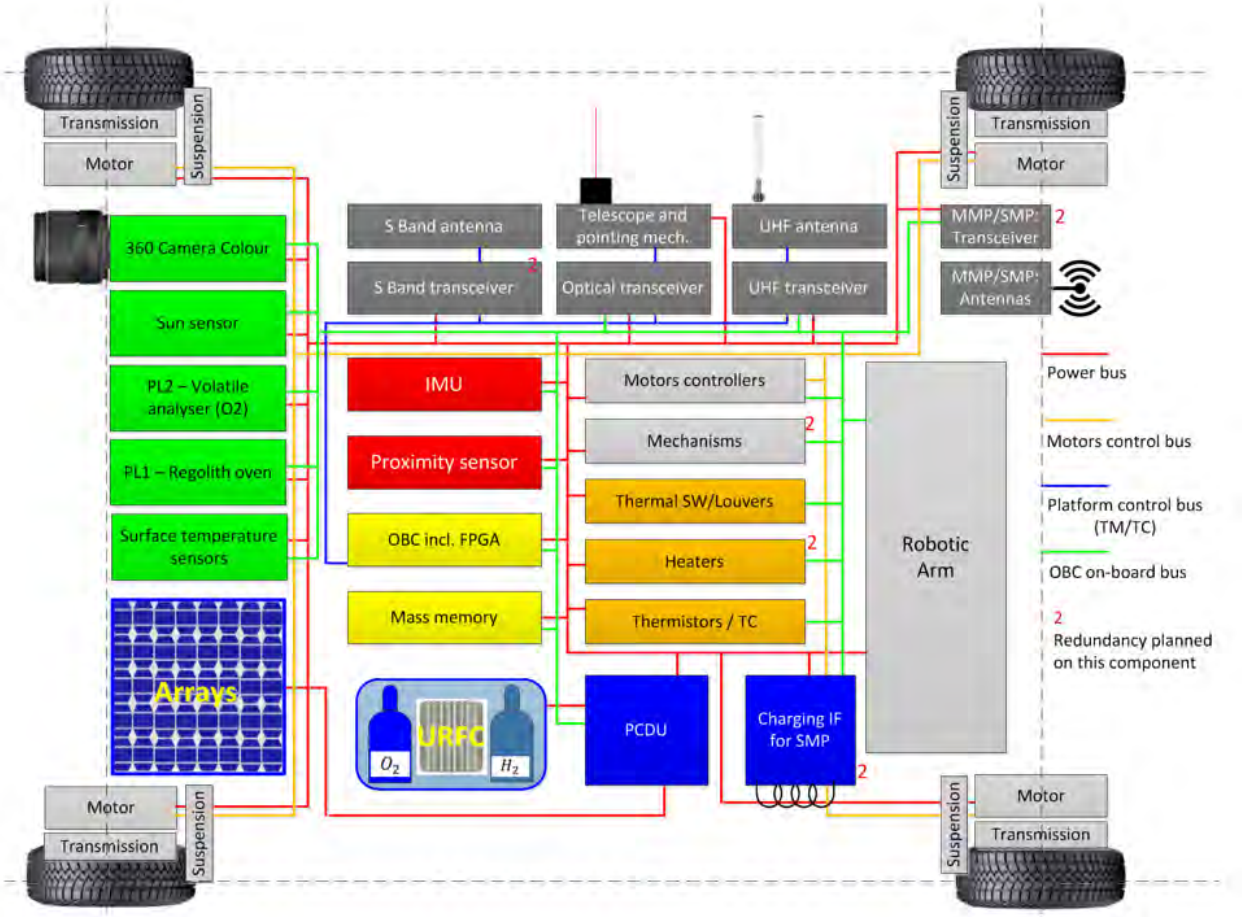

Figure 4.2: MMP architecture and subsystems

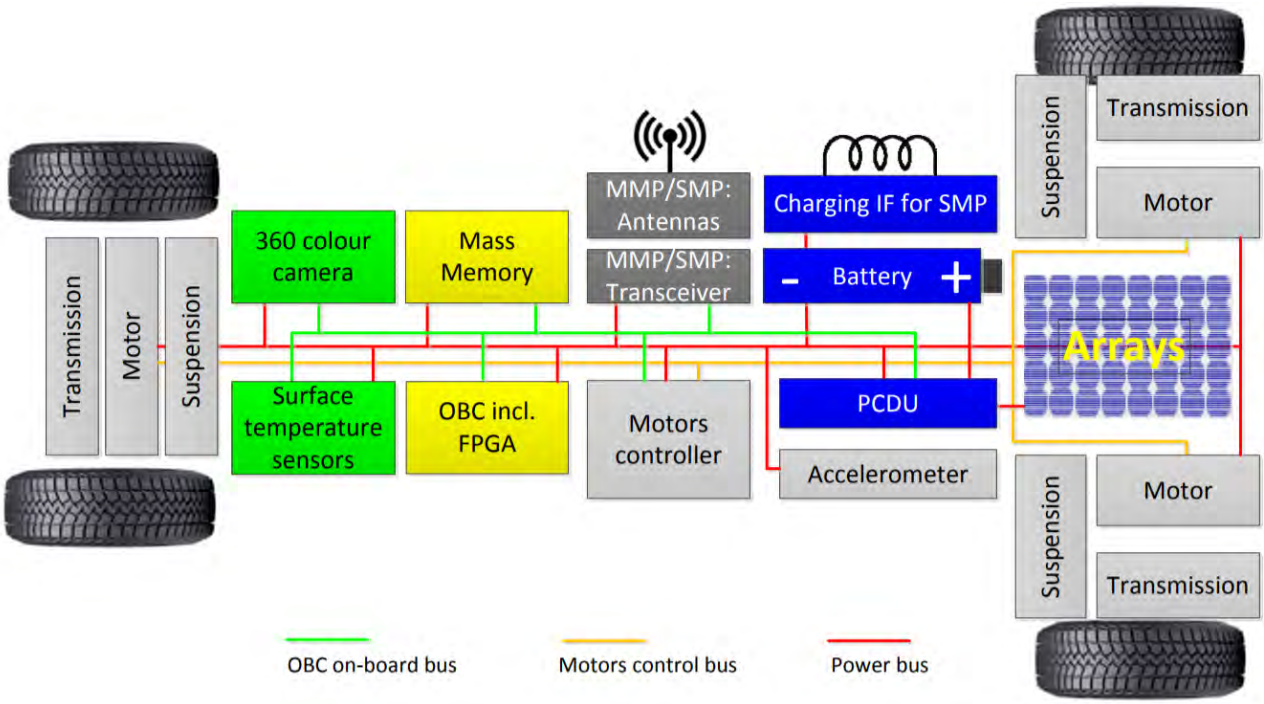

Figure 4.3: Nanobot architecture and subsystems

4.4 Payloads

Figure 4.4 presents the equipment selected to fulfil the scientific mission objectives. These objectives have been derived following a series of interviews conducted by LUNATIX with scientists from space agencies and principal investigators from academia. To make gaming possible, the mobility of the Nanobots will be complemented by 360-degree cameras.

Mission objective	MMP equipment	Nanobot equipment
To take images from surroundings	360 deg. camera, close-up infra-red cameras	360 deg. camera
To analyse space weathering to identify chemicals	Near infra-red volatiles spectrometer, radiation dosimeter, gas chromatograph/mass spectrometer	Thermometer
To characterise the dust grain and lunar soil	Neutron spectrometer, Up-looking photometer, multispectral imager, advanced volatile analyser, measurement wheels	
To locate O_2 resource	Multispectral imager	
To extract O_2 resource	Heating device, advanced volatile analyser, Gas chromatograph/mass spectrometer	
To determine the global density, composition and time variability of the lunar atmosphere	Gas chromatograph/mass spectrometer	

Figure 4.4: Payloads

4.5 Thermal Subsystem

The challenge of the thermal subsystem will be to ensure the survival of the mobile platforms in the extreme temperatures of the lunar environment. In the area of operations, the temperatures can exceed 100 degrees Celsius during the 14 days of sunlight, dropping down to less than -150 degrees Celsius during the 14 days of lunar night.

During lunar day, the MMP will achieve the function of dumping heat through:

- Carefully selected surface finishes. The chassis and underbelly of the MMP will be cased in brushed aluminium and the upper elements will be covered in Multi Layer Insulation (MLI) or painted white.
- The utilisation of a deployable radiator made of two elements: one horizontal and one vertical. Each element will have a size of 800 mm x 1400 mm finished in white paint (Z93 or S13G-LO).
- The conduction, achieved through the utilisation of two-phase ammonia fluid loop heat aluminium pipes.

During the lunar night, the MMP will retain heat through:

- Super insulation.

- The utilisation of heaters powered by the electrical power generated by Unitised Regenerative Fuel Cell (URFC). URFC is a fuel cell based on the proton exchange membrane which can do the electrolysis of water in regenerative mode and function in the other mode as a fuel cell recombining oxygen and hydrogen gas to produce electricity.
- The utilisation of the heat produced by the URFC as result of the production of the electrical power.
- The conduction will achieved through the utilisation of two-phase ammonia fluid loop heat aluminium pipes.

For the management of the transient regimes the MMP will rely on:

- A deployment sequence for the radiator at dawn. The sequence will be executed in reverse at dusk for the folding and enclosing of all appendages.
- The utilisation of a thermal control valve connected to the conduction loop.

The Nanobots will be entirely enclosed in brushed aluminium. Size, thermal and power constraints impose the insulation as the only realistic thermal solution for the Nanobots. During the lunar night, the Nanobots will be parked underneath the MMP to survive the extremely cold temperatures.

4.6 Mechanical, Kinematic and Locomotion Subsystems

The main purpose of the chassis of the mobile platforms is structural. In addition, the chassis plays an important role in thermal isolation, offering basic protection against dust and micrometeorites. The chassis of the MMP will be an aluminium box supported by a frame to increase the stiffness. Aluminium was chosen for its good fatigue properties under cryogenic conditions. A robot arm will be attached to the chassis. It can be equipped with a shovel for soil acquisition, a brush tool for dust mitigation on mechanical parts and a grab for possible manipulation of the Nanobots.

The Nanobots will have a cubical titanium chassis, surrounded by a spherical aluminium cage for protection against rollovers.

The MMP will have four wheels with a 4x4 drive and an independent suspension of each wheel. The wheels will have hub electro-motors with gearboxes directly attached. The type of wheels will be wired mesh, similar to the ones used in the Apollo Programme. Their main advantages are low weight, good traction and excellent suspension properties. The MMP will be able to move up to 20 km/h.

The Nanobots will also have 4 wheels, but with a 2x2 drive of hub electro-motors. The Nanobots will be able to reach up to 5 km/h. They will be also capable of hopping, using their suspension system as a catapult. The low-gravity lunar environment will allow hopping up to 10 m distance and more than 3 m high. After landing and due to the spherical shape of their cages, the Nanobots will have no problems to recover their mobility.

4.7 Power Subsystem

The power subsystem is responsible for power generation, conditioning, storage and distribution.

The MMP will use a Photovoltaic (PV) generator supported by a URFC for energy storage. The advantage of the PV generator is the excellent availability and reliability during the lunar day. On the other hand, the URFC will be critical in providing the energy to ensure the appropriate thermal conditions for the survival of the mobile platforms during the long cold lunar night.

The Nanobots will not be capable of generating power by themselves, with the exception of their solar

panels used for recovery purpose only. Key design drivers of cost and simplicity led to the selection of lithium-ion batteries. The batteries will allow more than 5 hours of autonomous operations. The Nanobots will recharge their batteries from the MMP. This will happen by means of wireless energy transfer, requiring the mobile platforms to be in close proximity (less than 1 m). Magnetic resonant coupling technology will be used. Not requiring electric plugs and sockets has clear advantages in the dusty lunar environment.

4.8 Communications Subsystem

The communications subsystem is crucial to ensure that the data generated by the mobile platforms on the Moon are correctly received on Earth and that the Earth is capable of commanding the mobile platforms by sending the pertinent telecommands.

The main communications link between Moon and Earth will be optical. The advantages are large bandwidth and reduced hardware mass. The drawbacks are the required pointing accuracy and the Earth atmospheric perturbations.

A back-up link can be ensured by a private Ultra High Frequency (UHF) relay service, possibly involving some communication relay satellites in low Moon orbit.

The Deep Space Network (DSN) S-band will be used in contingency situations, allowing the transmission of critical telecommands and the reception of housekeeping telemetry. The reception of payload telemetry will not be possible due to the low bandwidth of this interface.

On the Moon, the MMP will act as a gateway for all the communications with Earth. The Nanobots will be able to communicate with each other and with the MMP. This constitutes a mesh network topology, creating redundant communication paths and extending the communication range by using intermediate Nanobots as repeaters. The Wi-Fi standard IEEE 802.11 will be used as it is a mature commercial technology, allowing communication ranges of up to 1.5 km.

4.9 Guidance, Navigation and Control Subsystem

The core expectations for the Guidance Navigation and Control (GNC) subsystem are the following:

- state estimation (position, velocity, orientation, distance travelled)
- obstacle detection
- movement control

Moreover, the Nanobot shall be able to navigate back to the MMP to within 1 m for battery charging or night survival.

Due to the logistics and cost necessary to set in-orbit or on-surface assets prior to the deployment of the mobile platforms on the Moon, it has been decided to go for a solution based on on-board sensors. The selected navigation solution is vision-aided inertial. In addition, back-up proximity sensors will be used for hazard avoidance, to safeguard the mission.

The MMP navigation subsystem will include:

- Sensors: vision sensors (360-degree cameras), Inertial Measurement Unit (IMU) and separate proximity sensors for safety reasons.
- Navigation on-board processing function: in charge of sensor data acquisition, Kalman filter processing and computation of commands for the locomotion subsystem.

Due to the size constraints of the Nanobots, they will rely exclusively on vision-based navigation relative to the MMP.

4.10 Data Handling Subsystem

The Data Handling System (DHS) is responsible for processing the information from and to all on-board electronics, the handling of telecommands and telemetry, the hosting of the GNC algorithms and the Artificial Intelligence (AI) plant, the management of the active thermal control parameters and the implementation of the Fault Detection, Isolation and Recovery (FDIR).

The DHS is composed of the following elements:

- On-Board Computer (OBC), supported by a Field Programmable Gate Array (FPGA) to host the navigation subsystem image recognition algorithm and part of the AI algorithms.
- Mass Memory Unit (MMU) offering non-volatile flash memory as well as volatile DRAM memory.
- Communication bus.

The DHS of the Nanobot is highly integrated with all on-board electronics as a small, low-mass, energy-efficient system is required. It is a scaled down version of the MMP's DHS, with a computing power comparable to that common with cubesats.

4.11 Artificial Intelligence Subsystem

The AI subsystem will contribute to the following aspects of the mobile platforms:

- Autonomous movement: based on the definition of a target location (set either by the operator or by another AI element), the mobile platform will be able to autonomously reach that location. The AI will assist in the path planning, taking into account elements such as distance, duration, remaining power, safety, light conditions and communication with the MMP.
- Safety: given that the two-way communication delay between Earth and Moon is up to 3 seconds, the AI subsystems will react autonomously in critical situations. Moreover, during communication outages (either between the Earth and the MMP or between the MMP and a Nanobot), the AI will assure the safety of the mobile platform and, if possible, the continuation of the mission activities.
- Autonomous science acquisition: the AI will allow the MMP to perform autonomous science target identification, acquisition planning, and execution.

AI will be used to ease the operational tasks, to lower the operational costs and the risk of failures, and improve significantly science and entertainment return. Several AI system implementations are considered, depending on the specific objectives:

- The Expert/Rule Based System will be implemented to accomplish the autonomous science acquisition. The system is based on simple if-then-else rules.
- The Search Based System will be used to achieve autonomous movement. It relies on the identification of the optimal sequence of steps leading to the desired result. Examples of algorithms include Depth First Search, Breath First Search, Dijkstra and A*.
- The Machine Learning System will be helpful to ensure the safety of the mobile platforms. The advantage of this system is its ability to cope with new/unknown situations. The algorithms typically involve neural networks, decision trees, supervised, unsupervised and reinforcement learning.

4.12 Dust Mitigation Subsystem

Dust is a major challenge at the lunar surface. Moon dust is fine, sticky, abrasive and ferromagnetic. The dust mitigation subsystem will comprise the following techniques:

- A brush tool will be attached to the robot arm to clean rough structural elements such as the wheels.
- Vibrations created by the suspension will keep vertical and inclined surfaces clean.
- The creation of electrostatic and dielectrophoretic forces will enable electrostatic dust removal. This technique will be supported by electromagnetic shielding for the most dust-sensitive parts such as optics, solar cells, scientific instruments and fragile elements.

4.13 Ground Segment

The ground segment will be comprised of the following elements:

- MOC: for the monitoring, control, maintenance, planning, scheduling and safe operations of the mobile platforms. Spacecraft Control and Operation System (SCOS) is proposed as the main piece of software for the monitoring and control of the mobile platforms. SCOS is developed by ESA and used in a multitude of space missions. Since SCOS is a highly technical and professional application, an intermediate software will be developed to serve as an interface between the Internet applications or the smartphone apps of the Users and SCOS. The use of SCOS could be eventually superseded by the new European Ground Systems Common Core (EGS-CC).
- Data Centre: in charge of the storage and retrieval of data generated by LUNATIX, including the housekeeping and payload telemetry received from the mobile platforms, the history of commands issued by the MOC, all User registration information, payment details, etc.
- Earth Antennas: making possible the communications between Earth and Moon.
- Helpdesk: to interface with the Users for their registrations, queries and training. The LUNATIX's website will be the main gate to Helpdesk.

Chapter 5

Business Strategy

This chapter presents LUNATIX's four strategic business areas of activity, together with their associated addressable markets.

- Business line 1: Gaming
- Business line 2: Science
- Business line 3: Subsystems
- Business line 4: Merchandising

5.1 Business Line 1: Gaming

With 1.7 billion gamers around the world, the revenues from the gaming market in 2016 were about 100 billion USD. This corresponded approximately to four times the combined NASA and ESA budgets.

The reasons for gaming are diverse, including complex factors such as entertainment, sense of achievement, competition, safe-development, teamwork, socialising, and education.

With its Nanobots, LUNATIX's business strategy is to address the gaming market, focusing first on Europe and North America, with possibilities to expand eventually also to the market of Asia. The segments of the gaming market relevant to LUNATIX are adventure, action and puzzle, representing a quarter of the total market in 2016. Partners will be utilised to create specific gaming elements, objectives and rules.

The development phase of the Nanobots is expected to take about four years, including launch and deployment on the lunar surface. During this initial phase, a Virtual Reality game will be brought online to start attracting users. The game will allow controlling a virtual Nanobot in a simulated Moon environment. The games will be accessible over the Internet on a multitude of hardware platforms such as PCs, tablets, and smart phones. It will be free of charge during this phase, but LUNATIX will start getting some initial revenues from online advertising based on the number of certified views.

Once the Nanobots are deployed on the lunar surface, the game will be enhanced with real images and videos from the Moon. Given the enormous success of the game "Pokémon Go!", the game powered by LUNATIX will also include Augmented Reality techniques. Revenues will be made by monthly subscriptions to the game and by selling to gamers timeslots with the possibility to control the real Nanobots on the actual Moon. For a few exclusive users, an option will exist to control entirely their own Nanobot, without the need for sharing time slots with others users.

5.2 Business Line 2: Science

The Moon mobility service provided by LUNATIX will be offered also to space agencies such as ESA, NASA, CNES and DLR. The space agencies will be given the opportunity to have their own scientific payload instruments mounted onboard the LUNATIX's MMP. The MMP is designed with the possibility for hosting several scientific payloads provided by space agencies as CFIs.

For example, following a series of interviews with scientific institutions such as the Massachusetts Institute of Technology (MIT), LUNATIX concluded that there is an interest from the scientific community to study the location of oxygen on the Moon for potential In-Situ Resource Utilisation (ISRU). In addition, the operational area of the LUNATIX's mobile platforms has been intentionally selected to be close to the Moon Equator, where large lava tubes are present. These natural formations are of high interest for future human settlements, since they may provide thermal and radiation protection and constitute shelters against meteorites.

In return for the mobile services provided to the space agencies for their scientific payloads, LUNATIX would expect to get a flight opportunity for the mobile platforms. This is expected to be a Public-Private Partnership, involving no exchange of funds. LUNATIX will benefit from getting the launch and lunar landing service (a very costly element for any small space start-up) while the space agencies will collect valuable information from their scientific payloads mounted on the MMP. Both sides will profit from this win-win strategy, cooperating together towards the realisation of the Moon Village vision.

5.3 Business Line 3: Subsystems

Applying innovative methods and procedures, LUNATIX will develop a series of subsystems necessary for the success of these unique missions and dealing with the harsh lunar environment. The resulting subsystems are expected to have also applications on Earth. They will be commercialised, becoming a source of revenues together with the associated Intellectual Property Rights (IPRs), licences and consulting services. The proposed approach for this business line is business-to-business (b2b).

For example, efficient anti-dust subsystems for cleaning up (maybe electrostatically) the sticky lunar dust from the camera lenses of the mobile platforms could have direct applications for lenses of cameras, smart phones or tablets on Earth as well as applications for other businesses on the Moon. The Artificial Intelligence subsystem developed to enhance the navigation of the mobile platforms could also be of interest for the drone industry on Earth.

5.4 Business Line 4: Merchandising

Entertainment with mobile platforms on the Moon is a very innovative business case. The generated hype is expected to be considerable and hence will drive the revenues from merchandising, including the sales of toys and mock-ups, T-shirts, caps, clothing, mugs or even films. A good example is the video game "Angry Birds Space", which generated 30% of its total 190 million EUR yearly revenues in 2017 from merchandising.

Chapter 6

Business Implementation

LUNATIX's implementation strategy aims at securing the success of the company in its first development and operational phases i.e. from 2018 to 2021 and from 2022 to 2025, respectively. Later on, the company is expected to have solid grounds to expand its business lines and to target additional markets requiring mobility on the Moon. LUNATIX's unique selling proposition is the versatility of the mobility solution, capable of targeting simultaneously the scientific/resource prospecting and the entertainment/gaming markets. The company's implementation strategy is summarised in Figure 6.1.

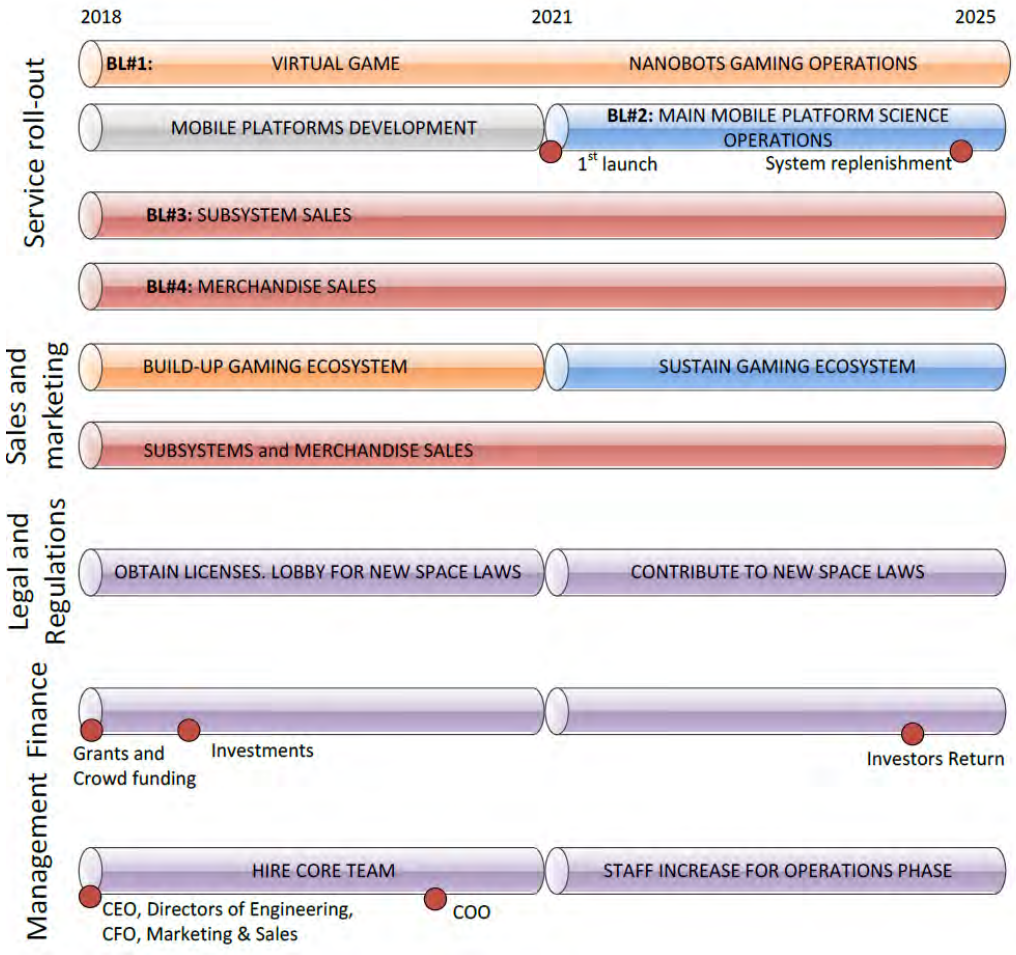

Figure 6.1: LUNATIX's implementation strategy

6.1 Phased Service Roll-out

The first phase of the implementation plan will last four years (2018 to 2021), corresponding to the development of the mobile platforms. In parallel, a virtual game product will be deployed and a marketing strategy will be put in place in order to build up the ecosystem allowing to capture a significant portion of the western world gaming community. This will also raise interest and awareness for the upcoming real Moon mobile platforms. The development of the Moon mobile platforms will be funded with grants, crowd funding and investments (a mix of debt, equity and venture capital). These financial sources will be gradually secured by progressively demonstrating LUNATIX's reliability and commitment as a company. It is anticipated that the award of grants will give confidence to investors. Our crowd funding strategy is designed to take advantage of the enthusiasm, novelty and hype generated by LUNATIX's proposal. Revenues will start being made from the subsystems and merchandising business lines.

The second phase will also last four years (2022 to 2025), corresponding to the deployment and operations of the mobile platforms on the Moon. At this stage, the MMP scientific missions will be carried out in parallel to the gaming operations of the Nanobots. The Virtual Reality game will continue to operate, enhanced with the possibility to control the real Nanobots on the actual Moon and will include some Augmented Reality techniques. Our strategy is to work together with game developers and publishers, relying on their gaming experience. During an interview, the game producer company Valve expressed a high degree of interest in collaborating. During another interview with Stevens Institute of Technology, LUNATIX also saw the opportunity to team up for the development of the Artificial Intelligence subsystem of the mobile platforms.

Following the success of the initial set of mobile platforms on the Moon, additional launches are envisaged for replenishing the fleet. Given that at the Moon Equator there are periods of 14 days of daylight alternated with 14 days of darkness, the mobile platforms will be operational half of the time and will be hibernating the rest. During the period of hibernation, the Virtual Reality game will be still operational, offering the control of virtual Nanobots in a simulated Moon environment. Launching an additional set of MMP and Nanobots, on a complementary geographical position along the Moon Equator, would allow scientific and gaming operations around the clock and not only during the 14 days of light.

Continuous updates of the games with the Nanobots and new software uploads to the mobile platforms are planned to keep high the interest of the general public in the game and hence to ensure the business continuity.

6.2 Marketing

During the development phase of the Moon mobile platforms, the marketing strategy is designed to create interest and awareness in the gaming community. This is the same community that will later on pay to be able to control the real Nanobots on the actual Moon. This strategy shall also ensure immediate revenues right from day one. This will be achieved with the virtual game (through advertising and game customisation options) and with the subsystem and merchandising business lines.

LUNATIX plans to deploy a viral marketing campaign, similar to the campaigns implemented by "Angry Birds Space", "Kerbal Space Program" and "Pokémon Go". With the excitement of the general public for space activities, the uniqueness of LUNATIX's value proposition and the expectation of support from the space agencies, LUNATIX does not need an excessive marketing budget. However, the marketing budget has been set at 3.5 million EUR over the financial planning period.

In addition to the company's own marketing efforts, LUNATIX will also seek marketing support

from space agencies such as ESA, NASA, CNES and DLR. Their advertising on websites and at major public events is considered very important. This strategic partnership will be key for the success of the company's marketing strategy as well as for the fulfilment of the raison d'être of the space agencies in terms of public outreach, engagement, contribution to technology development and fostering of private companies in the benefit of the wider society. Similar marketing support to private companies have been already applied with success by NASA. Some examples are the premiere of the game "Angry Birds Space" (presented by a NASA flight engineer onboard the ISS) and NASA's collaboration for defining gaming scenarios for the "Kerbal Space Program".

6.3 Regulatory Aspects

An analysis was performed to find the best-suited country to register the company LUNATIX. It was concluded that Luxembourg offers considerable advantages. In November 2016, Luxembourg became the first country from the European Union (EU) to set up a draft legal framework for the exploitation of space resources. It presents attractive options to minimise the company's expenses in taxes. Luxembourg is a Member State of ESA and, with more than 200 million EUR spent yearly in Research and Development, the country is getting quickly established as the "Silicon Valley" of space resource mining.

Additional legal regulations considered by LUNATIX include the arrangement of the launch licence with the government from which the launch will take place, the permit from the International Telecommunication Union (ITU) to use the radio-frequency links selected for communications, and the registration of the mobile platforms with the United Nations (UN).

6.4 Staffing

LUNATIX is an agile company with a reduced but strong core team, to be supported ad hoc by freelancers for some specific activities. The core organigram of the company is depicted in Figure 6.2.

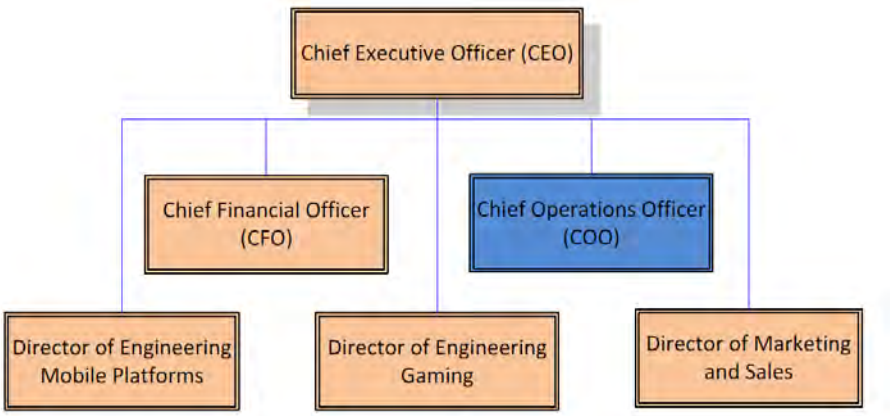

Figure 6.2: LUNATIX's Core Organigram

The Chief Operations Officer (COO) will be a key addition for the operational phase. At that point, the team is expected to grow by 50%, covering all operational and maintenance aspects, including a helpdesk and interfaces with users.

Chapter 7

Legal Framework

A pre-requisite for starting any project is the study of the applicable legislation. This is even more relevant for LUNATIX and the Moon Village, given the novelty of the proposed business case. This chapter will present the analysis of the current legal framework, together with the identification of some areas of improvement needed for the realisation of business activities in the Moon Village context.

7.1 Current Legal Framework

The activities of LUNATIX and the Moon Village fall simultaneously within several categories of legislation: international, regional and national.

At international level, the main legal entity is the UN. The UN has issued several important Space Treaties. Two of them are of special relevance to LUNATIX and the Moon Village: the Outer Space Treaty (1967), also called "Magna Carta" and the Moon Treaty (1979). The general purpose of these Treaties is to enhance and guide the cooperation of all countries in space.

Our analysis found that the vision of LUNATIX is completely in line with these Treaties. The following extracts from the "Magna Carta" are excellent examples:

- *"Facilitate and encourage international cooperation."*
- *"For the benefit and in the interests of all countries."*
- *"The common interest of all mankind in the progress of the exploration and use of outer space for peaceful purposes."*

The "Magna Carta" is particularly stringent regarding introducing any environmental contamination. LUNATIX took special care in the design of the mobile platforms to avoid any use of radioactive materials.

At regional level in Europe, LUNATIX shall seek guidance from ESA. ESA is an observer to the UN for space matters, acting as a facilitator. For the time being however, ESA has not produced any specific legal regulation regarding the Moon Village.

At national level, two countries clearly stand out: the US, with Former President Obama's Space Act issued in 2015, and Luxembourg, with its draft space laws adopted in 2016. The objectives of these national legislations are to create a favourable legal context to private commercial exploration and utilisation of space resources. Unfortunately, in the case of Luxembourg the adopted space laws remain at national level, without being formally applicable at the level of ESA or the EU.

7.2 Areas of Improvement

The business activities proposed by LUNATIX in the context of the Moon Village are compliant with the current space regulation. However, most of the Space Treaties adopted by the UN date from the sixties and the seventies of the last century. With the imminent possibility of deploying profitable business activities on the Moon, the space legislation has to be further developed and clarified to avoid potential conflicts.

Some of the areas where additional legislation is needed deal with IPRs, ownership rules, tax regulation, resolution of disputes and conflicts, and debris and waste management.

Luckily there are already some very good examples of successful international legislations which could be studied, further developed, and adapted to the particularities of the Moon Village. Noteworthy cases are the activities onboard the ISS, regulated by various Memorandum of Understanding (MOU) and several Implementing Agreements among a multitude of different countries; the Antartic Treaty from 1959, signed currently by more than 53 parties, and the United Nations Convention on the Law of the Sea (UNCLOS), ruling all commercial activities in international waters.

LUNATIX strongly believes that given the international nature of the Moon Village, its Legislative, Executive and Judiciary framework shall be established directly at the level of the United Nations. It is a unique opportunity to set up a brand new framework, based on past successful international cooperations and needed to allow the harmonious development of business activities. ESA, as main driver of the Moon Village vision, should have a leading role. LUNATIX remains eager and ready to support ESA with this endeavour.

Chapter 8

Financial Plan

The financial plan presented in this chapter undertakes a deep analysis of all financial aspects relevant to the company LUNATIX. The span of the financial plan is eight years, starting in 2018, with the formal creation of the company. It includes four years of mobile platforms development and manufacturing, followed by four years of operations on the Moon. These analyses demonstrate the probably profitability of the business case within the eight-year plan.

8.1 Revenue Forecast

During the first four years of mobile platforms development, the games allowing to control virtual Nanobots on a simulated Moon environment will be made available free of charge. Some initial revenues will be made from online *advertising* based on the number of certified views. About 60 million page views per month are expected. Additional revenue will be made from *sales of subsystems and licences*, including IPRs. The main source of revenues during this phase will come from *merchandising*. The revenues estimated in the figure are comparable to the numbers presented by the game "Angry Birds Space".

The revenue forecast for the first four years of mobile platforms development is presented in Figure 8.1.

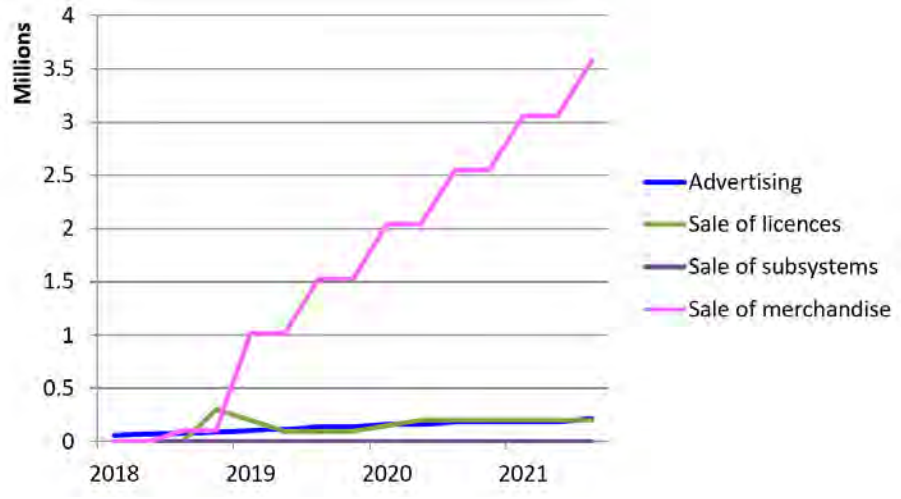

Figure 8.1: Revenue forecast during the development phase 2018-2021

During the four years of mobile platform operations on the Moon, the game will be enhanced with real images and videos from the Moon, charging 2 EUR per user per month as a *subscription*. The amount is comparable to other games.

Regarding the Nanobots, five units are planned to be deployed with the first launch. Timeslots of 20 minutes to *control the real Nanobots* on the actual Moon will be sold to users for 500 EUR. Some timeslots will be offered as reward to those players of the virtual game who reached the highest scores in the game, meaning that they had already spent a significant amount of time and money in subscription fees. The full ownership of one of the five Nanobots will be sold to *one exclusive user* through an auction starting at 15 million EUR, which is roughly half the price for a 10-day trip to the ISS.

The revenue forecast for the four years of mobile platform operations on the Moon is depicted in Figure 8.2.

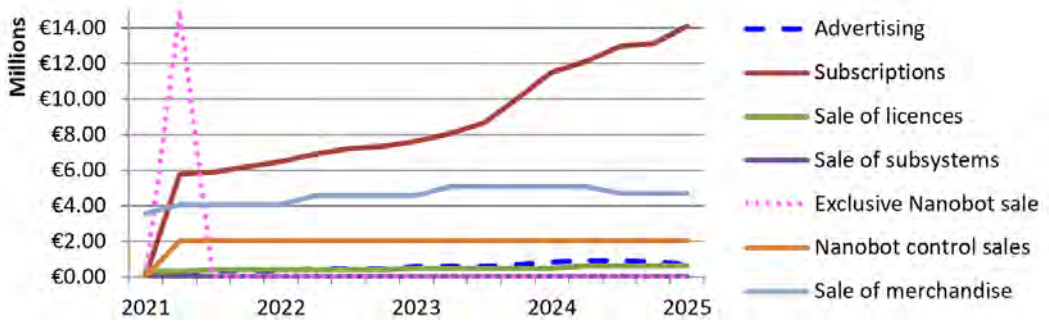

Figure 8.2: Revenue forecast during the operational phase 2021-2025

Most of the revenues come from the monthly subscription to the game. Although the revenues from controlling the real Nanobots are smaller, they are of key strategic importance, making possible the whole business case. Without the real Nanobots, the revenues generated by the virtual game and merchandising would certainly be much lower.

The total forecast revenues of LUNATIX are displayed in Figure 8.3.

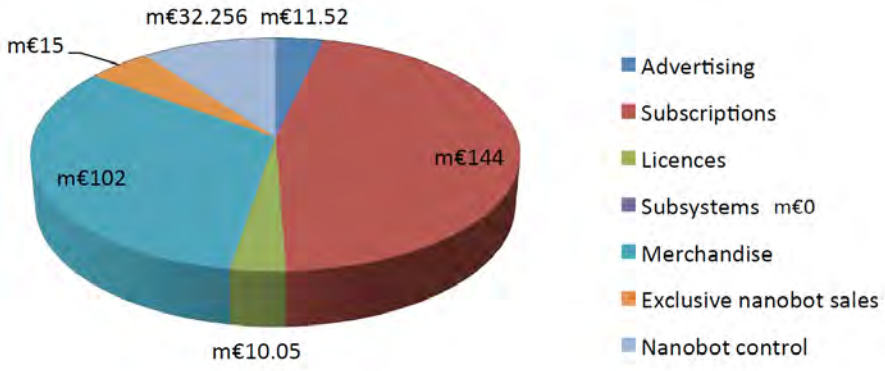

Figure 8.3: Total revenue forecast 2018-2025

8.2 Operational Expenses and Costs of Goods Sold

The major part of the Operational Expenses (OPEX) include *space segment operating expenses* (functional testing of the mobile platforms, the monthly fee of the communication service Earth-Moon and other costs associated to the website hosting and data storage service). The *business operating expenses* are comprised of office rents, IT services, staff recruitment and marketing campaigns, business travels and legal support. The expenses related to *human resources* are also included in the OPEX.

The estimated operational expenses are represented in Figure 8.4.

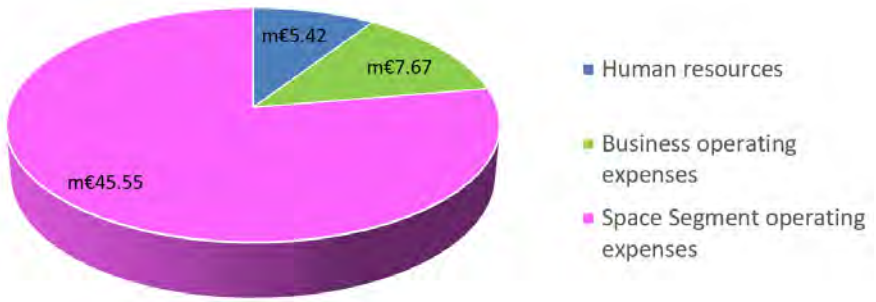

Figure 8.4: Operational Expenses (OPEX) 2018-2025

Figure 8.5 shows the costs of goods sold. They include the costs of producing the *merchandise* and the cost of the *exclusive Nanobot* which will be sold to a single user. Please note that at this point in time the production costs falling within the *subsystem* business line have not been accounted for and are identified as an open point.

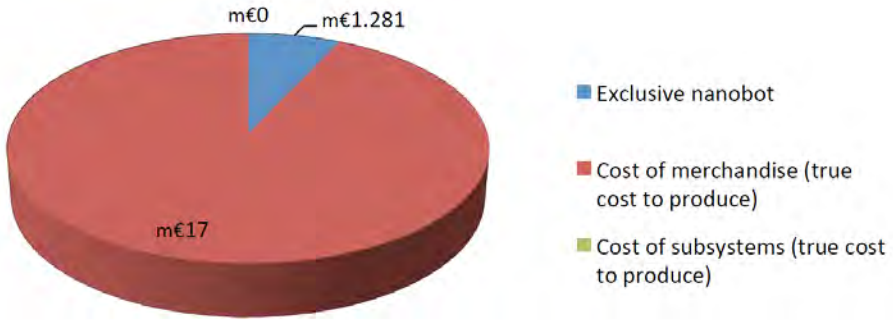

Figure 8.5: Costs of goods sold 2018-2025

8.3 Capital Expenses

The major part of the Capital Expenses (CAPEX) are the costs associated to the *mobile platforms* which will remain in ownership of LUNATIX. The cost of the development and manufacturing the mobile platforms have been estimated at 1.22 million EUR per kilogram. The tool PRICE TruePlanning 14.2, kindly provided by ESA's Cost Engineering Office, was used for this calculation.

Except for the mobile platforms, LUNATIX's strategy is not to incur a considerable amount of

costs related to tangible assets. Offices will be initially rented, not bought. Assembly and Integration Test facilities (AIT) will not be owned by LUNATIX but by industrial partners.

The *launch and landing service* will be secured via partnership with space agencies. If LUNATIX had to procure this service by its own, through private companies such as Astrobotic, the estimated cost would be about 1.2 million EUR per kilogram.

The cost of some intangible assets such as the necessary software *licences*, *website* and *game* development are also included in the CAPEX.

The estimated capital expenses are represented in Figure 8.6.

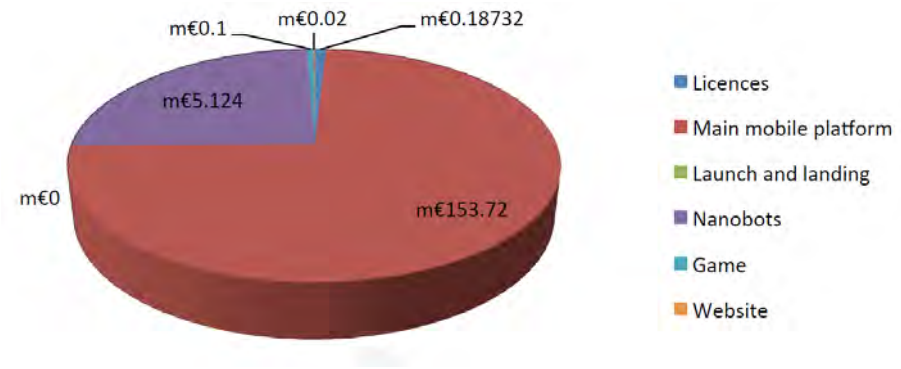

Figure 8.6: Capital Expenses (CAPEX) 2018-2025

8.4 Investor Involvement Strategy

LUNATIX has established a strategy to attract funds necessary to get the business off the ground. It follows a staggered approach:

1. *EU grant.* LUNATIX will apply for the EU "Horizon 2020 Research and Innovation Actions", which targets to boost the Research and Development, exploring the feasibility of a new technology, product, process, service or solution.

2. *ESA grant.* Through Luxembourg, LUNATIX will apply for ESA's General Support Technology Programme (GSTP), which purpose is to transform promising engineering concepts into mature products.

3. *Investments.* Obtaining the EU and ESA grants will help to build credibility needed to attract private investors.

4. *Crowd funding.* This relatively new way of funding has proved to be very efficient, especially for innovative start-ups similar to LUNATIX. It is based on small private sponsorships. In return, the company could for instance display the names of the sponsors in the virtual game or even engrave them on the real Nanobot.

Figure 8.7 shows the distribution of grants and private investment. The main source of funding comes from private investors. The estimated amount is comparable to what was already achieved by the game "Angry Birds Space".

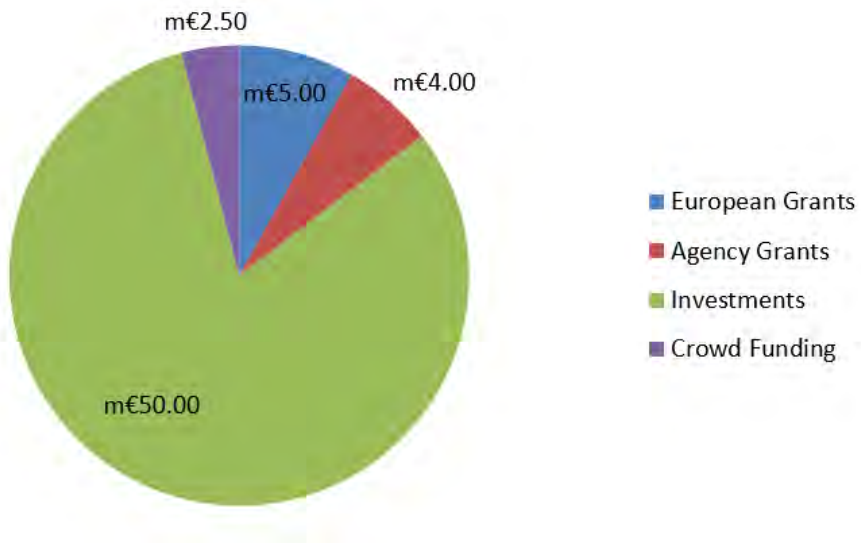

Figure 8.7: Distribution of grants and private investments 2018-2025

8.5 Cash Flow

In the financial domain, the cumulative cash flow figure for a start-up is popularly known as "hockey stick". This is due to the particular shape of the curve. The beginning of the company will be a financial period driven by the initial investments. After about four years, around 2021, the cumulative cash flow will start increasing and hence the company will start being cash-positive. This corresponds to the beginning of the real mobile platform operations on the Moon.

Around mid-2024, the cumulative cash flow will become positive. Therefore, about 6.5 years after the creation of LUNATIX, the investors will begin to get back their initial investments and will start making a profit.

Based on the level of investments, expenses and revenues presented in the previous sections, Figure 8.8 shows the estimated cumulative cash flow.

8.6 Profit and Loss Sensitivity Analysis

The cumulative cash flow in the previous section corresponds to the most likely case scenario. In order to prove the robustness of the financial plan, a detailed sensitivity analysis has been performed estimating reasonable best case and worst case scenarios for several financial parameters. In all these conditions, the results showed that the company remains profitable.

One important example is the sensitivity analysis performed on the revenue from advertisements, which is LUNATIX's main source of revenue. It is directly linked to the number of web page views and downloads per month. The sensitivity analysis displayed in Figure 8.9 shows that for the most likely case (60 million web page views and downloads per month) the return of investment is within six and a half years, as already presented previously. If this gaming concept gets hot in the gaming world, 100 million web page views might represent a feasible best case scenario yielding return of investment in just six years. The worst case scenario (20 million views) suggests return of investment in eight years.

Further sensitivity analyses were performed with additional parameters such as the revenues from merchandising, the total amount of secured investments or the mass of the mobile platforms at the

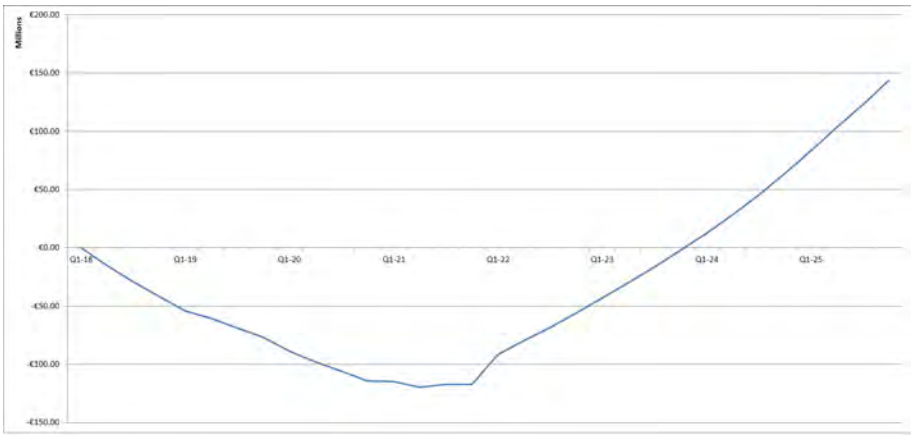

Figure 8.8: Cumulative cash flow 2018-2025

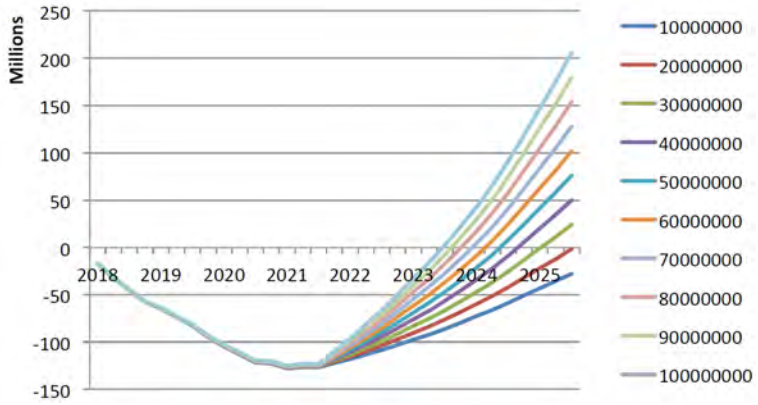

Figure 8.9: Sensitivity analysis for the revenues from advertisements (web page views and downloads)

launch pad. In all cases, considering different scenarios, the results indicate that LUNATIX will be financially viable.

Chapter 9

Risks

Successful project management is successful risk management.

LUNATIX implemented risk management to assure project success. The ECSS risk management approach was followed, where risks were identified in the following categories:

- Business risks
  - Product
  - Market
  - People
  - Financial
  - Competitive
- Technical risks
  - Requirements
  - Technology maturity
  - Subsystem (interfaces)
  - MMP and SMP interface
  - Engineering
  - Lunar environment
  - Normal technical lifespan (fatigue)
  - Operations
  - Enabling systems availability

After the risk identification, each risk is ranked according to their severity (the impact it has on the project if it occurs) and their likelihood (the probability of occurrence). The severity and likelihood are combined to get the risk index of each risk, which runs from very low to very high. Mitigation strategies are defined for the medium, high and, very high risks with the objective to either lower their severity or their likelihood.

LUNATIX has implemented a detailed risk register to keep track of all identified risks, their ranking, and the mitigation strategies. From this risk register the four major risks are represented in Table 9.1 together with their mitigation strategies.

ID	Category	Title	Description	Mitigation
BR2	Financial	Ability to secure grants, value of grants secured	First part of the funding for the business proposition relies on grants from ESA and other institutions. Risk of not securing these grants.	Plan for Public-Private Partnership; rely on more crowd funding; earlier subsystem and merchandising sales
BR14	Financial	Success of the marketing campaign	The success of a business relying on entertainment is linked the effectiveness of the marketing strategy	Make sure the best marketing strategists are employed. Rely on publicity made by space agencies.
TR6	Lunar environment	MMP and Small Mobile Platform or Nanobot (SMP) survival during night periods	The long duration of nights in the lunar operation area of the MP(s) increase the risk of not surviving.	Special attention during design to ensure night survival. Stable thermal condition to the MP(s). Tests on ground.
TR7	Technical	Loss of communication between MMP and Earth	Loss of control from Ground of the MP(s).	Back-up communication system. Autonomy of MP(s) to ensure their safety in case of temporal loss of communication.

Table 9.1: Major risks overview

In summary, the mitigation strategies appear to put a reasonable control on the risks. LUNATIX will continue to evaluate the risks as new learning is accumulated. For example, keeping the games attractive to the users will be a growing risk and will take management actions to be mitigated.

Chapter 10

Conclusions and Future Outlook

The ambition of the space start-up LUNATIX is to become the creative leader in lunar mobility experiences. The company invites its customers to leave their mark on the Moon. LUNATIX approaches both the general public and the scientific community, proposing versatile multi-purpose mobile platforms for entertainment and scientific purposes.

The market addressed by LUNATIX is considered to have a significant potential, especially since there are no competitors already offering similar services. The time to enter the market is excellent. The services will be deployed progressively, beginning as early as the start of the business, in less than one year. The products proposed are versatile and evolvable. Technically they are innovative and still only relying on mature technology. The business strategy is robust, giving credibility to investors. The time to profit of 6.5 years is reasonable, taking into account the baseline financial assumptions justified in this proposal.

The performed overall analysis shows that LUNATIX has a great opportunity to enter the gaming and entertainment market and to open a new market segment for direct control of assets on the Moon by the public. The products also contribute to the Moon Village vision by supporting scientific missions related to the establishment of a human presence on the Moon and to ISRU.

LUNATIX will be well positioned in the competitive landscape, being differentiated by other potential industries through the versatility, flexibility and innovative aspect of the proposed mobility solutions.

No significant legal and regulatory issues have been identified. LUNATIX is ready to assist the space lawmakers in the clarification of international legal space framework in view of increasing activities by multiple partners, on the Moon and beyond.

At the moment of writing this document, the technical design of the product is only preliminary. The next step would consist of further detailing the design and implementation plan. A session with ESA's CDF (Concurrent Design Facility) could be helpful to consolidate these aspects.

The project will raise public awareness and enthusiasm, allowing for further expansion and evolved mobility products on the Moon. Following the success of the initial set of mobile platforms, additional launches could be envisaged for replenishing the fleet with new types of mobile platforms carrying diversified payloads.

There are some very attractive possibilities to extend LUNATIX's activities along the same core products to other future markets requiring mobility on the Moon. For example, the next generation of mobile platforms could actively contribute as workers to the implementation of Solar Power Sta-

tions (SPS) for the Moon Village.

And where next? Once the validity of the business proposal has been demonstrated on the Moon, LUNATIX's next stop could be Mars!

Figure 10.1: SpaceTech 2016 participants (top to bottom from left to right: Sylvain, Aníbal, Lucía, Jon, Ana, Eugen, Milen, Jorge)

SpaceTech 2016 participants (listed in alphabetical order by surname):

- Sylvain Bouchart
- Jorge Fiebrich
- Lucía Hernando
- Aníbal López
- Jon Reijneveld
- Ana Rugina
- Eugen Svoboda
- Milen Tahtadjiev

List of Acronyms

AI	Artificial Intelligence
b2b	business-to-business
C3PO	Commercial Crew and Cargo Programme
CAPEX	Capital Expenses
CCP	Central Case Project
CFI	Customer Furnished Item
CNES	Centre National d'Études Spatiales
DHS	Data Handling System
DLR	Deutsches Luft Und Raumfahrt
DSN	Deep Space Network
ESA	European Space Agency
FDIR	Fault Detection, Isolation and Recovery
FPGA	Field Programmable Gate Array
GNC	Guidance Navigation and Control
IMU	Inertial Measurement Unit
IPR	Intellectual Property Right
ISRU	In-Situ Resource Utilisation
ISS	International Space Station
ITU	International Telecommunication Union
MIT	Massachusetts Institute of Technology
MLI	Multi Layer Insulation
MMP	Main Mobile Platform
MMU	Mass Memory Unit

MOC	Mission Operations Centre
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
OBC	On-Board Computer
OPEX	Operational Expenses
PV	Photovoltaic
SCOS	Spacecraft Control and Operation System
SMP	Small Mobile Platform or Nanobot
UHF	Ultra High Frequency
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
URFC	Unitised Regenerative Fuel Cell