# Xors Moon base - interdisciplinary project

Hubert Gross[1], Justyna Pelc[2], Piotr Torchała[3], Magdalena Łabowska[4], Beata Suścicka[5], Łukasz Sokołowski[6], Małgorzata Popiel[7], Arkadiusz Kołodziej[8], Ewa Borowska[9], Aleksandra Wilczyńska[10], Michał Garus[11], Cyrus Sidor[12], Marcin Zieliński[13]

[1])Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology
hubertgross97@gmail.com
[2])Faculty of Computer Science and Management, Wroclaw University of Science and Technology
juspelc@gmail.com
[3])Innspace
piotr.torchala96@gmail.com
[4])Faculty of Mechanical Engineering, Wroclaw University of Science and Technology
magdalena.labowska@pwr.edu.pl
[5])Faculty of Architecture, Wroclaw University of Science and Technology
beata.suscicka@gmail.com
[6])Innspace
lukaszsokolowski01@gmail.com
[7])Faculty of Law and Administration, Adam Mickiewicz University in Poznań
malgosiapopiel94@gmail.com
[8])Faculty of Medicine, Medical University of Warsaw
arkado.kolodziej@gmail.com
[9])Inter-faculty Individual Studies in Mathematics and Natural Sciences, University of Warsaw
ewa.borowska86@gmail.com
[10])Innspace
aleksandra.wilczynska3@gmail.com
[11])Innspace
m.garus.praca@gmail.com
[12])Innspace
cyrus.sidor@gmail.com
[13])Innspace
kontakt@marcinzielinski.com

## 1 Introduction

While working on the "Xors" project for the Moon Base Design Contest, one of the biggest issues was determining which subsystem or base building steps are critical to the success of the project and which of the environmental information obtained is able to determine the requirements for the base. This issue not only justifies the further education of systems engineers who, based on experience and literature, are able to lead a project from the first assumptions, through the concept, to the final real component, but also shows how necessary a purely scientific exploration of space is. Only by combining the information received through scientific analysis as well as the engineers mind it is possible to realize current as well as future projects in the space sector. By describing selected elements of the project this paper aims to show how advanced space sector projects are and how much they challenge human intelligence and knowledge.

The Moon base "Xors" is an interdisciplinary project combining both science and engineering ingenuity. The premise of the base is to be able to conduct scientific research on the Moon for at least 4 astronauts for a period of 3, 6 or 9 months. One of the first stages of the project without which work could not begin was to determine the location of the base. Then, after determining exactly what conditions the base must meet, work began on determining the structure of the base, its transport, the modules used and the structural aspects of the radiation shielding from the regolith. Later, life support systems that play a critical role in human survival were identified.

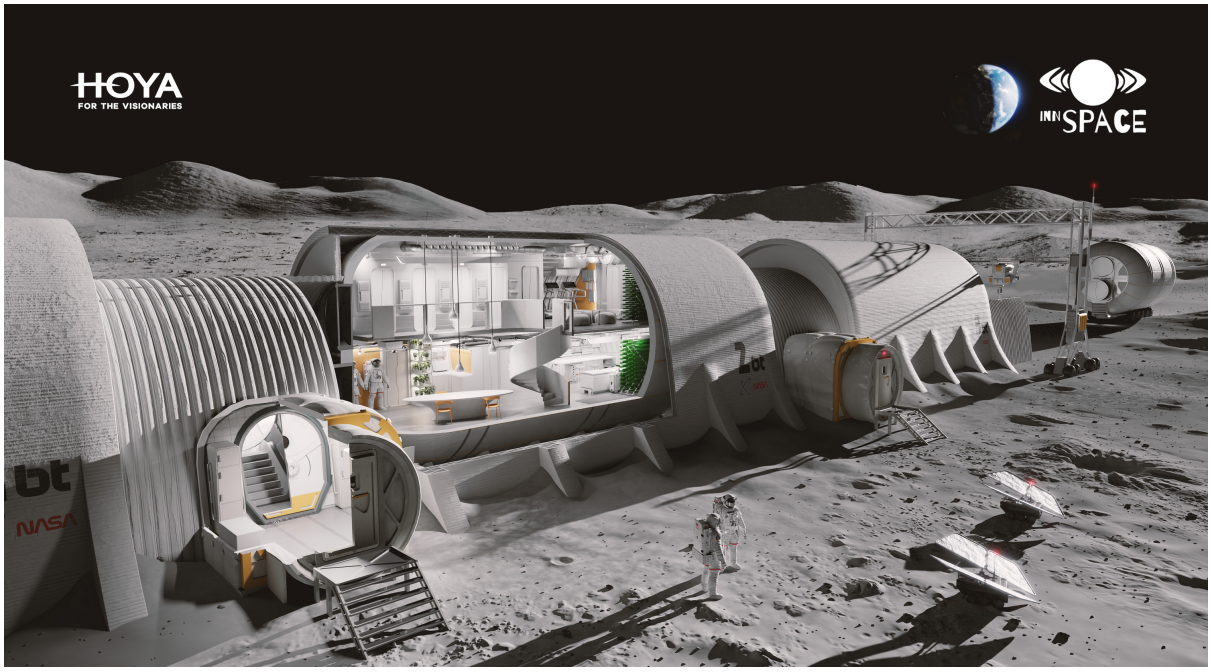



Figure 1: Part cross-section overview of the Xors Moon base [1]

## 2 Moon base location

Choosing a suitable location for a base on the Moon is one of the most important choices. It must allow astronauts to work in the terrain for as long as possible, have scientific value, i.e., have nearby sites particularly suitable for study by geologists, astronomers, and other scientists. The location should also have the most abundant possible deposits of resources for the ISRU, because it should be independent of supplies from Earth. In addition, it should provide the longest possible average annual dose of sunlight to take care of the astronauts' mental health, as well as allow for moonwalks with full visibility.

To summarize the above excerpt, base location primarily affects:

- Earth to Moon transport
- transportation from the landing site to the actual location
- amount of payload taken from the Earth (radiation shielding printing, life support systems)

- energy production
- thermal control
- communication
- ISRU like water and oxygen extraction
- psychological and physical health
- value of scientific research

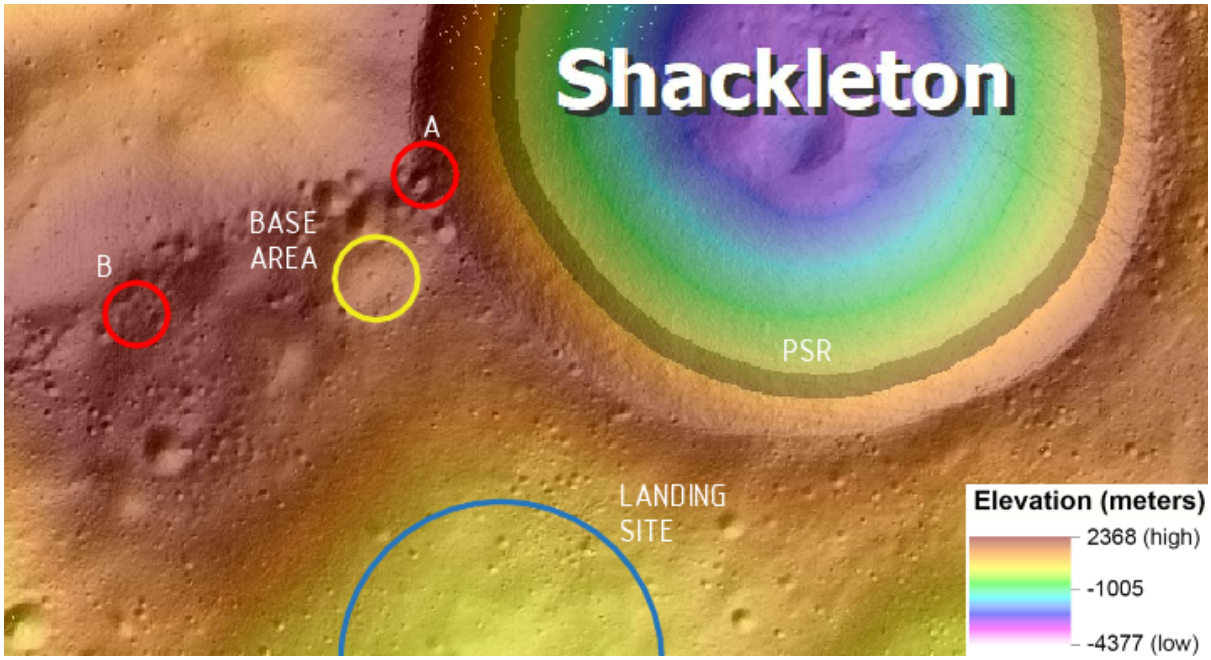



Figure 2: Base area, landing site, PSR and selected areas with greatest annual illumination [2]

The location of the lunar base was decided to be at the South Pole, near Shackleton Crater (fig. 2). It was chosen because of its proximity to two extremes: areas that are illuminated most of the time (points A and B) and Permanent Shaded Regions (PSRs) that have never been illuminated by the sun. The base sits on a gentle hill that separates it from possible lunar dust impacts during rocket and lander operations in the landing site area.

The time the base is illuminated plays a key role in solar energy generation and reduces the number of additional batteries or generators the base must have for the duration of the lunar night. Points A and B are illuminated together for 8 continuous months and for over 94% of the total time. In 2020, Point A had an average annual illumination of 81% and Point B had an average annual illumination of 82%. The PSR allows us to study the Moon's geologic past and features not illuminated by the Sun, and to provide future inhabitants with the water that is trapped there in the form of water ice. Points A and B also have a direct-to-Earth communication availability of 51%, which is a very good place to test future technologies as well as continue projects started by NASA. As you can see, this area has not only a high scientific value, but also allows the ISRU of water and oxygen, which relieves the entire project financially, as well as makes its operation partially independent from the supply of resources from Earth [3, 4, 5].

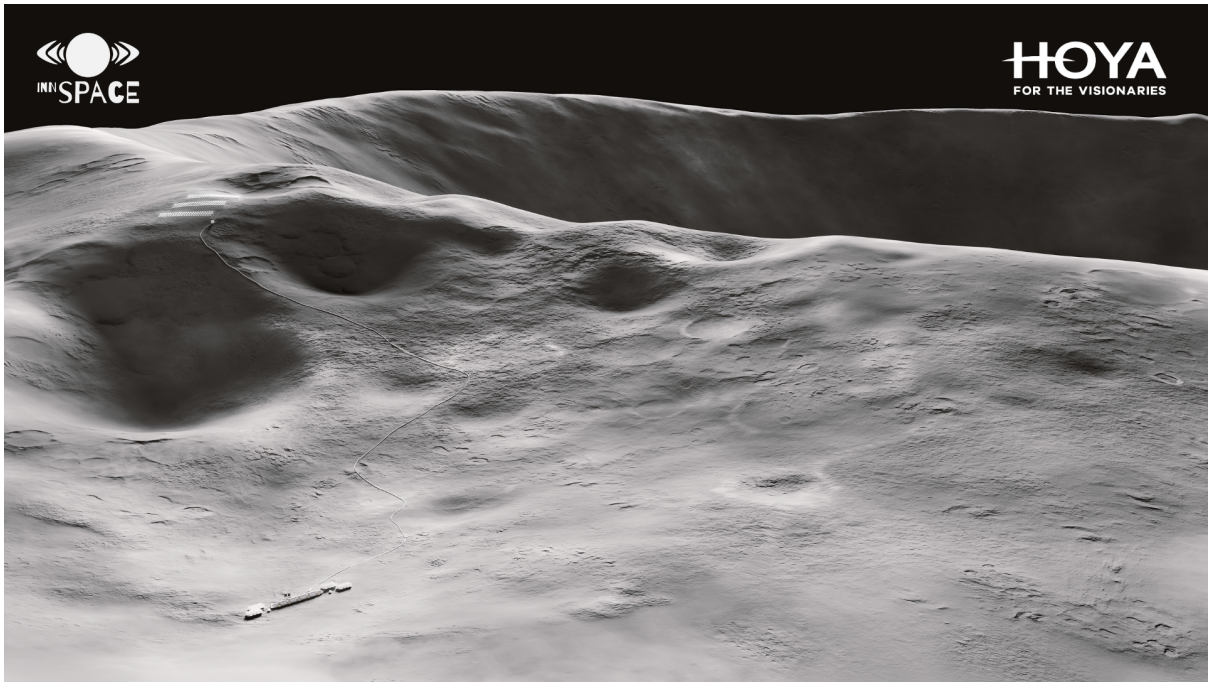



Figure 3: View on the Xors Moon base with the 3D Moon model taken from Lunar Reconnaissance Orbiter Camera [1]

# 3 Moon base construction

The base module structure is based on inflatable modules from Bigelow Aerospace. It was decided to use them because their solutions have been tested in space on the ISS with positive results (fig. 4). In case of Xors they were modified for the needs and dimensions of the base.

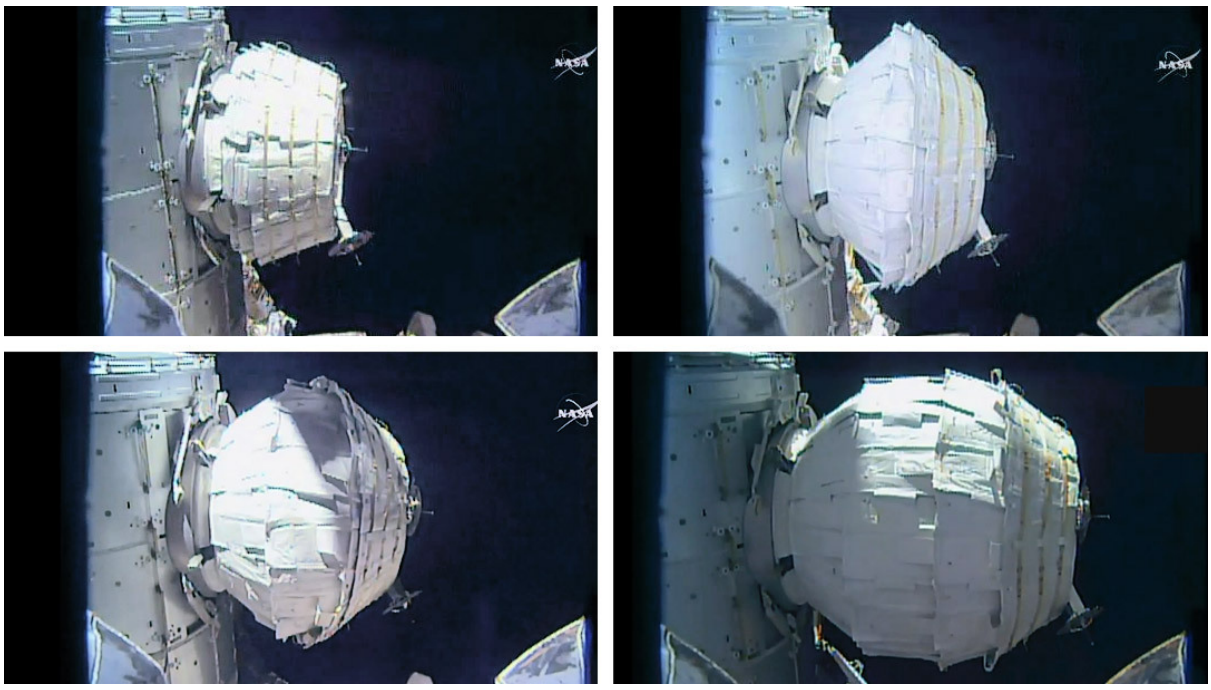


Figure 4: Bigelow Aerospace module tested on the ISS [6]

The modules used in the base consist of an aluminum structure and a thick layer of flexible composite of $0.5m$ thickness. This composite starting from the outside consists of carbon fiber, polymer foam, another layer of carbon fiber, another layer of foam and on the inside a layer of kevlar. Kevlar is on the inside because it is UV sensitive. By using this structure, it was possible to achieve protection against radiation and micrometeorites impacts. Besides, if the module wall is damaged, this structure will be sealed by itself. After applying appropriate modifications one module is $17m$ long and $9m$ in diameter. Such a module (not inflated) could be made up to $10m$ long and $6m$ in diameter, making it easier to transport both from Earth to the Moon and from the landing site to the location. At the front there is an airlock along with a connector to connect one module to another. Above this connector, there is also space for another connector which allows you to go directly from the floor of one module to the floor of another module without having to go down to the first floor.



Figure 5: Bigelow Aerospace modules [7]

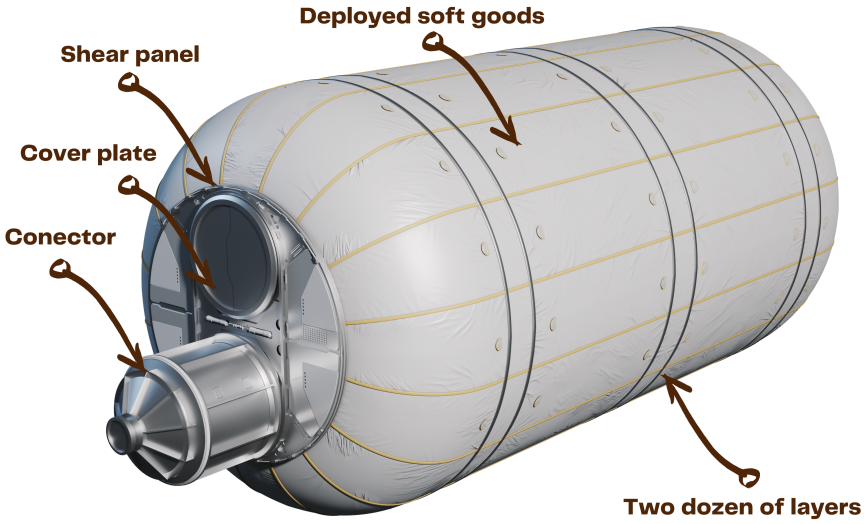



Figure 6: Bigelow Aerospace based modules used in Xors [1]

The modules are transported by rovers on special platforms from the landing site to the location of base assembly. On site, they are placed in designated areas and then unfolded and inflated. A 1-meter-thick regolith is then printed onto the modules using mobile 3D printers, which minimizes the risks and costs associated with building and transporting material other than regolith. As a printing technology we used D-shape technology as an efficient and time-saving method. It involves applying a liquid binder to a powdered mixture of cement and sand. Research indicates that with lunar regolith this method is also possible, and furthermore if all the water needed is obtained through ISRU, the only material needed to be taken from Earth will be MgO [8, 9].

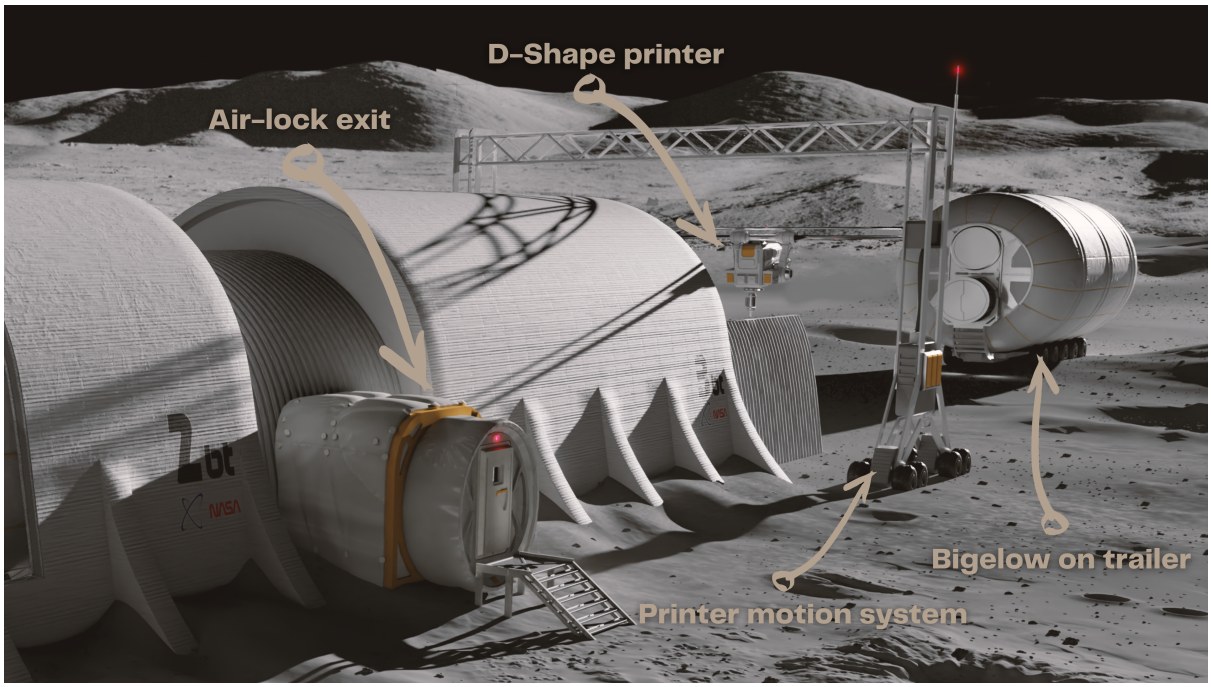



Figure 7: Xors Moon base regolith printing site overview [1]

# 4 Thermal control system

One of the most important systems used on the station, which depends on humans, environmental conditions and electrical equipment in the base is the thermal control system. It is designed not only to ensure the survival of astronauts in the base, but also to ensure comfort of manual or mental work. The approach to this topic is not obvious, because the problem of maintaining a constant temperature in the habitat is complex. First of all, the only system that can be used as a reference is ACTS, used for many years on the ISS and proven in practice. Also conditions on the Moon are not conducive to the construction of such a system. Taking into account the large temperature fluctuations outside the habitat or the heat emitted by the electrical equipment and people inside the modules is difficult, and from the system engineering point of view requires the use of considerable margins. Of course, it is also necessary to ensure that as the base increases, the system can be sufficient to remove heat from all additional modules of the base [10].

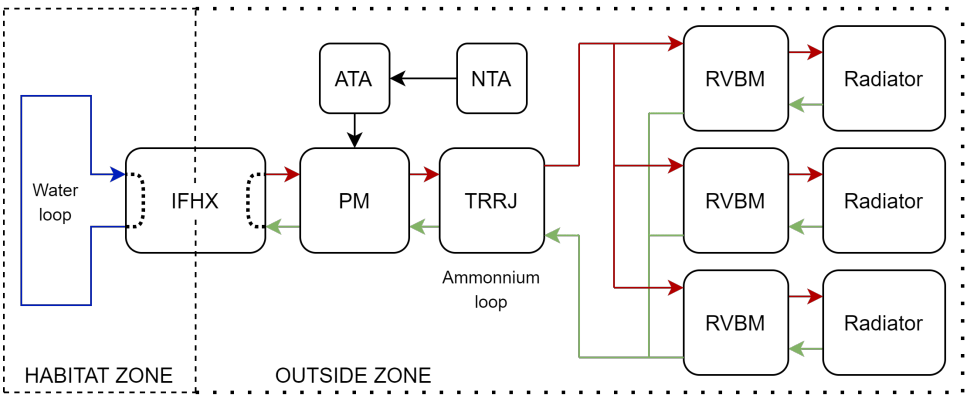



Figure 8: Habitat Thermal Control System diagram [1]

The Habitat Thermal Control System (HTCS) at Xors base was designed as a repeatable, redundant system modeled after a proven design from the ISS. There are 4 units of the HTCS system at the base. Its primary components are:

- Interface Heat Exchanger (IFHX) - a heat exchanger that regulates the temperature in the habitat by transferring heat from the internal water loop to the external ammonia loop
- Pump Module (PM) - circulates, regulates ammonia pressure and temperature
- Ammonia Tank Assembly (ATA) - regulates the amount of ammonia in the outer loop as it expands and contracts, due to temperature changes
- Nitrogen Tank Assembly (NTA) - forces ammonia flow from the ATA to the outer loop
- Thermal Radiator Rotary Joint (TRRJ) - transfers ammonia to the RVBM and radiator
- Radiator Valve Beam Module (RVBM) - controls ammonia transfer in each radiator
- Radiator - radiates heat to the outside of the loop

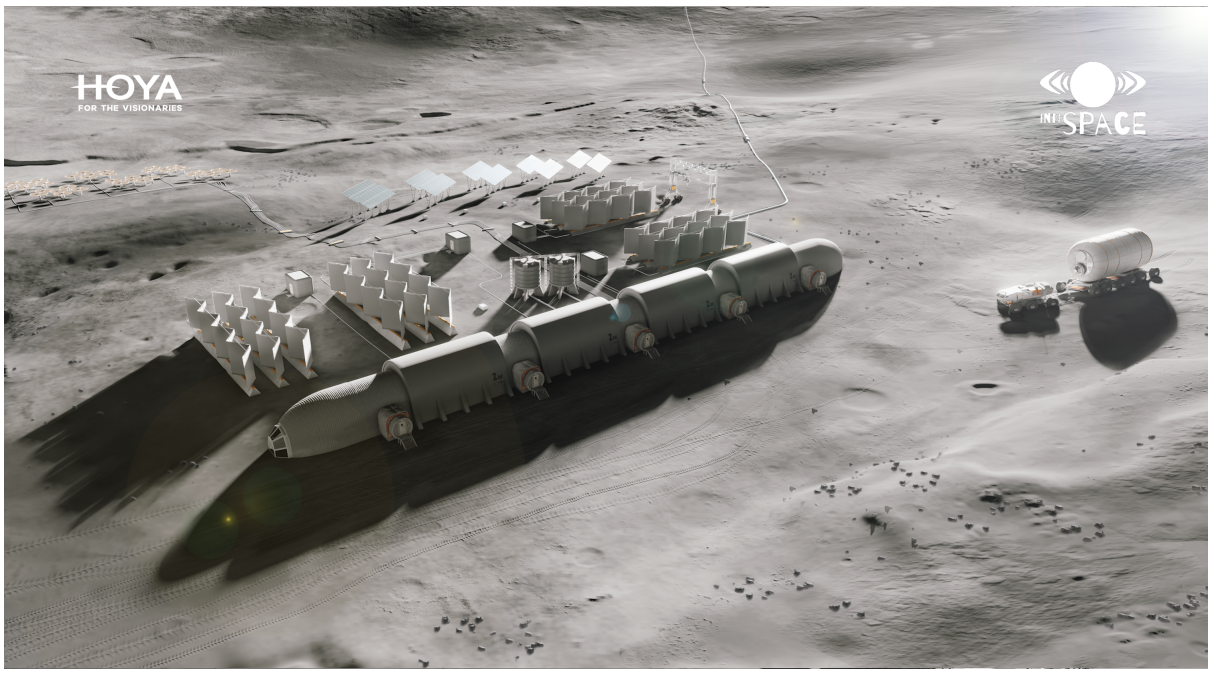



Figure 9: Xors Moon base with visible HTCS [1]

# 5 Summary

The Xors Moon base is an interdisciplinary project requiring knowledge of every field of study and cooperation between scientists, engineers, logistics, management and much more. The presented reflection paper discusses only some aspects of the base - mostly analyzing engineering problems. However, the entire database consists not only of engineering issues, but also interior design, laboratory equipment and medicine, emergency systems, human factors, communication systems, optimal schedule for astronauts wellbeing or even international relations and law. Future possible and planned projects in the space industry therefore make us reflect not only on the complexity of the projects, but also on the skills of the people through whom these projects are created and their ability to design more and more technologically advanced projects.

# References


[1] Justyna Pelc; Piotr Torchała; Magdalena Łabowska; Beata Suścicka; Łukasz Sokołowski; Małgorzata Popiel; Hubert Gross; Arkadiusz Kołodziej; Ewa Borowska; Aleksandra Wilczyńska; Michał Garus; Cyrus Sidor; Marcin Zieliński. *Xors Moon Base*. Innspace team, 2021.

[2] Lunar Regional Planetary Image Facility and Texas USA Planetary Institute, Houston. Topography and permanently shaded regions (psrs) of the moon's south pole.

[3] P.D. Spudis C.D. Neish H. Noda Y. Ishihara D.B.J. Bussey, J.A. McGovern and S.A. Sørensen. *Illumination conditions of the south pole of the moon derived using kaguya topography*. Icarus, 2010.

[4] S. Bryant. *Lunar pole illumination and communications maps computed from goldstone solar system radar elevation data*. The Interplanetary Network Progress Report, vol. 42-176, p. 1-43, 2009.

[5] Ice confirmed at the moon's poles, 2018. https://www.jpl.nasa.gov/news/news.php?feature=7218.

[6] Beam expansion progress, 2016. https://www.planetary.org/space-images/beam-expansion-progress.

[7] The bigelow expandable activity module (beam) comes to the iss, 2013. https://space.nss.org/the-bigelow-expandable-activity-module-beam-comes-to-the-iss/.

[8] D-shape - report, 2016. http://3dprintetbyggeri.dk/pdf/bes%C3%B8gsrapporter/D-Shape.pdf.

[9] X. De Kestelier V. Colla G. Cesaretti, D. Enrico and L. Pambaguian. *Building components for an outpost on the lunar soil by means of a novel 3d printing technology*. Acta Astronautica, 93:430–450, 01, 2014.

[10] Active thermal control system (atcs) overview. https://www.nasa.gov/pdf/473486main_iss_atcs_overview.pdf.