MLIT Ministry of Land, Infrastructure, Transport and Tourism / MEXT Ministry of Education, Culture, Sports, Science and Technology-Japan

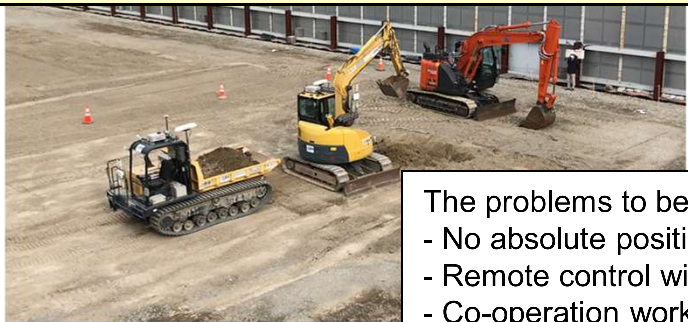
○Technology:　　　　　　　○Phase: R&D (Research and Development)

Project name	Development of Autonomous and Remote Construction Technology Adaptable to the Construction Environment - Application of Next Generation Construction System for Space
Practitioner	**Representative: Kajima Technical Research Institute** Joint implementer: Japan Aerospace Exploration Agency (JAXA), Shibaura Institute of Technology

<The Target of Our Project > To establish an automated and remotely operated construction system on the Moon in the future, we will assess the system using autonomous construction simulations in the lunar environment and demonstrations on Earth. Besides, it is necessary to build a platform to bind several simulators. Our research will be divided into three phases (see below), and we will obtain outcomes in each development step to bring the "real" lunar construction closer. With the fruits of our research, we will refine the automated construction system on Earth.

Three steps of our research project

1. Experimental validation of the automated construction system



The problems to be solved on the Moon.
- No absolute positioning like GNSS.
- Remote control with long delay comm.
- Co-operation work of many machines.

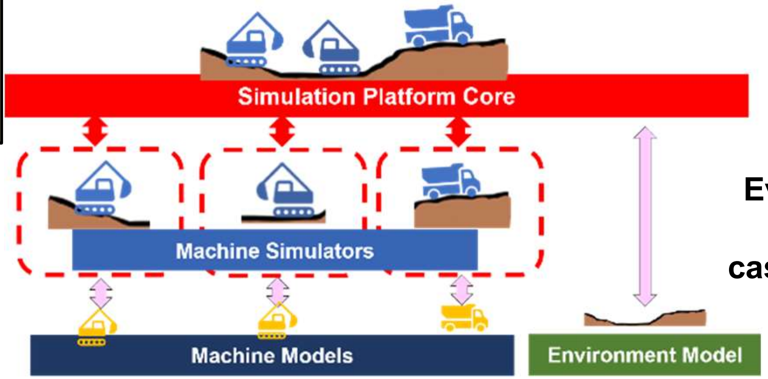
Gap :
- **Gravity**
- **Terrain**
- **No Air**
- **Etc.**

(Finally) Actual Construction on the Lunar Surface

Realization as a digital twin system

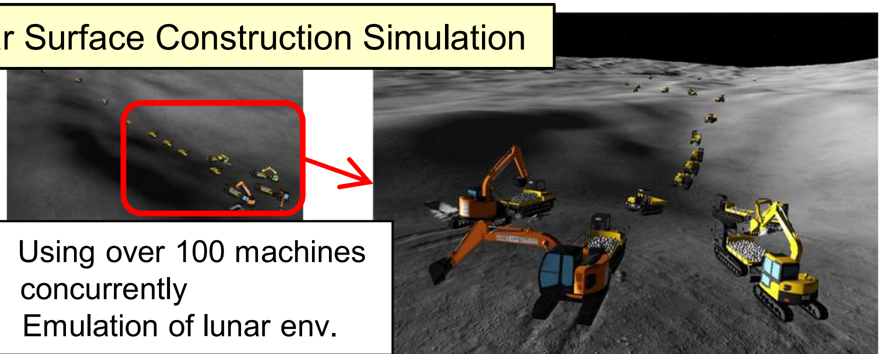
Simulation of the experiments on Earth

2. Build a simulation platform



Evaluation with case studies

3. Lunar Surface Construction Simulation



- Using over 100 machines concurrently
- Emulation of lunar env.

〇Technology：Unmanned construction(Autonomous and remote) - Construction(spreading, etc.) 〇Phase： R&D（Research and Development）

Project name	Development of an environmental awareness infrastructure system for autonomous construction and demonstration of construction
Practitioner	**Representative: Shimizu Corporation** Co-implementer: Bosch Engineering

【Objective･Summary】

Autonomous construction on the Moon is essential due to communication delays from Earth. AI-powered systems that can make decisions for the construction machinery enables near-autonomous decentralized construction. We also aim to establish a recognition system in a special environment such as the Moon.

【Content･Point】

Using only simple instructions, the AI generates work paths, thus enabling more advanced autonomous construction. A foundation for such environment recognition system enables diversified autonomous construction equipment.

【Implementation image】

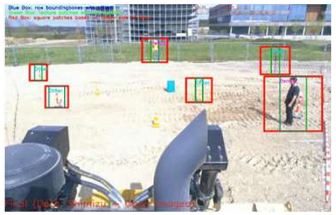
【On Earth】

Development and demonstration of autonomous construction systems leading to advanced uncrewed construction technology

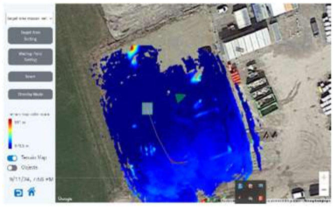
The environment recognition system recognizes terrain and obstacles, and the bulldozer itself uses AI to generate paths and perform land leveling work autonomously.

〇Implementation and improvement of automatic path generation algorithm for bulldozers

The bulldozer's route is automatically generated using the terrain map generated by the environmental recognition platform system, and its operation is verified in a test environment.



Example of detection



Example of terrain map

〇Demonstration of autonomous construction in soil leveling work

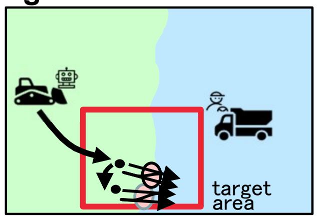


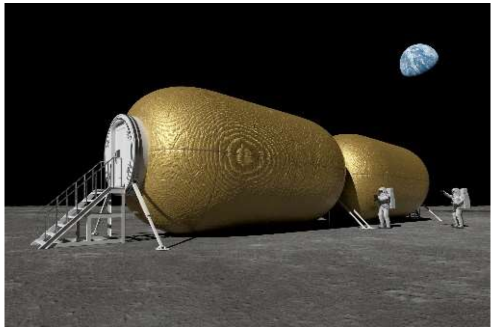
Image ：Automated path planning

This will demonstrate soil leveling work in a real-world environment using an autonomous construction bulldozer that performs a series of operations with automated detection and judgment.

【On the Moon】

Expansion to uncrewed construction on the Moon.

Image：Lunar base construction phase（Shimizu Corp.）



Image： Lunar habitat module（Shimizu/Taiyo Kogyo/TUS）

〇Technology：I　Unmanned construction - Construction (Positioning)　　〇Phase：R&D（Research and Development）

Project name	Development of SLAM autonomous driving technology for lunar surface adaptation
Practitioner	**Representative:Taisei Corporation** Joint implementer:Panasonic Advanced Technology Co., Ltd. TAISEI CORPORATION For a Lively World　Panasonic

【Objective･Summary】

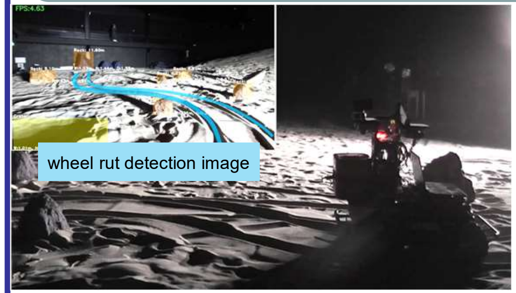
Autonomous driving requires accurate location information. No positioning satellite system exists in the lunar environment, we aim to develop a hybrid SLAM technology that combines LiDAR-SLAM using environmental data and landmark-SLAM using artificial features, enhanced with wheel rut detection functionality, to enable autonomous driving adaptable to lunar conditions.

【Content･Point】

Experiments conducted so far have confirmed the suitability of hybrid SLAM technology for a simulated lunar environment. Improve operability by adding technology focused on repeated transportation tasks along explored long-distance routes.

【Implementation image】

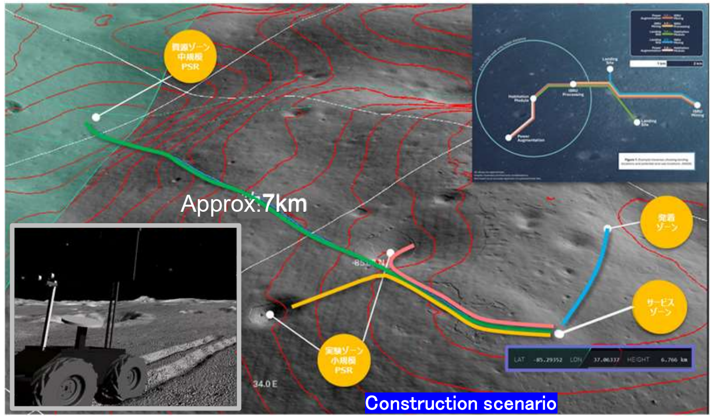
Adding a wheel rut detection (trace) function to Hybrid SLAM improves robustness and operability specialized for transportation tasks



Demonstration Experiment @ JAXA Space Laboratory

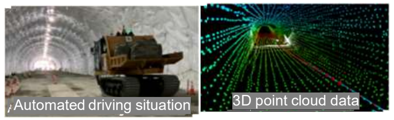
Experimental Rover

Long-distance travel of the explored route for lunar construction is achieved by tracing the wheel rut of the preceding vehicle.



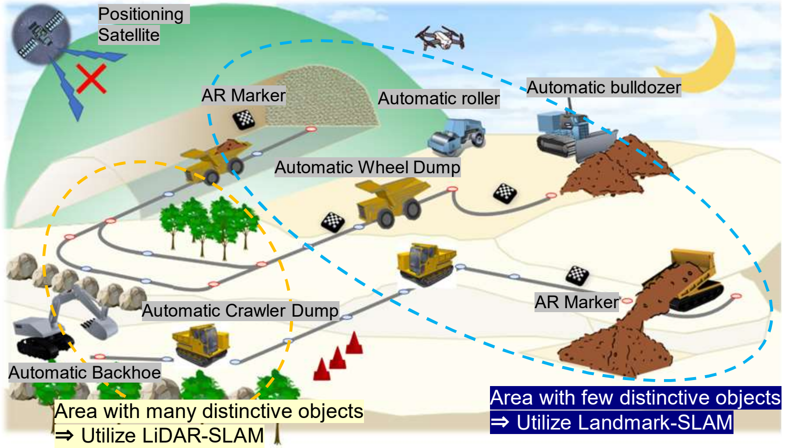
Evaluate the adaptability of the detection function to wheel rut on the virtual lunar surface with light similar to the lunar polar region.

【Application image on the earth】

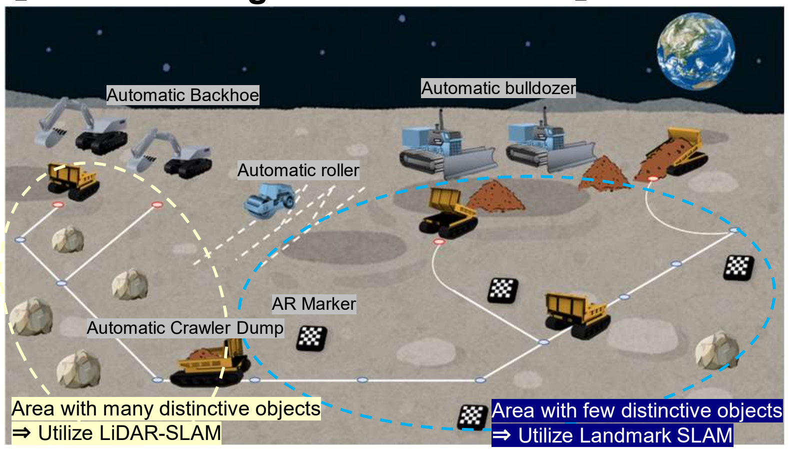


LiDAR-SLAM demonstration in a tunnel

LiDAR-SLAM demonstration in mountainous area



【Practical image on lunar surface】



〇Technology:

〇Phase: R&D(Research and Development)

Project name	Lunar simulator and simulation model construction
Practitioner	**Representative: Japan Manned Space Systems Corporation (JAMSS)**

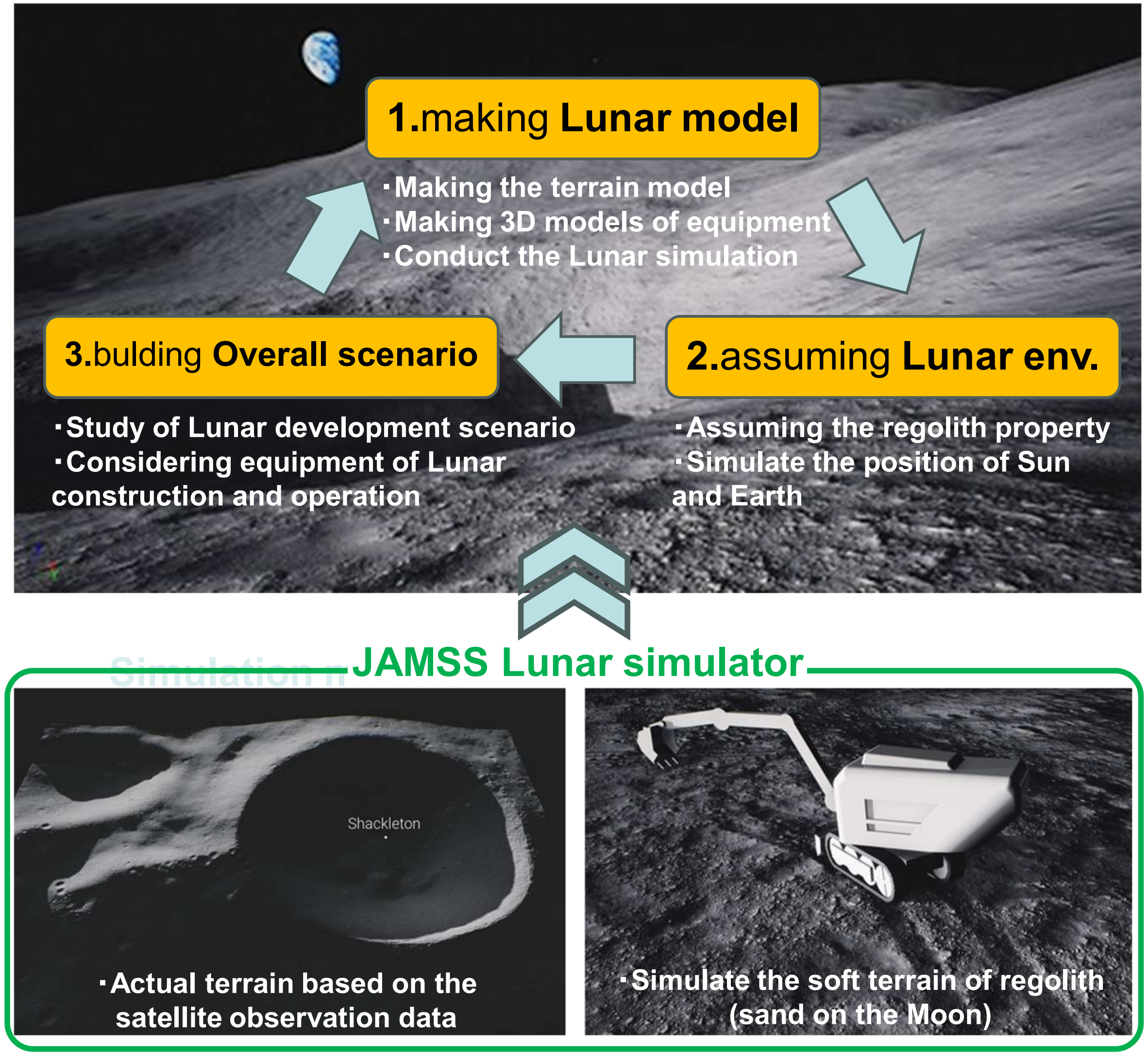
【Objective･Summary】

Making Lunar model assuming actual survey area and launch pad candidates.
We consider the necessary simulation functions for the transportation of equipment, assembly, activation, auto-operation, and enhance JAMSS Lunar simulator, to contribute Lunar auto/remote construction.

【Content･Point】

We are developing Lunar simulator, which is useful for Digital twin and has the actual terrain, by iterating 1) making Lunar model, 2) Assuming the lunar surface environment, and 3) building the overall scenario.
We will update Lunar model assuming operations and clarify the specifications of Lunar construction.

【Development image】



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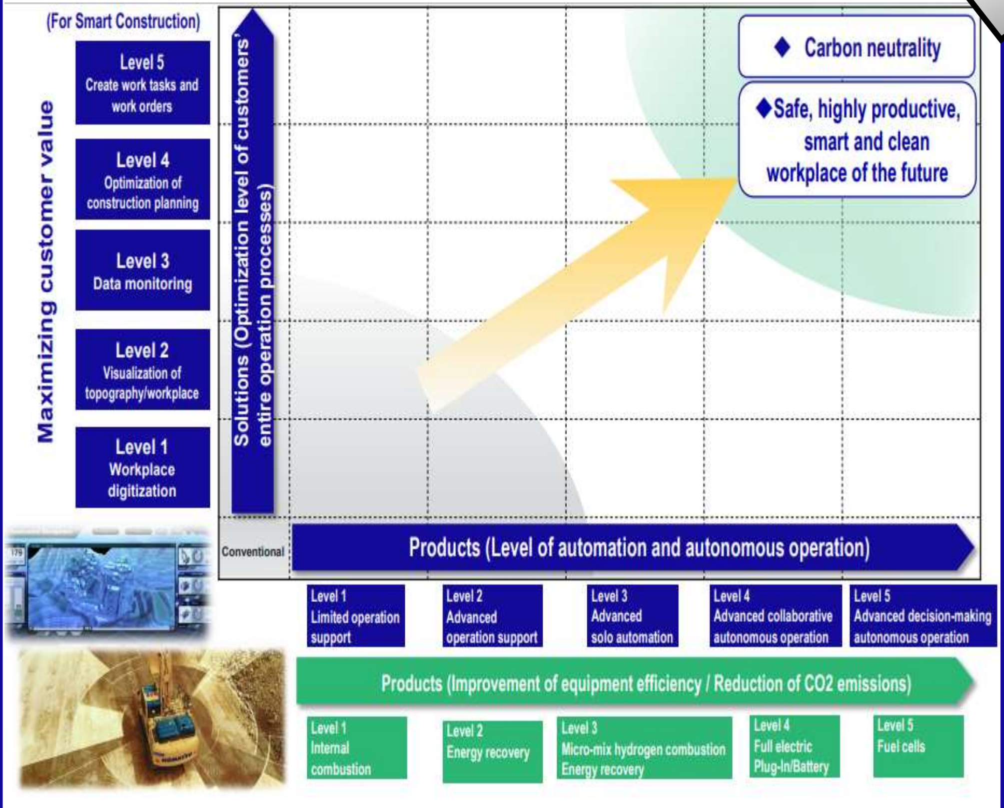
〇Technology：[I] automatic and remote operation – construction equipment and construction 〇Phase：R&D（Research and Development）

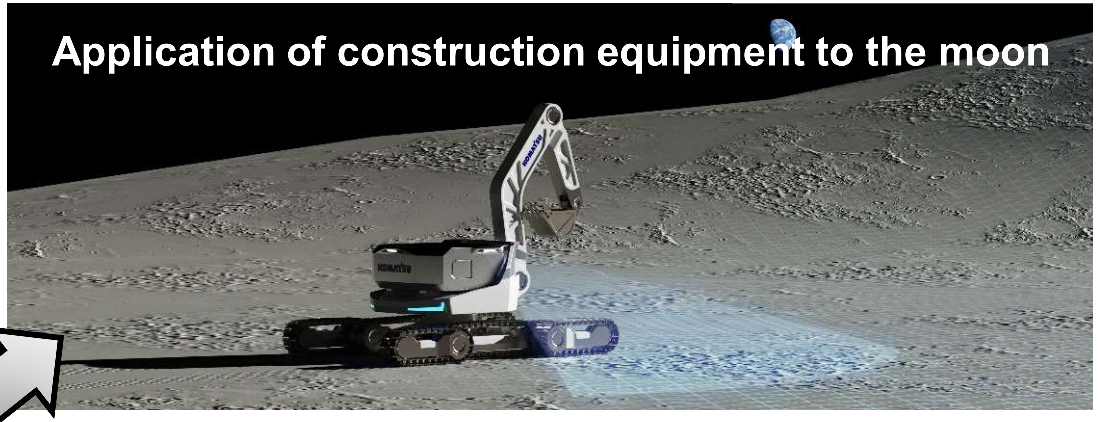
Project name	Research and Development for Lunar Construction Equipment using Digital Twin Technology
Practitioner	Komatsu Ltd.

KOMATSU

Approach to GEMBA of the future

We are adopting a two-pronged approach in the roadmap: **Products** and **Solutions**.
We seek to contribute to "**safe, highly productive, smart and clean workspace of the future**" by improving products themselves and efficiency of operation processes and combining both improvements.





【Objective/Summary】

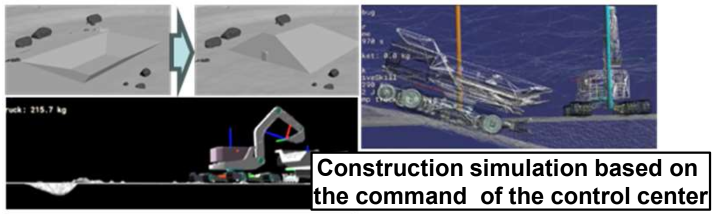
Because of the difficulty of reproducing a lunar environment on the Earth, it is essential to develop "**digital twin technology**" that accurately simulates the lunar construction equipment and its workspaces.

In this R&D, we **add the necessary functions and improve the accuracy** for developing lunar construction equipment and unmanned autonomous construction technology to the simulator developed at the F/S in FY2021 and use the simulator to study lunar construction equipment.

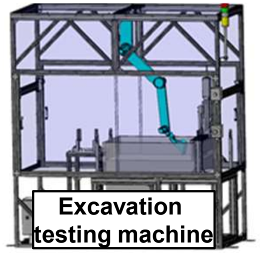
In addition, we use the knowledge achieved in this R&D for upgrading construction equipment and construction on the Earth.

【Content/Point for FY 2025 and Beyond】

1. Input the data assumed on the command of the control center into the construction simulator developed in previous years, we will simulate a series of operations by lunar construction machinery and verify the automatic and autonomous construction.
2. In preparation for lunar geotechnical investigation, we will replace the excavation test machine with space usable parts and consider the applicability in lunar environment.



Construction simulation based on the command of the control center



Excavation testing machine

〇Technology： Unmanned Construction (Automation/Remote)　　〇Phase： R&D（Research and Development）

Project name	Methods for Topographic Survey and Geotechnical Investigation for Constructing a 3D subsurface Geological and Geotechnical Map on the Moon
Practitioner	**Representative: Ritsumeikan University** Joint implementer: Shibaura Institute of Technology, University of Tokyo, Yokohama National University, Port and Airport Research Institute, Asia Air Survey Co, Kiso-Jiban Consultants, Soil and Rock Engineering

【Objective-Summary】Development of an Unmanned Exploration Robot for Topographic Survey and Geotechnical Investigation for Lunar Exploration and Lunar base Construction

- The lunar surface remains largely unexplored in terms of soil mechanics, geology and topography.
- **Geological and geotechnical risk assessment and management are essential** to ensure the safety of lunar surface activities.

【Content-Point】

- Developing a **geotechnical engineering framework encompassing the entire process, from acquiring topographical and geotechnical data to utilizing** it in planning lunar surface activities.
- Developing an investigation strategy to enable **reliable design that accounts for the uncertainties of lunar surface**.

RGIS: Robotic Geotechnical Investigation System

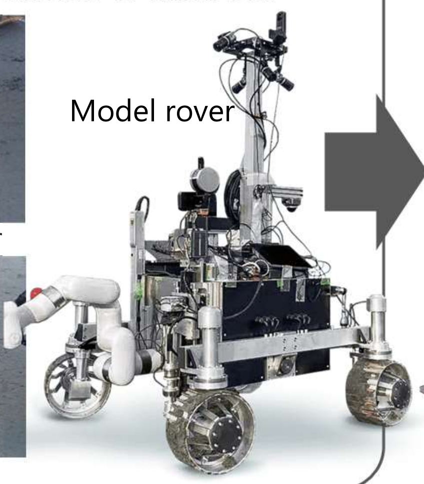
Micro-topography, Subsurface stratigraphy, Soil bulk density, and Mechanical characteristics of lunar soil


3D mapping tool


RI density meter

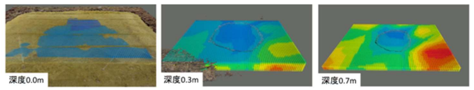

Active seismic exploration tool

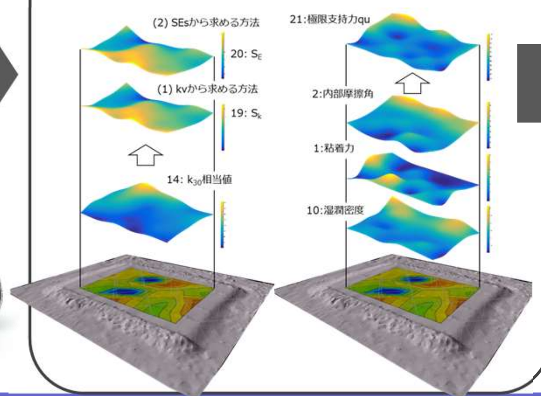

Soil testing tool


Model rover

3D subsurface geological and geotechnical model

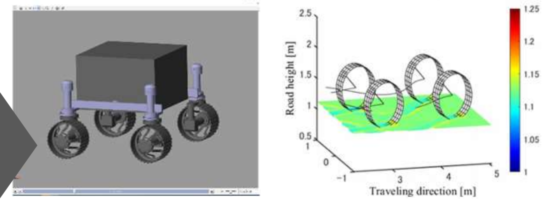
Mapping, Modelling, GIS, and BIM



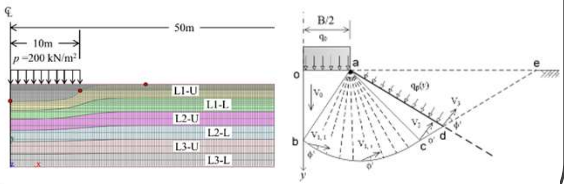


Data utilizations

Prediction, Simulation, Reliability analysis, and Performance-based design



Terramechanics-based simulation



Geotechnical analysis and design

〇Technology:Ⅰ Unmanned construction (Automation･remote) –Transportation (survey)　〇Phase: R&D（continuaton）

Project name	Development of disaster response transportation technology using cableway technology
Practitioner	**Representative: Kumagai Gumi Co.,Ltd.** Joint implementer:Sumitomo Forestry Co., Ltd., KYC MACHINE INDUSTRY CO.,LTD., KATO WORKS CO.,LTD., Kogakuin University

【Objective･Summary】

The important issues of material injection into the interior of craters and caves on the Moon and transportation of mined resources require automated technology that reduces the risk of transportation routes and is excellent in dealing with the work environment. In this development, by utilizing cableway technology, which is a stable material transport, for disaster response, technological research and development will be conducted to put supplies into caves on the lunar surface and to develop a continuous transport system between the lunar permanent shadow and the sunlit area.

【Content･Point】

Technology that enables rapid and efficient transportation when a disaster strikes is highly needed in society, such as for early restoration of infrastructure and other facilities. On the ground, the goal is to develop a technology that enables early restoration of infrastructure and other facilities through remote and automated control by developing a simple strut and a portable winch with improved cable yarding for the cableway technology of overhead line collection.

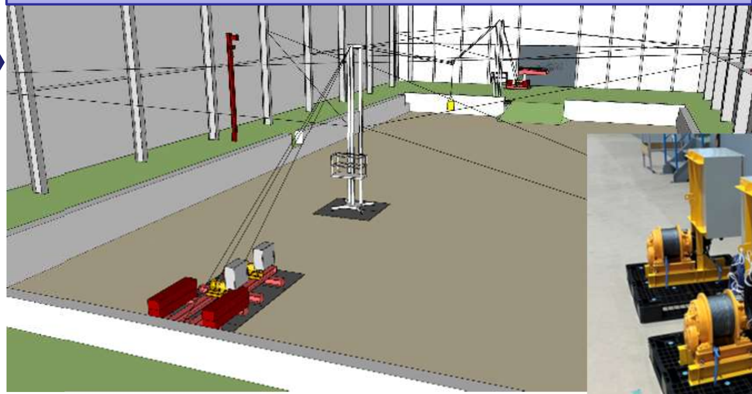
Disaster response

Sandbags are frequently used to protect slopes as emergency restoration measures in times of disaster, but they are often transported manually, which requires a great deal of labor and is not rapid

Problem solving

Simple Strut and Winch

Transport Test Using Simple strut for cableway technology



Servomotor winch

Japan's own idea

【Implementation image】

Lift-up type strut assembly equipment

In addition to resource extraction and transportation of permanent shadows inside craters, it enables the investigation of lunar cavities with little environmental change and material transportation to base construction

put supplies into caves on the lunar surface

continuous transport system between the lunar permanent shadow and the sunlit area

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○Technology:　○Phase: R&D (Research and Development)

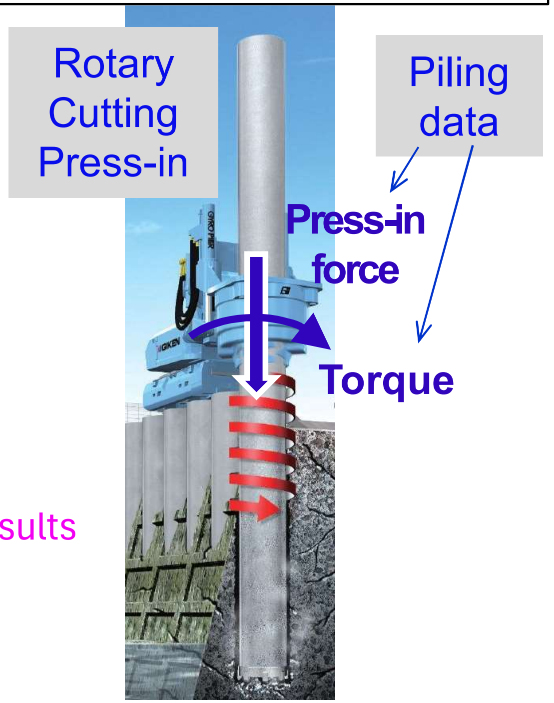
Project name	Proposal and assessment of rational process of design and construction for construction projects on the Moon, by the use of piling data in Rotary Cutting Press-in
Practitioner	**Representative: GIKEN LTD.**

【 Aims in FY2022～2026 】

Establish the technology to rationalize the design and construction process by using information during construction work, and secure its applicability to the Moon.

【 Key points in FY2022～2026 】

- ✓ Field tests to validate the technology of the use of piling data (estimating subsurface information & pile capacity / autonomous operation)
- ✓ Field tests to establish "simplified load test" using press-in machine
- ✓ Case study of design and construction on the Moon

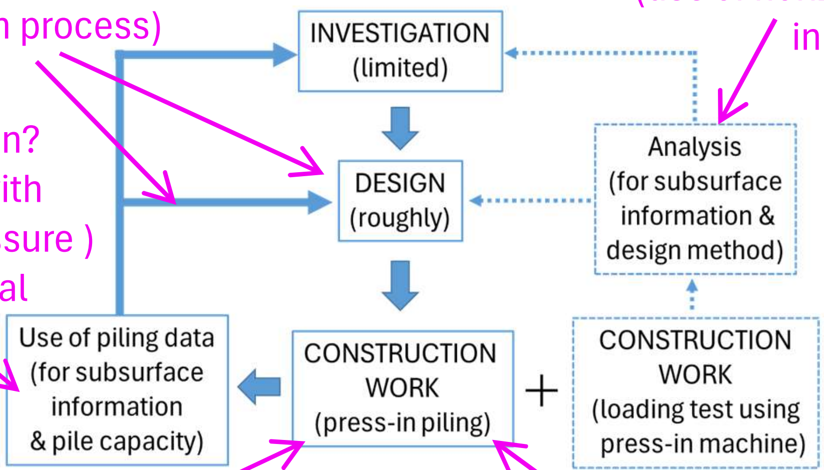


【 Viewpoints in FY2025 】

Specific scenario for specific structure? (construction process)

Validity of estimation? (use of horizontal loading test results in lunar simulant)

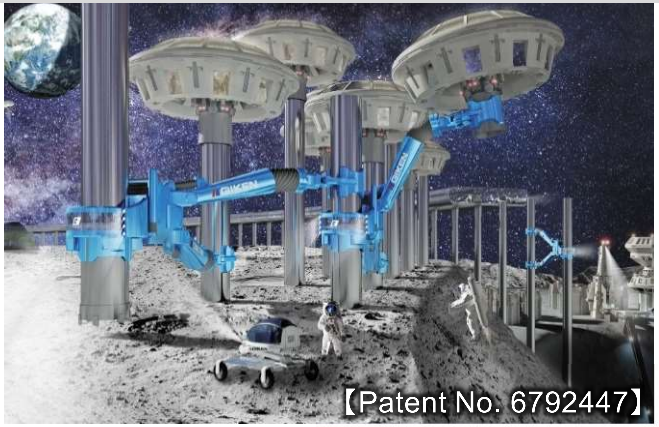
Validity of estimation? (in lunar simulant with higher overburden pressure) (including horizontal resistance)



Feasibility of press-in piling on the Moon? (in lunar simulant with higher overburden pressure)

Validity of estimated pile temperature?
Preferable pile is closed- or open-ended?
Validity of measurement?
Effect of atmospheric pressure?

Example of possible infrastructure



〇Technology Classification: II Building materials manufacturing 〇Phase：R&D（Research and Development）

Project name	Technical development of production and construction methods for moon base construction materials using lunar resources
Practitioner	**Representative: Obayashi Corporation** Joint implementer: Nagoya Institute of Technology, Institute for Laser Technology

【Objective･Summary】

It costs a huge amount of money to transport construction materials from Earth by rocket to construct **bases for lunar exploration.** Therefore, we are conducting R&D on a technology that **uses lunar regolith** as a material, heats regorith **with microwaves, lasers, etc, produces a product on site**, and uses this **as a construction material.**

【Content･Point】

We are improving **the quality and manufacturing efficiency** of heating manufacturing technology using lasers, microwaves, etc. , and verifying **its applicability in lunar environments such as vacuum and low gravity.** We are also proceeding with the development of manufacturing **inorganic fibers**. Furthermore, we are also working on exploring **continuous manufacturing and automated construction technologies.**

【Implementation image】

Lunar simulant

Simulated moon sands are used for the tests.

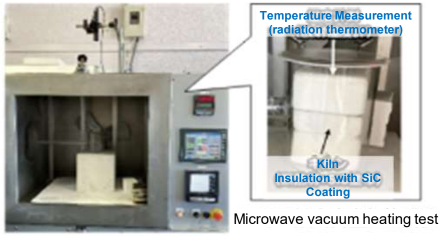
Mare simulant

High land simulant

Development of construction material manufacturing system using microwaves

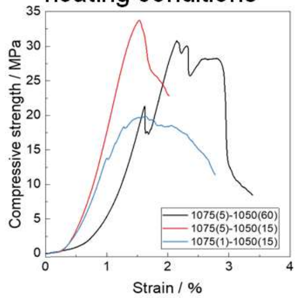
We are controlling the microstructure by optimizing heating conditions, examining improvements in mechanical strength, verifying the applicability of manufacturing techniques to different simulants, and developing equipment for parabolic flight tests.

Microwave production test under high vacuum

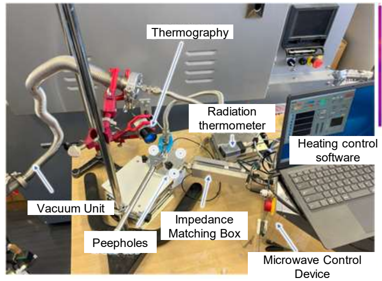


Microwave vacuum heating test

Improved mechanical strength through optimized heating conditions



Development of a parabolic flight test device

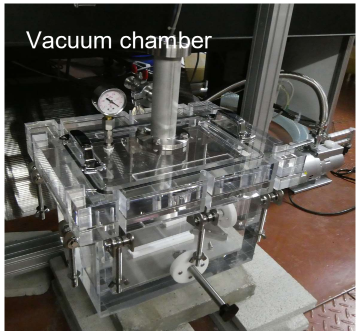


Development of construction material manufacturing system using laser

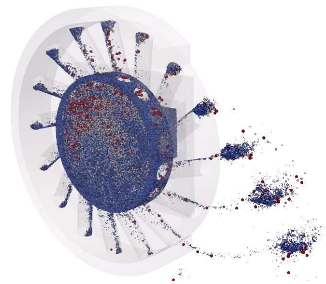
We are investigating manufacturing various shapes by additive manufacturing, improving bending strength through laser reheating, conducting additive manufacturing tests in vacuum, and simulating powder transport and additive manufacturing.

Manufacturing various shapes of objects using CAM

Laser additive manufacturing test in vacuum



Simulation of powder transport by centrifugal force in low gravity and vacuum.



Development of manufacturing methods other than heat technology

We are developing manufacturing inorganic fibers, which have many potential applications..

Establishing the concept of an automated construction system

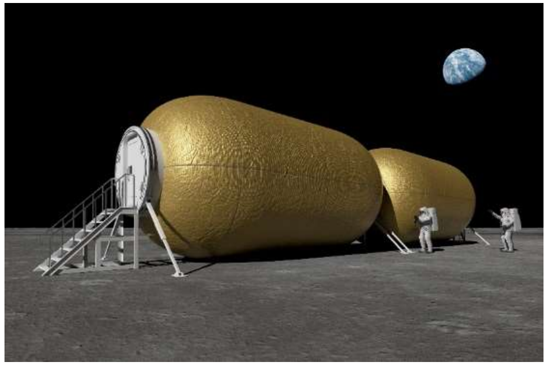
We investigated existing automated construction technologies for block paving, etc., and identified issues.

〇Technology: Fast Structure Deployment – Inflatable membrane 〇Phase: R&D (Research and Development)

Project name	On-Ground Testbed Development of an Inflatable Lunar Habitat Module
Practitioner	**Representative: Shimizu Corporation** Joint implementer: Taiyo Kogyo Corporation, Tokyo University of Science

【Objective･Summary】

Folding lunar habitat modules up and deploying them on the moon can reduce transportation costs by reducing payload weight and space on rockets fairing. Our Team focuses on realizing an on-ground testbed of an inflatable structure of flexible membranes.

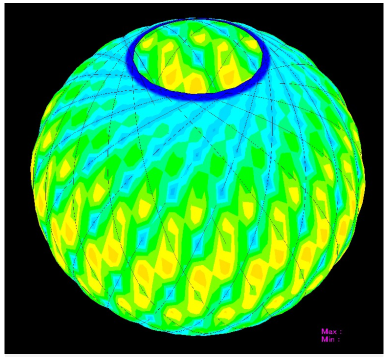


Inflatable Lunar Habitat Module (Image)

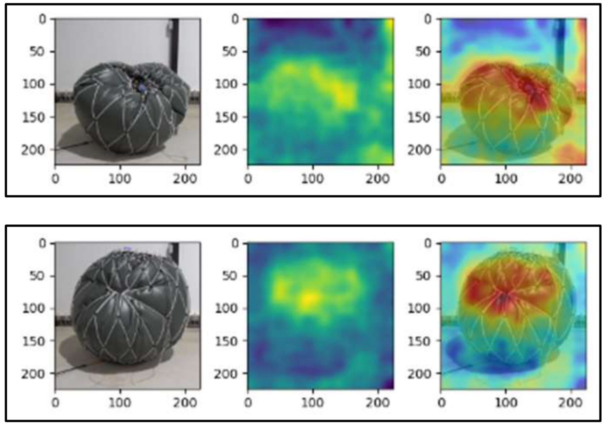
【Content･Point】

Based on the technical issues identified in the 2021 feasibility study phase, our team will develop (1) a high-strength flexible structure that can withstand the severe environment on the moon while maintaining a pressurized habitable room, (2) an autonomous decentralized status monitoring and deployment control system, and (3) structural analysis models to compute and design the entire structural strength.

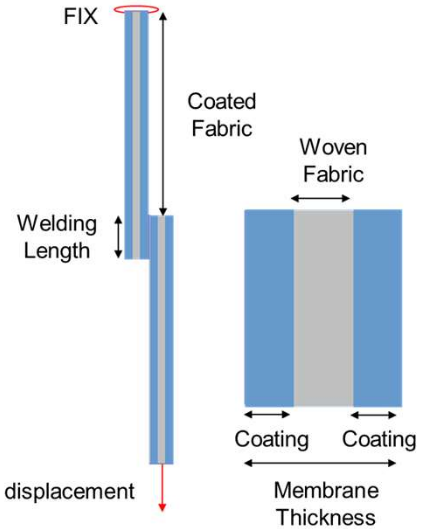
Full-scale Model (5m Diameter)



Analytical Model (Structural Strength)



Inflation Anomaly Detection



Analytical Model (Welding Strength)

○Technology Classification：III ○Phase： R&D（Research and

Project name	Requirement Definitions of Deployable Structures and R&D of Unmanned Setup System on Lunar Surface
Practitioner	**Representative: Obayashi Corporation** Joint implementer: Japan Aerospace Exploration Agency Sakase AdTech co., ltd

【Objective･Summary】

At an initial Lunar base construction stage, reducing materials and construction works is desirable.
From several candidates studied in a past feasibility study, some most effective deployable structures are selected, and their R&D is undergoing while making required performance and setup methods clear based on demands in each Lunar exploration phase.

【Content･Point】

For the deployable structures such as Lunar habitat modules, shelters and utility modules, the technical innovativeness and superiority for the resemblance technologies of this system shall be confirmed along with social effects and its possibility of the utilization in a practical use for future application to space developments such as Lunar surface.

【Non-pressurized structure】

In 2024, a test of a BBM test of a hexapod type deployable tower are confirmed, and a 10m length (real length) of the CFRP bistable boom's extension test was successfully done.

Since 2025, the tower will be improved to be available for non-flat surface on the moon reflected to the BBM, also an influence of the regolith to the mechanics will be studied.

【Pressurized structure】

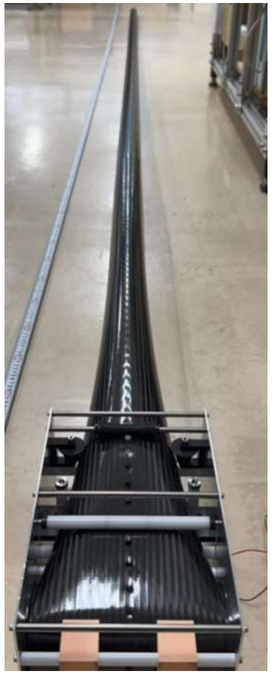
In 2024, the self-deployable membrane structure buried under the regolith is analyzed by 3D particle models and its structural feasibility is confirmed, also a BBM of a deployable inner frame is tested.

Since 2025, feasibility of the membrane structure to be deployed along with the inner frame will be studied and its basic design will be developed.

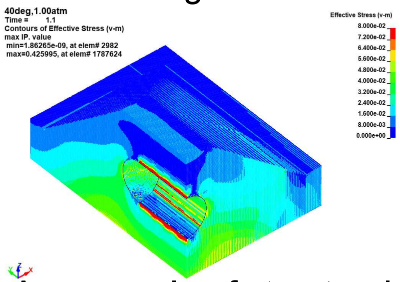
【Scenario study 】

Since 2025, analysis of scenario-task for those deployable structures will be done to be reflected to the structures.

BBM of a hexapod type deployable tower



Extension test of 10m length CFRP bistable boom



An example of structural analysis results (stress)

BBM of a deployable inner frame

〇Technology：Ⅲ 〇Phase：R&D（Research and Development）

Project name	Minimal Composition and Deployment Mechanisms for the Base Camp on the Lunar Pole and in the Lava Tube
Practitioner	**Representative: The Univ. of Tokyo** Joint implementer: Kyushu University, Takenaka Corporation, JAXA

【Objective･Summary】

The initial base camp on the lunar pole and in the lava tube can be composed as a minimum and deployable for quick establishment. It helps crewed exploration, remote construction for the long stay. A tiny module for the pilot exploration is also developed.

【Content･Point】

A habitat module equipped with infrastructure is packed while transported, deploys passively, and touchdowns onto bumpy terrain.

Deployment mechanisms are tested through the full scale partial prototypes including the pillow-shaped envelope, an overhang unit, and an earwig wing fanning panels. Cramped space is filled up with dense vegetation.