○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.

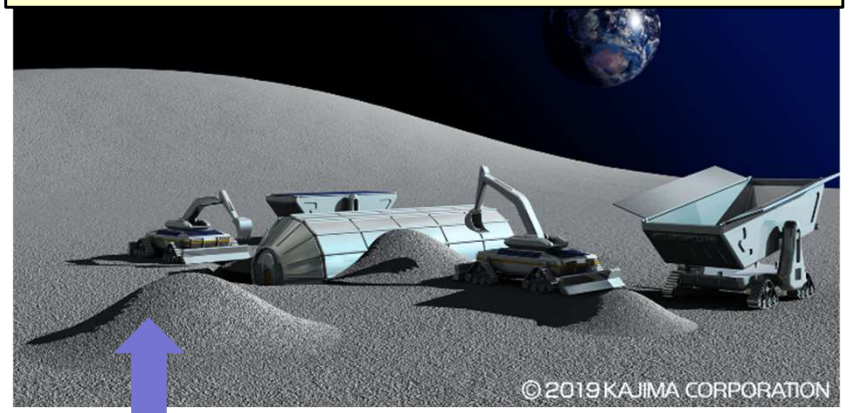
Three steps of our research project

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.**

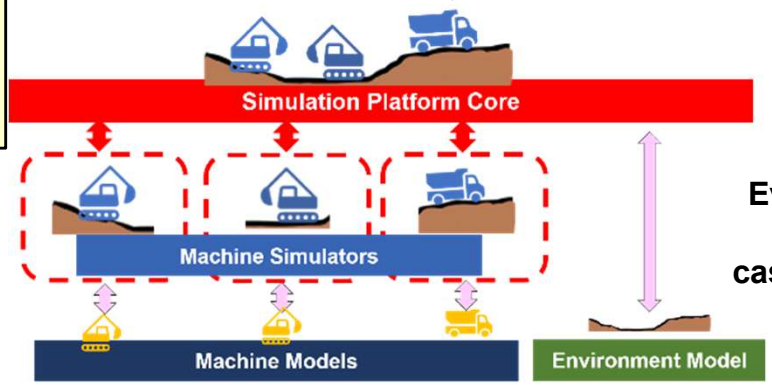
(Finally) Actual Construction on the Lunar Surface



Realization as a digital twin system

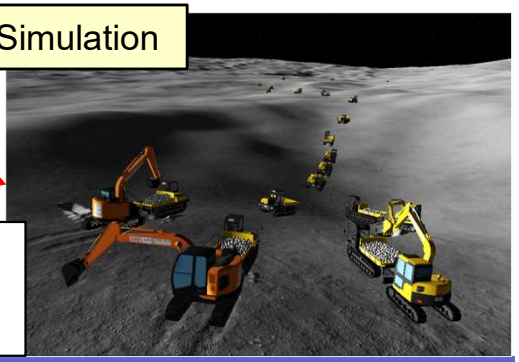
Simulation of the experiments on Earth

2. Build a simulation platform



Evaluation with case studies

3. Lunar Surface Construction Simulation



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

○Technology：Unmanned construction(Autonomous and remote) - Construction(spreading, etc.) ○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.

○Evaluation of environmental awareness systems by digital simulation

Evaluation of an environment recognition system using an algorithm that is less sensitive to environmental conditions in order to eliminate collision events caused by false object detection.

Devices for systems

Example of detection

○Study on Automated path planning algorithm

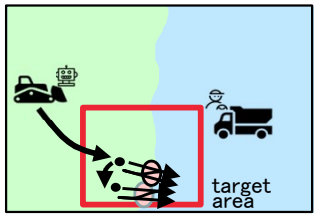


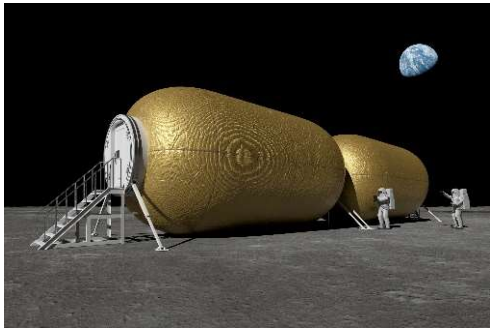
Image ：Automated path planning

Study of an algorithm that can work autonomously by setting the target area and dispersal route based on self-position and terrain elevation.

【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）

○Technology：Ⅰ　Unmanned construction - Construction (Positioning)　　○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.

【Objective・Summary】

Autonomous driving requires location information. No positioning satellite system exists in the lunar environment. Therefore, we will develop a hybrid SLAM technology that combines LiDAR-SLAM using environmental information and landmark-SLAM using artificial feature to develop an autonomous driving that can adapt to special environments such as the lunar surface.

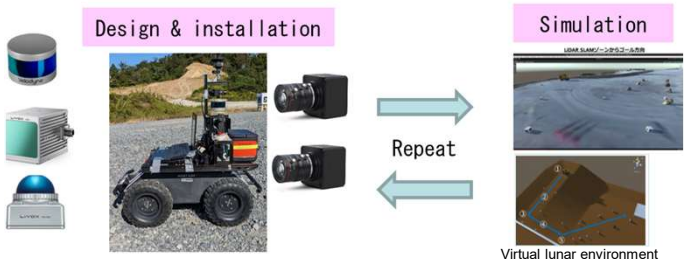
【Content・Point】

Experiments at Tottori Dunes Lunar Field and JAXA Facility have confirmed a hybrid SLAM can be adapted to a simulated lunar environment. To realize long-distance transportation for lunar surface, we will develop a more operational system.

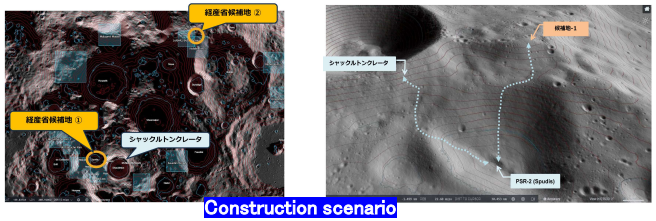
【Implementation image】

Improvement of robustness and operability by multiplexing sensors

To develop a robust and highly operational SLAM technology by integrating multiple LiDARs and cameras.



Demonstration experiment to realize long-distance transportation between takeoff-landing sites and construction sites on the moon

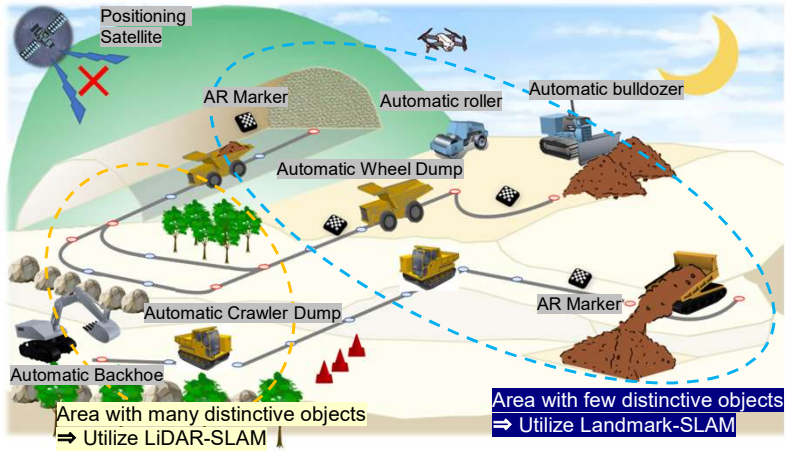


We will demonstrate adaptability to diverse environments by challenging long-distance SLAM automated operation in a simulated lunar environment .

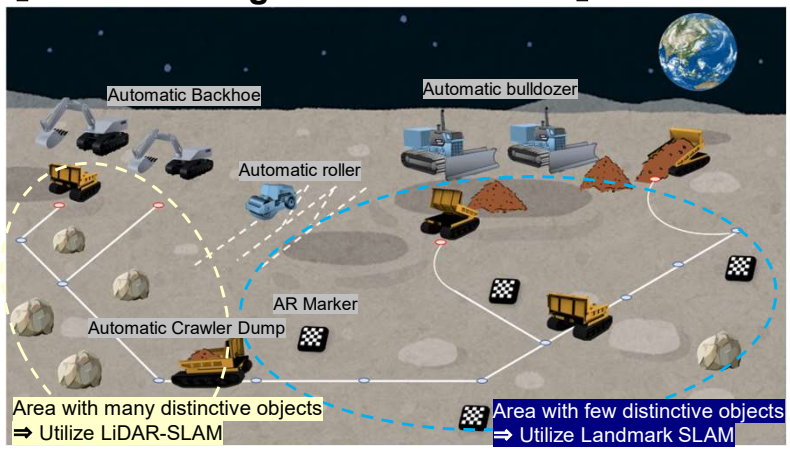
【Application image on the earth】

LiDAR-SLAM demonstration in a tunnel

LiDAR-SLAM demonstration in mountainous area



【Practical image on lunar surface】



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

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

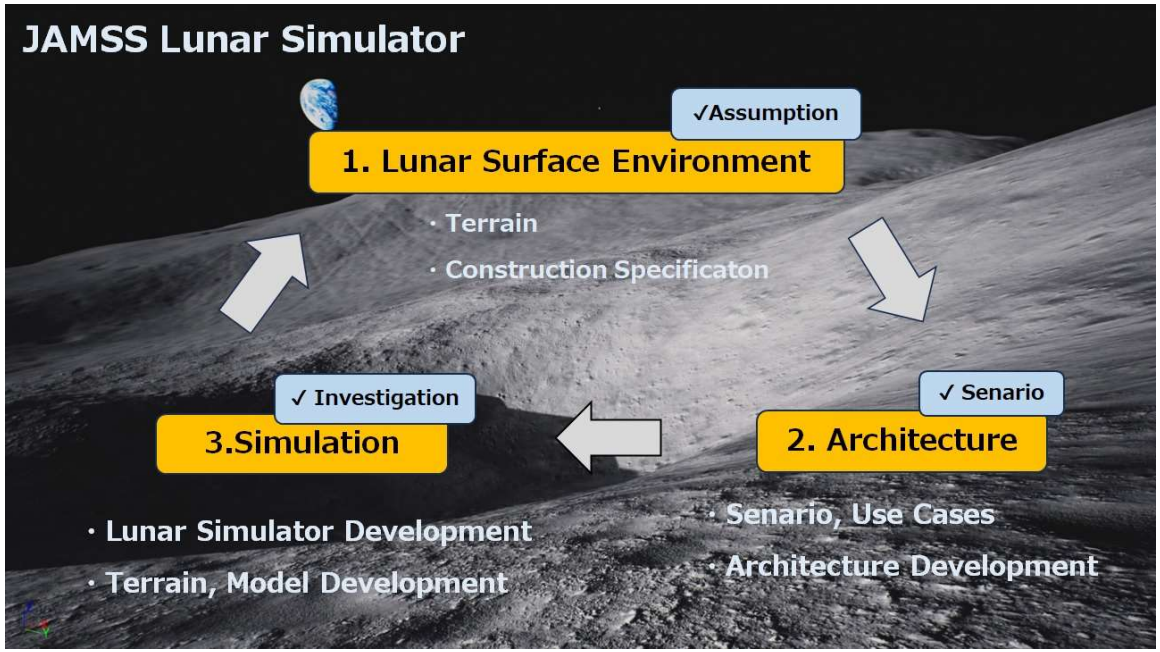
【Objective・Summary】

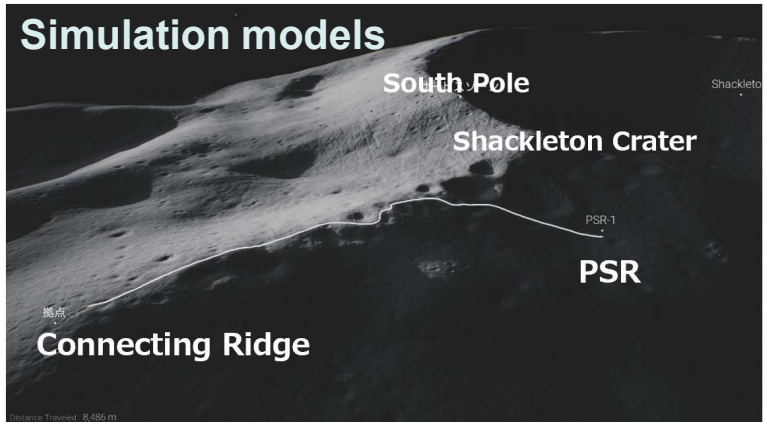
Develop the Lunar simulator and simulation model construction, in order to overcome the challenge, there is no lunar simulator that everyone can use easily.

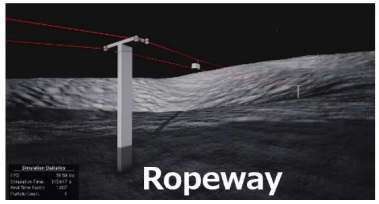
【Content・Point】

Iterating 1) Assuming the lunar surface environment, 2) building the overall scenario, and 3) building the lunar surface model, we are developing and maturing our Lunar simulator with considering the actual terrain around the South pole, the resource extraction area in PSR, the impact of soft ground of regolith, by simulating regolith transportation routes by rovers and ropeways.
We will make our Lunar simulator and terrain model as an application software finally.

【Development image】





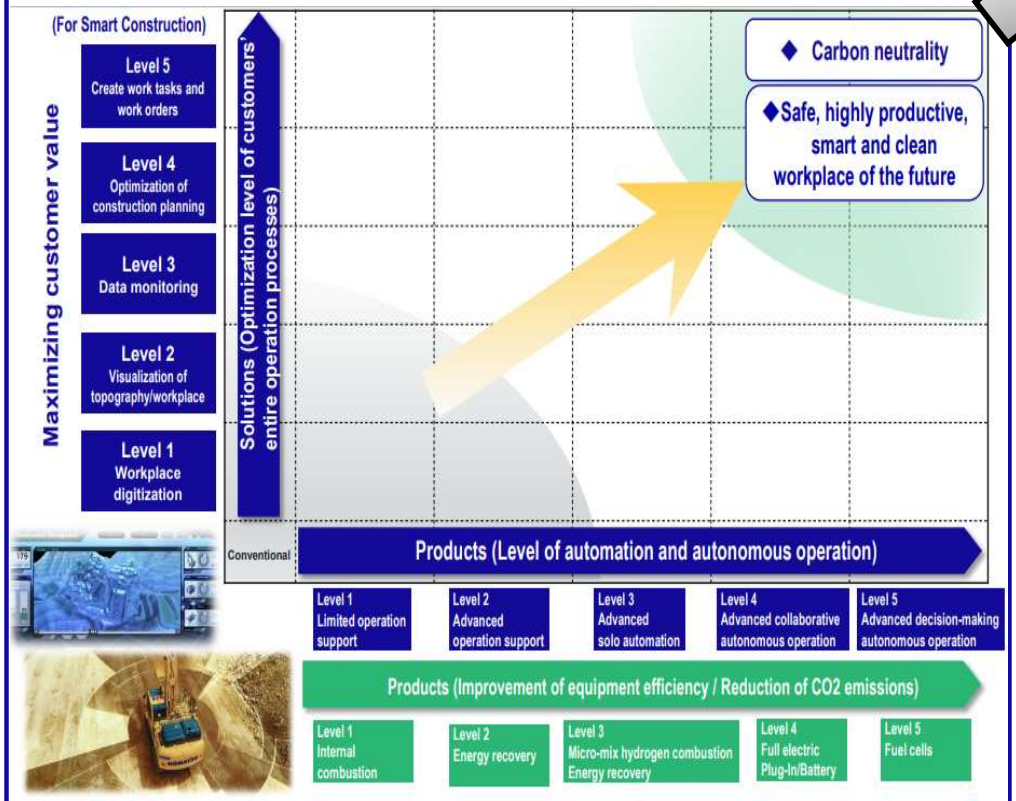


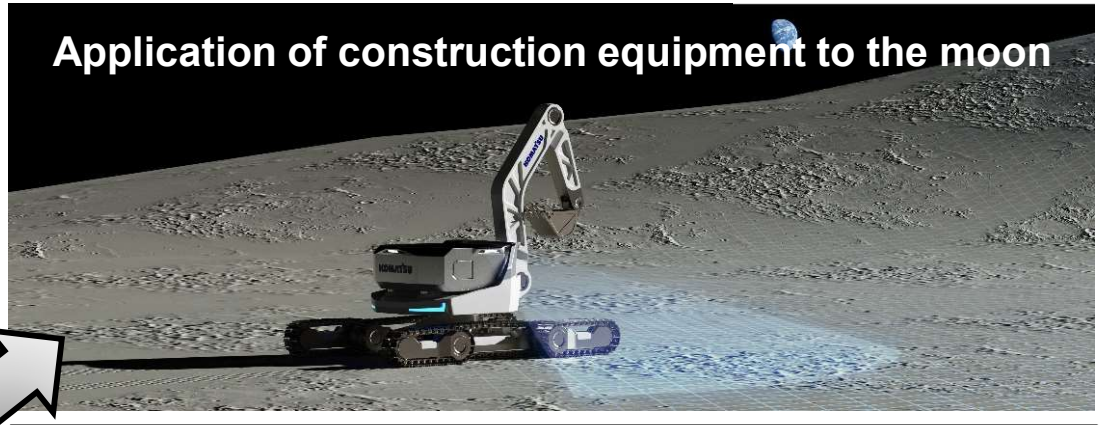
○Technology：[I] automatic and remote operation – construction equipment and construction ○Phase：R&D（Research and Development）

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

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】

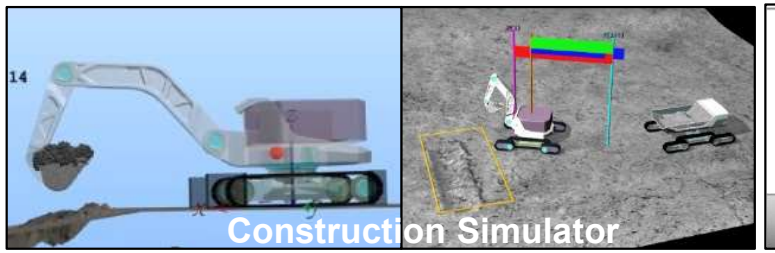
Because of the difficulty of reproducing a lunar environment on the Earth, it is essential to develop "**digital twin technology**" that accurately simulates the lunar construction equipment and its workspaces.

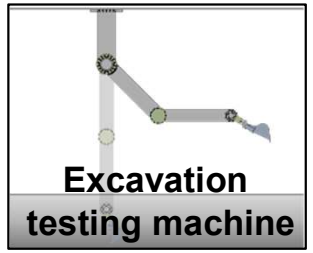
In this R&D, we **add the necessary functions and improve the accuracy** for developing lunar construction equipment and unmanned autonomous construction technology to the simulator developed at the F/S in FY2021 and use the simulator to study lunar construction equipment.

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

【Content/Point for FY 2024 and Beyond】

1. Building upon last year's digital-twin simulator, we aim to create a more advanced construction simulator that simulates a wider range of tasks, such as excavation, transportation, and loading. And we will conduct specific examinations to realize a lunar construction machinery.
2. In preparation for excavation tests on lunar surface, we will develop a small and lightweight excavation testing machine whose components and materials suitable for the lunar surface.





○Technology： Unmanned Construction (Automation/Remote)　　○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

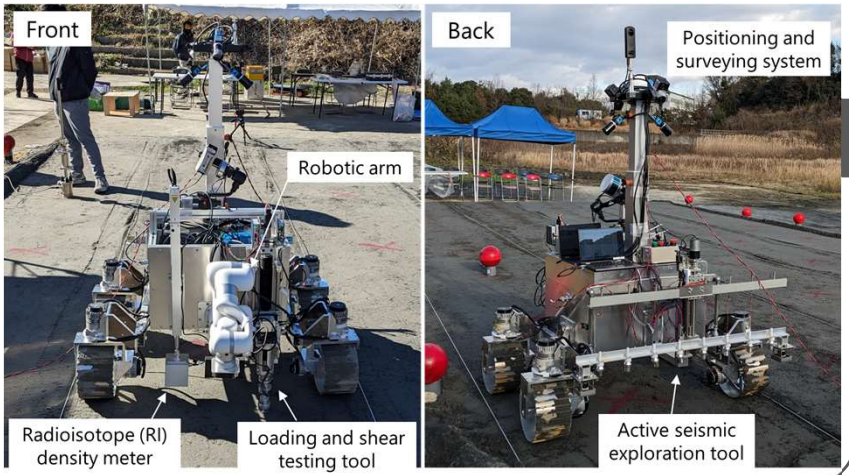
- The lunar surface remains largely unexplored in terms of soil mechanics, geology and topography.
- **Geological and geotechnical risk assessment and management are essential** to ensure the safety of lunar surface activities.

【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**.

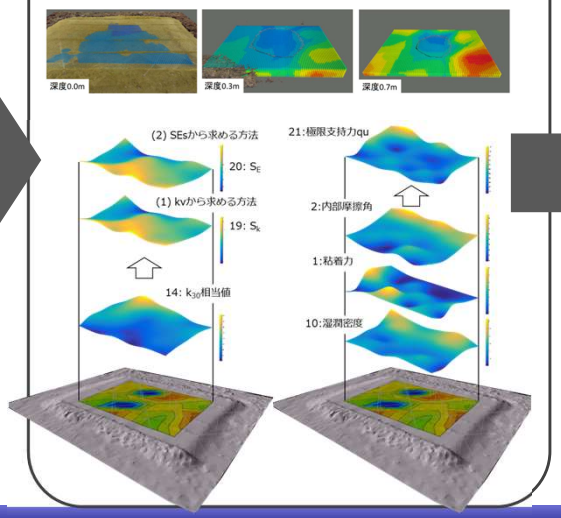
RGIS: Robotic Geotechnical Investigation System

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



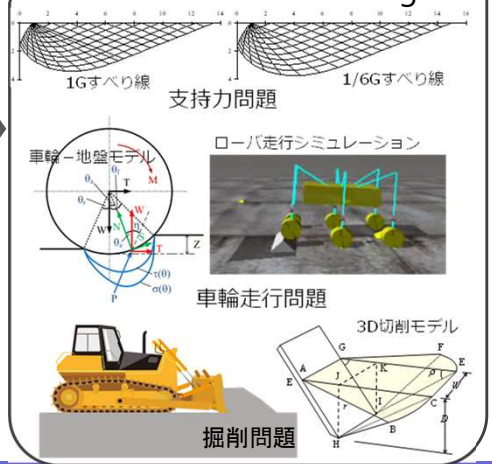
3D subsurface geological and geotechnical model

Mapping, Modelling, GIS, and BIM



Data utilizations

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



○Technology：I Unmanned construction (Automation・remote) –Transportation (survey)　○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

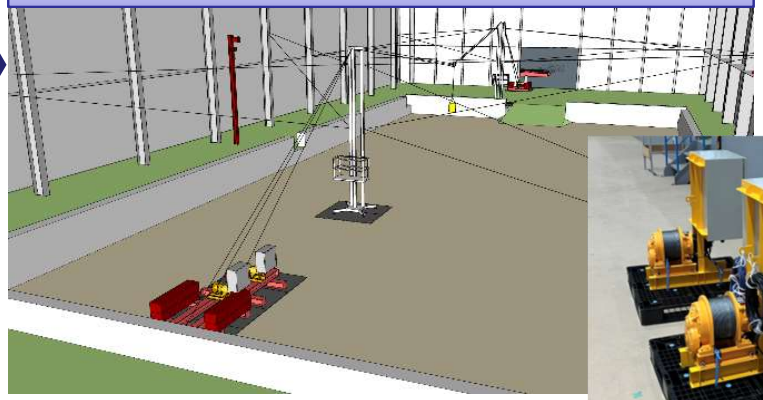
Sandbags are frequently used to protect slopes as emergency restoration measures in times of disaster, but they are often transported manually, which requires a great deal of labor and is not rapid

Problem solving

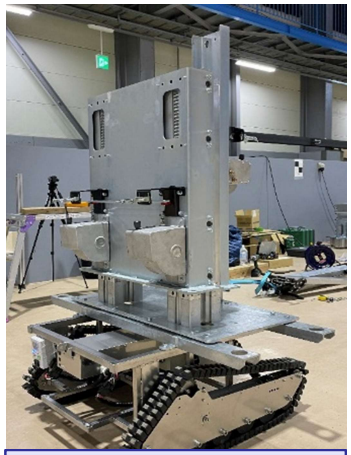
Simple strut and winch

Japan's own idea

Transport test using simple strut for cableway technology



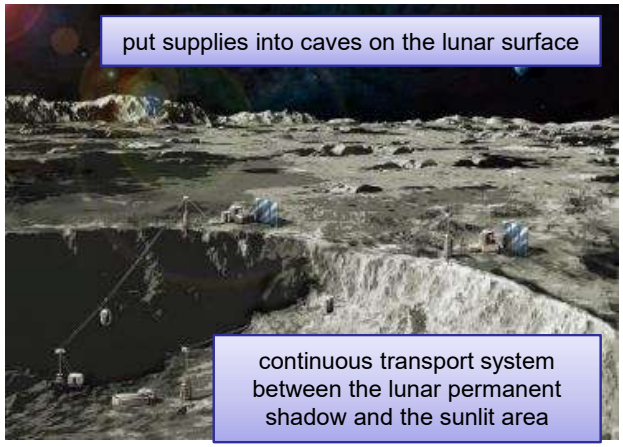
Servomotor winch



Transport mechanism of simple strut

【Implementation image】

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



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

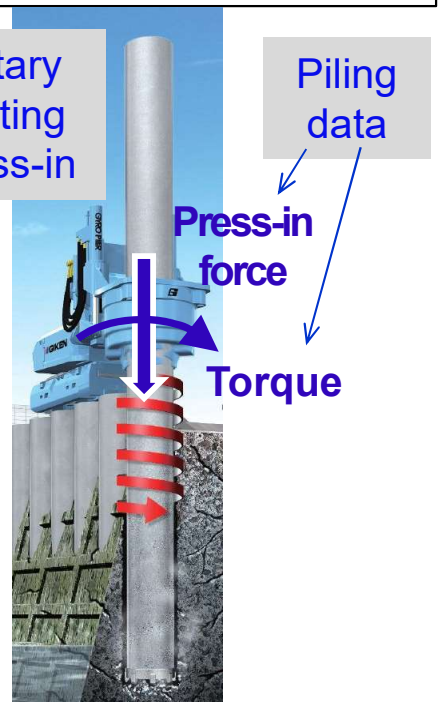
Project name	Proposal and assessment of rational process of design and construction for construction projects on the Moon, by the use of piling data in Rotary Cutting Press-in
Practitioner	**Representative:　GIKEN LTD.**

【 Aims in FY2022～2025 】

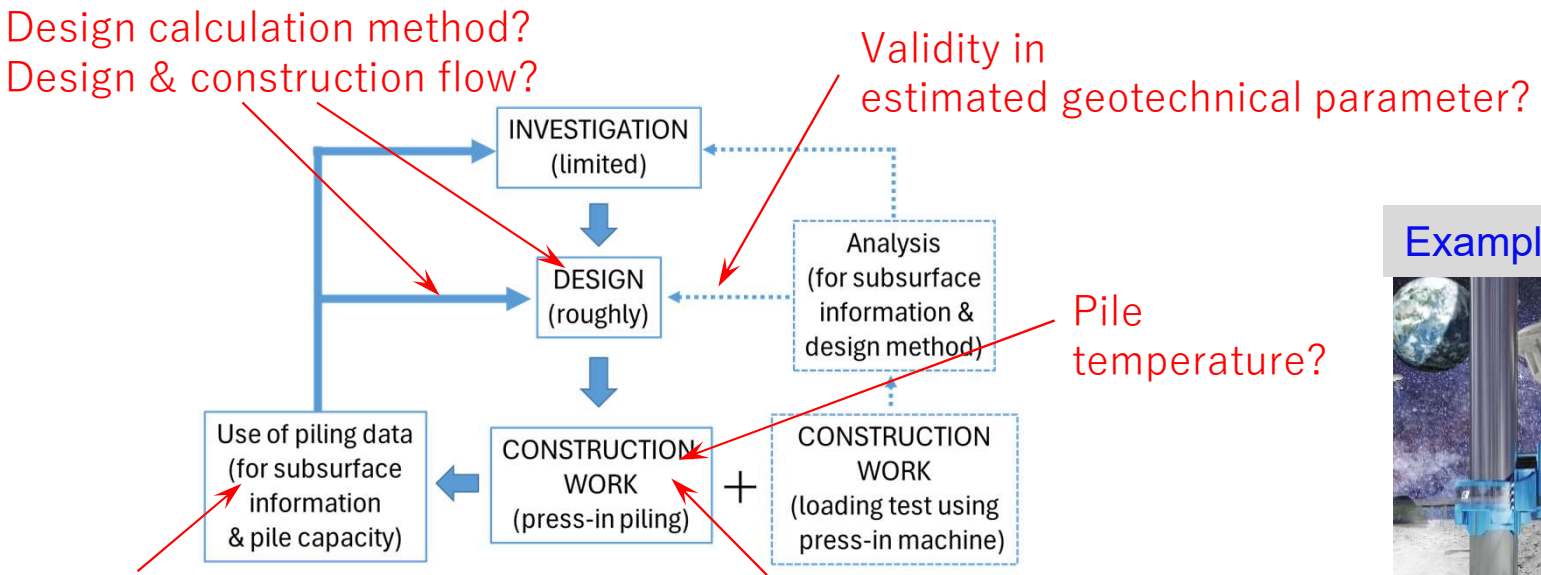
Establish the technology to rationalize the design and construction process by using information during construction work, and secure its applicability to the Moon.

【 Key points in FY2022～2025 】

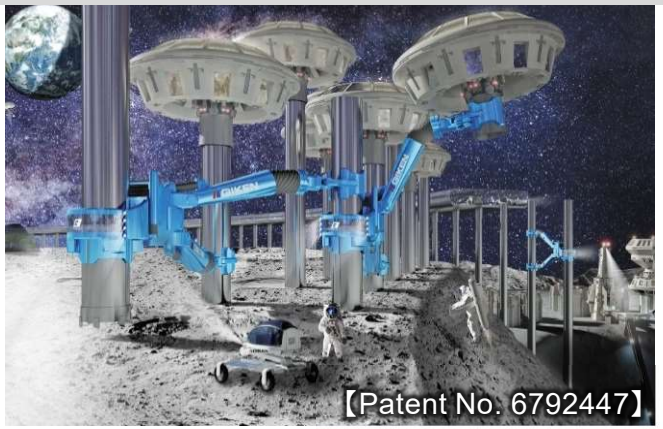
- ✓ Field tests to validate the technology of the use of piling data (estimating subsurface information & pile capacity / autonomous operation)
- ✓ Field tests to establish “simplified load test” using press-in machine
- ✓ Case study of design and construction on the Moon



【 Viewpoints in FY2024 】



Example of possible infrastructure



○Technology Classification: II Building materials manufacturing　○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 activities.** Therefore, we are conducting R&D on a technology that **uses lunar regolith** as a material, heats regorith **with microwaves, lasers, etc.** using solar power energy**, produces a product on site**, and uses this **as a construction material.**

【Content・Point】

We will improve **the quality and manufacturing efficiency** of heating manufacturing technology using lasers, microwaves, etc. , and verify **its applicability in lunar environments such as vacuum and low gravity.** We will also proceed with the development of **materials other than heated products,** such as inorganic fibers. Furthermore, we will clarify the superiority of this technology over similar technologies

【Implementation image】

Lunar simulant

Simulated moon sand was used for the test.

Mare simulant

High land simulant

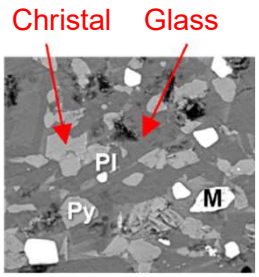
Development of construction material manufacturing system using microwaves

We will examine manufacturing conditions that can improve the quality of heated products, as well as manufacturing testing methods in vacuum and low gravity.

Microwave production test under high vacuum

Specimen manufactured under vacuum

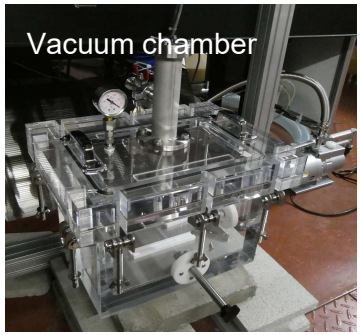
Chemical structure analysis



Development of construction material manufacturing system using laser

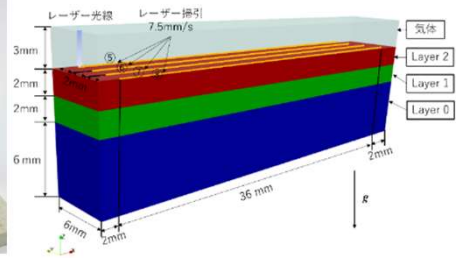
We are investigating diversifying shapes, improving bending strength through laser reheating, testing additive manufacturing in a vacuum, and simulating powder transport and additive manufacturing.

Laser additive manufacturing test in vacuum



Test production of various shapes of objects

Simulation of laser manufacturing in 1/6g and vacuum condition.



Development of manufacturing methods other than heat technology

We will develop inorganic fibers, which have many potential applications..

○Technology： Fast Structure Deployment – Inflatable membrane　　○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.

【Content・Point】

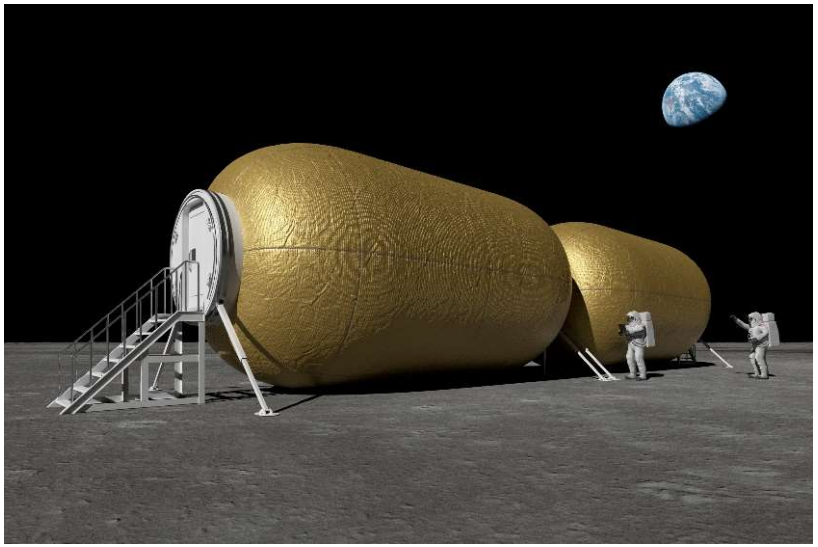
Based on the technical issues identified in the 2021 feasibility study phase, our team will develop (1) a high-strength flexible structure that can withstand the severe environment on the moon while maintaining a pressurized habitable room, (2) an autonomous decentralized status monitoring and deployment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

Initial State (Folded)　Intermediate State (Various Shapes)　Final Stage (Unfolded)

Unfolding and deploying 1/10 scale mockup

Numerical Analyses on Inflatable Structures

【Implementation image】



Inflatable Lunar Habitat Module (Image)

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

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, Muroran Institute of Technology, 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】

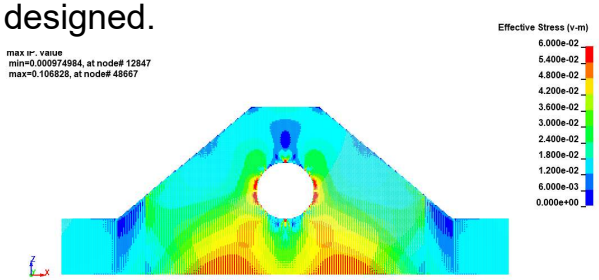
A test of an advanced bread board model (BBM) a self-deployable multipurpose tower using CFRP bistable booms to confirm its deployable function of the booms and SAP panels is successfully confirmed, and a real size CFRP bistable boom manufacturing is undergoing (up to half size now).

Test fabrication of half size CFRP bistable booms

BBM of the advanced deployable tower

【Pressurized structure】

To confirm mechanical behavior of the self-deployable membrane structure buried under the Lunar regolith, structural analyses of the membrane and regolith are done, and its feasibility is confirmed. In addition, a deployable inner flame including walls and floors inside the membrane structure is newly developed and its BBM is designed.



An example of structural analysis results (stress)

A fundamental BBM of the inner structures (more authentic model is undergoing)

○Technology：Ⅲ　○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.