Space construction innovation project (image diagram)

FY2023 Research & Development List

F/S・・・Feasibility Study【1 year】
R&D・・・Research & Development 【For multiple years】

Technology classification		Project name	Practitioner (○Representative, Co-implementer)	Phase
Technology I:Unmanned construction (Autonomous and remote)	Construction (excavation, loading, etc.)	**Development of Autonomous and Remote Construction Technology Adaptable to the Construction Environment - Application of Next Generation Construction System for Space**	**○Kajima Technical Research Institute Japan Aerospace Exploration Agency, Shibaura Institute of Technology**	R&D (continuation)
	Construction (spreading, etc.)	**Development of Environment Recognition Infrastructure System for Autonomous Construction and Demonstration of Autonomous Construction**	**○Shimizu Corporation Bosch Engineering**	
	Construction (Positioning)	**Development of SLAM Autonomous Driving Technology for Lunar Surface Adaptation**	**○Taisei Corporation Panasonic Advanced Technology Co., Ltd.**	R&D (transition from F/S)
	Construction (Whole system)	**Lunar Construction Simulator**	**○Japan Manned Space Systems Corporation**	
	Construction equipment and construction	**Research and Development for Lunar Construction Equipment using Digital Twin Technology**	**○Komatsu Ltd.**	R&D (continuation)
	Surveying/survey	**Methods for Topographic Survey and Geotechnical Investigation for Constructing 3D subsurface Geological and Geotechnical Model on the Moon**	**○Ritsumeikan University 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**	
	Transportation (survey)	**Development of Disaster Response Transportation Technology using Cableway Technology**	**○Kumagai Gumi Co., Ltd. Sumitomo Forestry Co., Ltd., KYC MACHINE INDUSTRY CO., LTD., KATO WORKS CO., LTD., Kogakuin University**	
	Foundation (survey)	**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**	**○GIKEN LTD.**	
Technology II: Production of building materials		**Technical Development of Production and Construction Methods for Moon Base Construction Materials using Lunar Resources**	**○Obayashi Corporation Nagoya Institute of Technology, Institute for Laser Technology**	
Technology III: Simple facility		**On-Ground Testbed Development of an Inflatable Lunar Habitat Module**	**○Shimizu Corporation Taiyo Kogyo Corporation, Tokyo University of Science**	
		Requirement Definitions of Deployable Structures and R&D of Unmanned Setup System on Lunar Surface	**○Obayashi Corporation Japan Aerospace Exploration Agency, Muroran Institute of Technology, Sakase AdTech Co., Ltd.**	
		Minimal Composition and Deployment Mechanisms for the Base Camp Embedded into the Lava Tube on the Moon	**○The University of Tokyo Kyushu University, Japan Aerospace Exploration Agency**	R&D (transition from F/S)

○Technology I : Unmanned construction(Autonomous and remote) - Construction(excavation, loading, etc.)

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** Co-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.

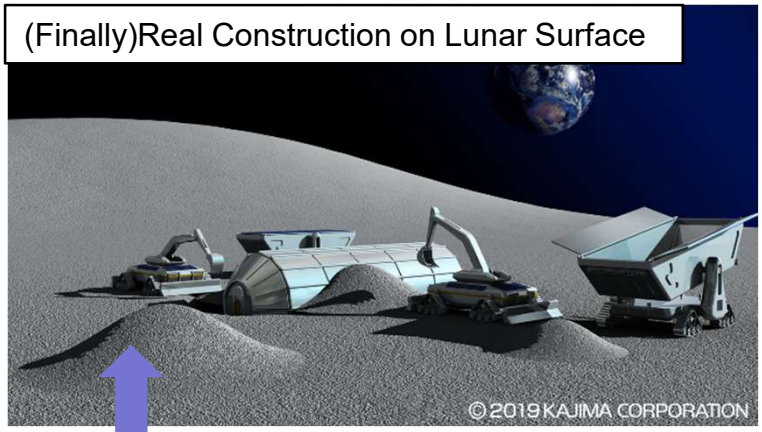
Three steps of our research project

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**
- **…**

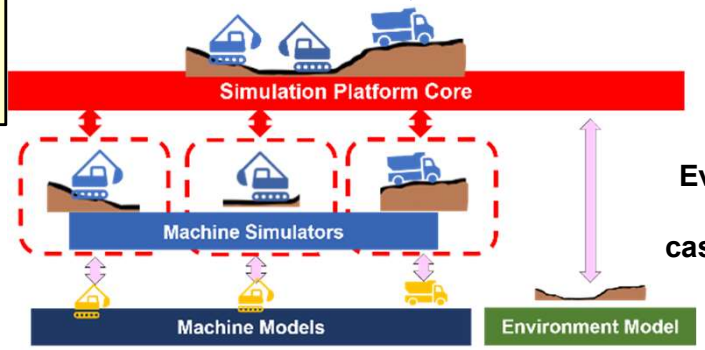
(Finally)Real Construction on Lunar Surface



Realization as digital twin system

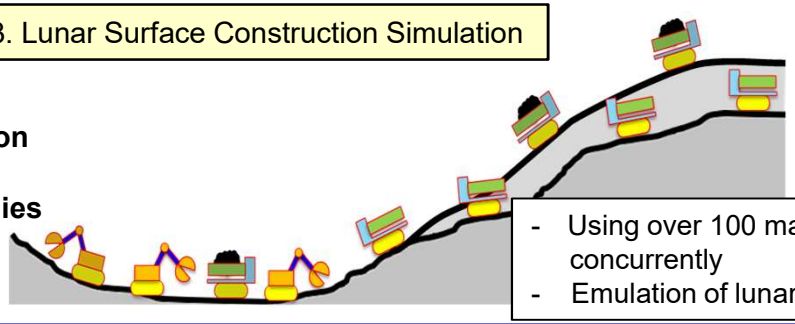
Simulation of the experiments on Earth

2. Build a simulation platform



Evaluation with case studies

3. Lunar Surface Construction Simulation



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

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

Project name	Development of Environment Recognition Infrastructure System for Autonomous Construction and Demonstration of Autonomous 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 on the construction machinery enables near-autonomous decentralized construction and recognition systems for special environments such as the Moon. 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

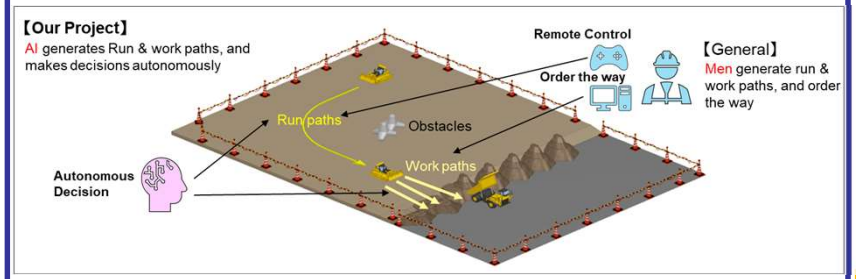
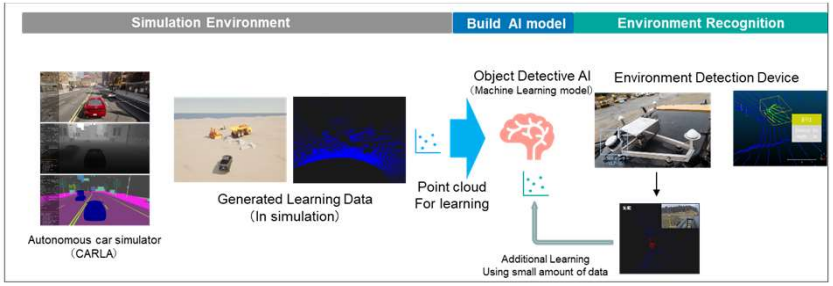


Image ：Autonomous construction in embankment work

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



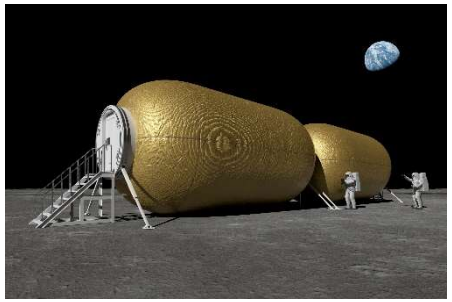
【In simulation】

Object detection technology using point cloud data

【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(Autonomous and remote) - Construction(Positioning)

Project name	Development of SLAM Autonomous Driving Technology for Lunar Surface Adaptation
Practitioner	**Representative:Taisei Corporation** Co-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】

The results obtained from the feasibility study by simulation will be verified. We are planning "self-position estimation experiments" and "marker detection experiments" in locations that simulate the lunar and ground environments.

【Implementation image】

Lunar environment

"Self-localization experiment" using a small UGV is planned at the Tottori Sand Dunes Lunar Field.

Lunar Demonstration Field "Luna Terrace" (from Tottori Pref. HP)

"Marker detection experiment" using artificial solar lights is planned at JAXA Exploration Laboratory.

Space Exploration Laboratory (from JAXA HP)

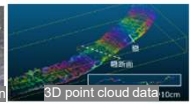
Ground environment

"Self-localization experiment" and "marker detection experiment" are planned at the experimental field simulating a construction site.

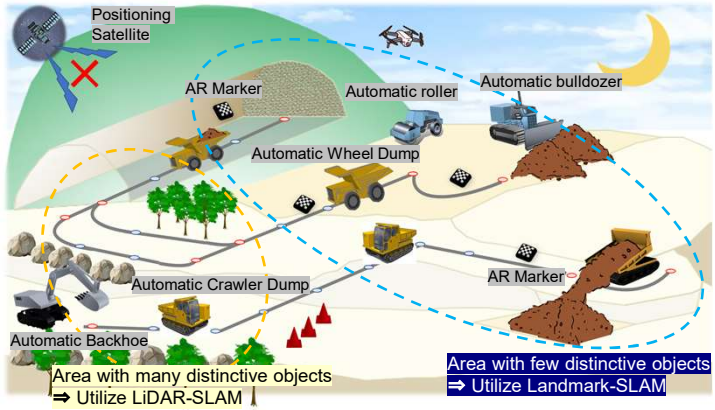
UGV : Unmanned Ground Vehicle)

【Application image on the earth】

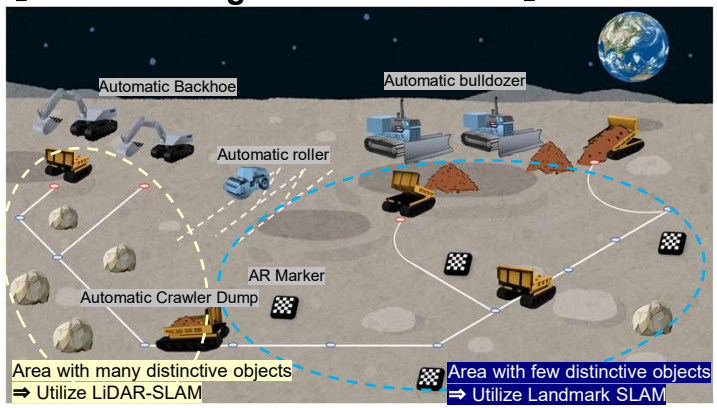
LiDAR-SLAM demonstration in a tunnel



LiDAR-SLAM demonstration in mountainous area



【Practical image on lunar surface】



○Technology I : Unmanned construction(Autonomous and remote) - Construction(Whole system)

Project name	Lunar Construction Simulator
Practitioner	Japan Manned Space Systems Corporation (JAMSS)

【Objective・Summary】

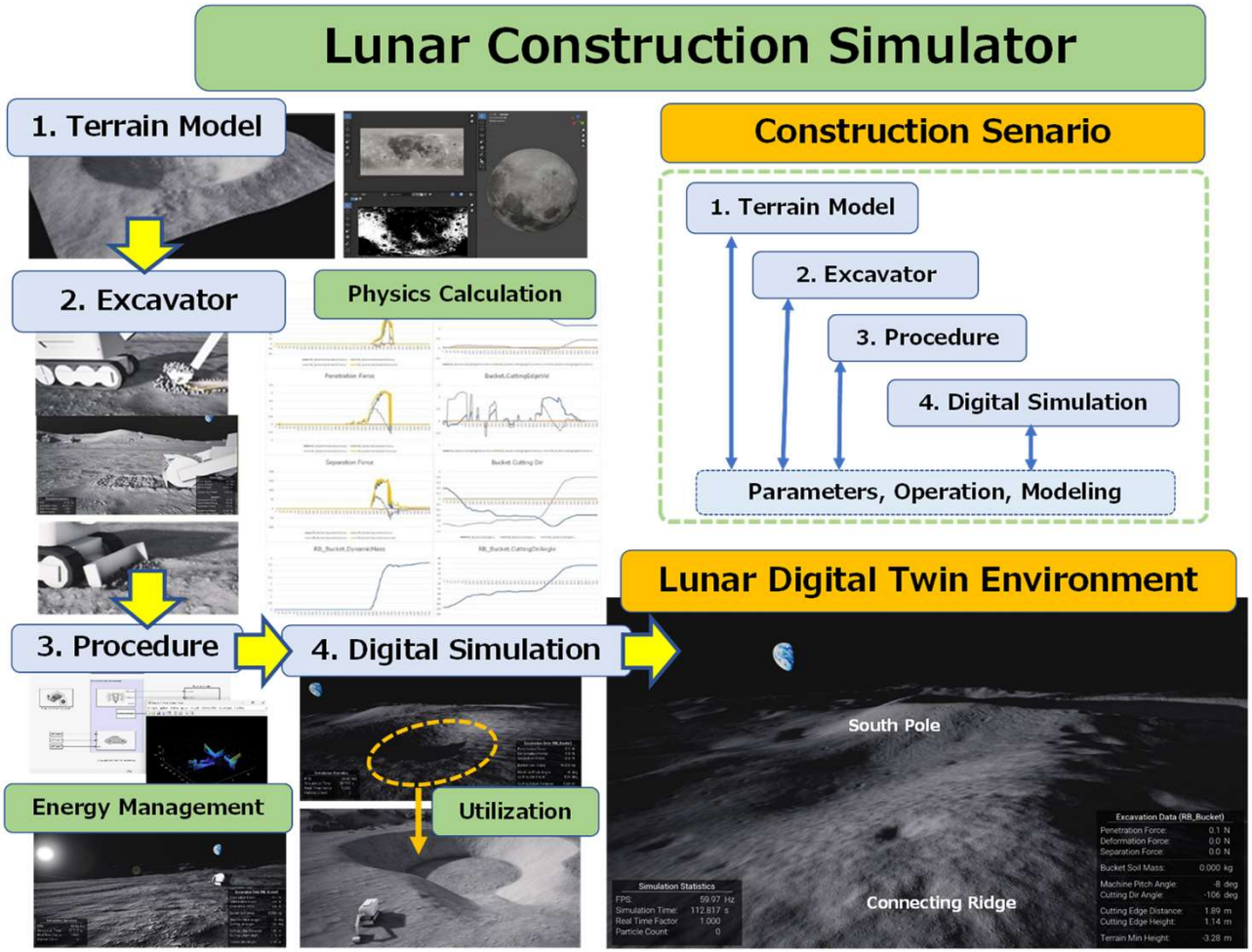
Assuming actual resource extraction sites and potential landing sites in the lunar south pole, taking into account the terrain gradient and sunlight environment.

【Content・Point】

Using the digital twin environment on the lunar surface, we will consider automating transportation, construction, assembly, startup, and operation after landing in the lunar south pole.

The aim is to develop mutually with terrestrial technology by establishing automatic and autonomous technology for environments without positioning and at a high level.

【Implementation image】

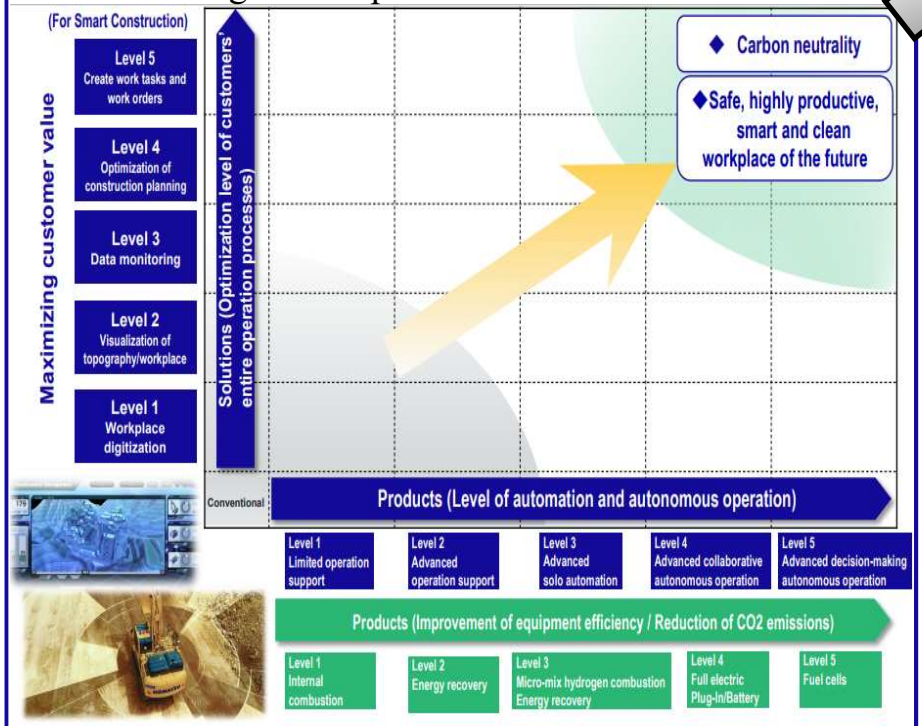


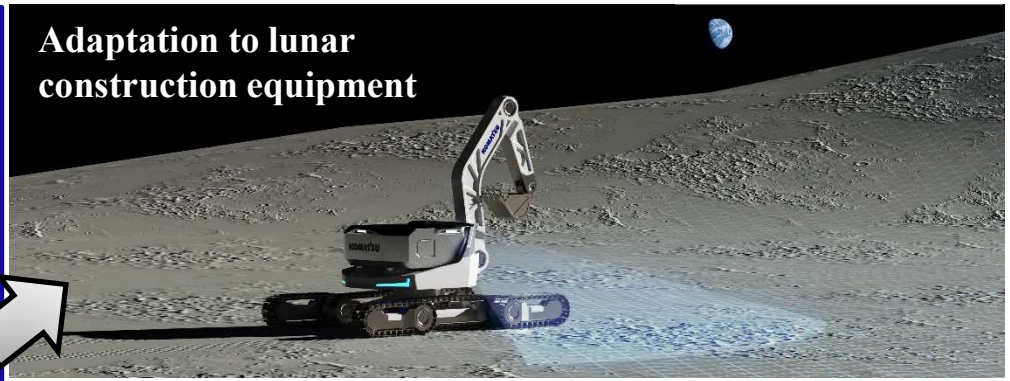
○Technology I : Unmanned construction(Autonomous and remote) - Construction equipment and construction

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.





[Purpose/Outline]

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 for developing lunar construction equipment and unmanned autonomous construction technology and improve the accuracy of 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]

①We improve the accuracy of the simulator for an excavator operating in cyberspace created in FY2021 and respond to the addition of functions necessary for the study of lunar construction equipment and the change of the shape and size of construction equipment.
②We use this simulator to examine how to solve the issues extracted for lunar construction equipment and verify the validity and feasibility of the measures.

- **Shape**
- **Size**
- **Weight balance**
- **Digging method**

○Technology I : Unmanned construction(Autonomous and remote) - Surveying/survey

Project name	**Methods for Topographic Survey and Geotechnical Investigation for Constructing 3D subsurface Geological and Geotechnical Model on the Moon**
Practitioner	**Representative: Ritsumeikan University** Co-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 uncharted regarding soil mechanics, geology and topography.
- **Geological and geotechnical risk assessment/management are essential** for ensuring the safety of lunar surface activities.

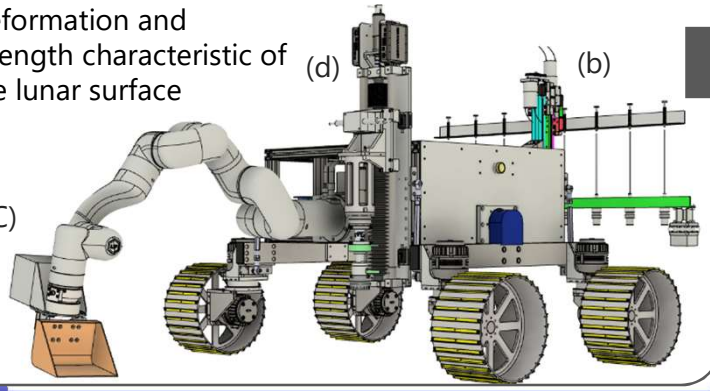
【Content-Point】

- Developing a **geotechnical engineering scheme that covers the entire process, from the acquisition of topographical and geotechnical data to utilization of data** in planning and design of lunar surface activities.
- Developing an investigation strategy aimed at enabling **reliability design considering the uncertainties of lunar surface**.

RGIS: Robotic Geotechnical Investigation System

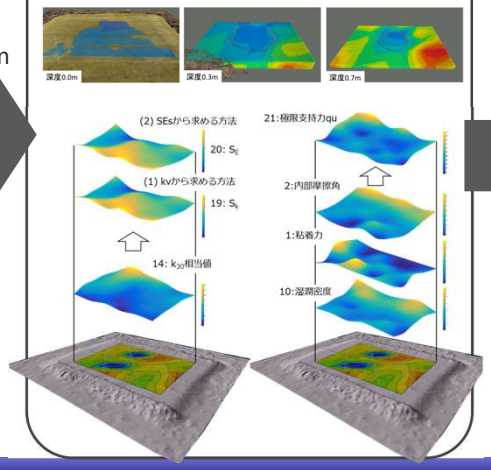
Micro-topography/
Subsurface Stratigraphy/
Soil bulk density/
Deformation and strength characteristic of the lunar surface

(a) Positioning and surveying system
(b) Active seismic survey system
(c) RI (Radio Isotope) density meter
(d) Plate loading and shear testing system



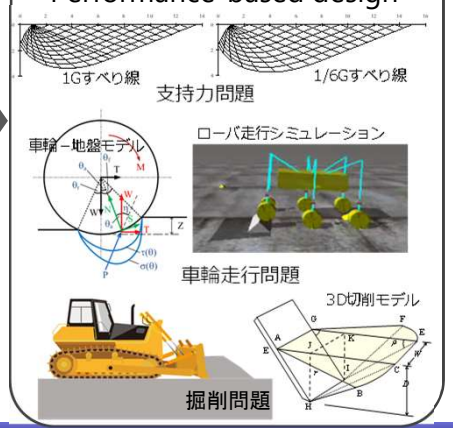
3D subsurface geological and geotechnical model

Mapping/Modelling/ GIS/BIM



Data utilizations

Prediction/Simulation/
Reliability analysis/
Performance-based design



○Technology I : Unmanned construction(Autonomous and remote) - Transportation(survey)

Project name	Development of Disaster Response Transportation Technology using Cableway Technology
Practitioner	**Representative: Kumagai Gumi Co.,Ltd.** Co-implementer:Sumitomo Forestry Co., Ltd., KYC MACHINE INDUSTRY CO.,LTD., KATO WORKS CO.,LTD., Kogakuin University

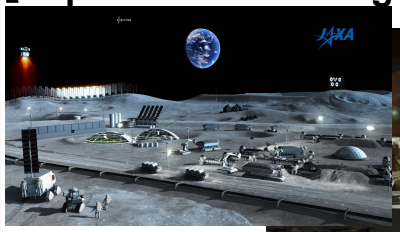
【Objective・Summary】

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.

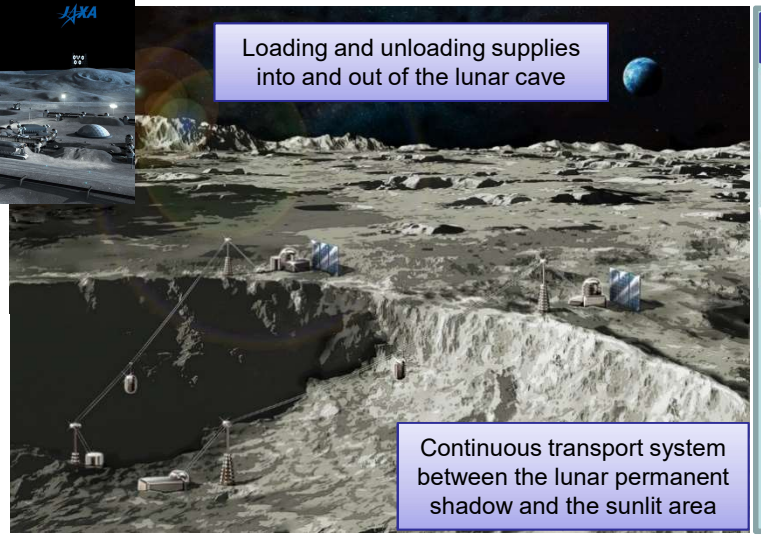
【Content・Point】

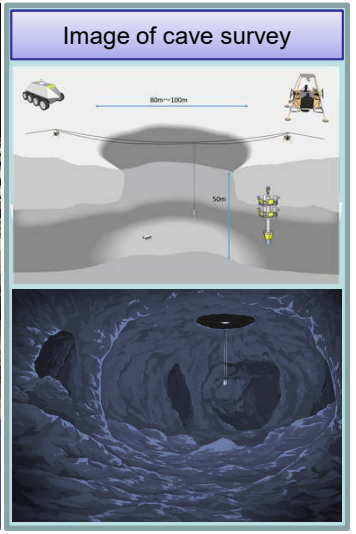
Technology that enables rapid and efficient transportation when a disaster strikes is highly needed in society, such as for early restoration of infrastructure and other facilities. On the ground, the goal is to develop a technology that enables early restoration of infrastructure and other facilities 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.

【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.



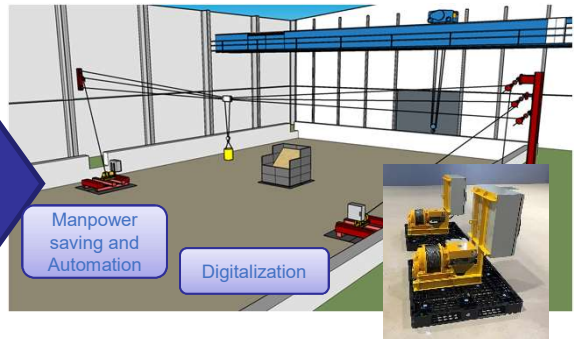


Japan's own idea

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



Cableway transport test using a simple prop

○Technology I : Unmanned construction(Autonomous and remote) - Foundation(survey)

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	**GIKEN LTD.**

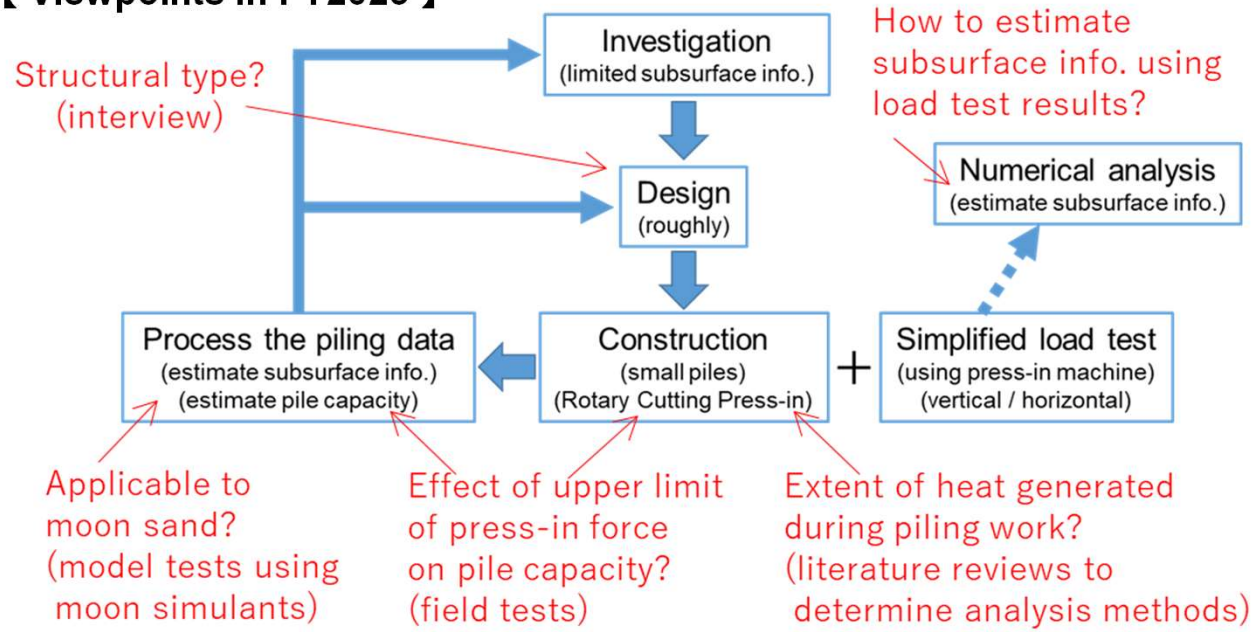
【 Aims in FY2022～2025 】

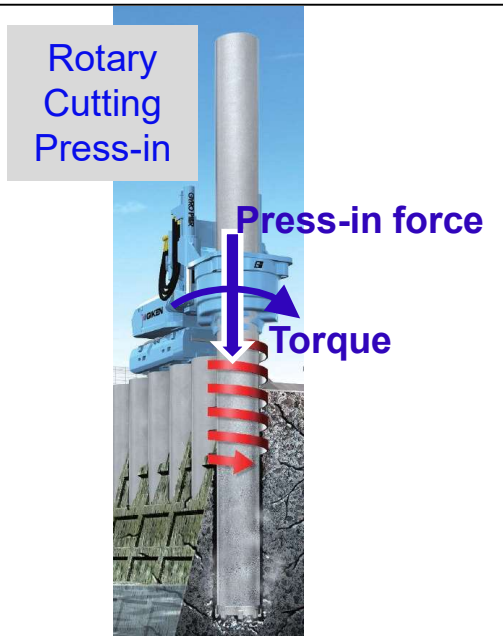
Establish the technology to rationalize the design and construction by using piling data, and secure its applicability to the moon.

【 Key points in FY2022～2025 】

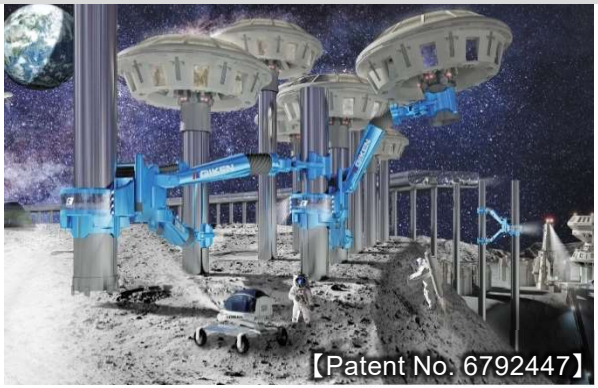
- ✓ Field tests to validate the technology of the use of piling data (estimating subsurface information & pile capacity / autonomous operation)
- ✓ Field tests to establish “simplified load test” using press-in machine
- ✓ Case study of design and construction on the moon

【 Viewpoints in FY2023 】





Example of possible infrastructure



○Technology II : Production of building materials

Project name	Technical Development of Production and Construction Methods for Moon Base Construction Materials using Lunar Resources
Practitioner	**Representative: Obayashi Corporation** Co-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 fired 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.

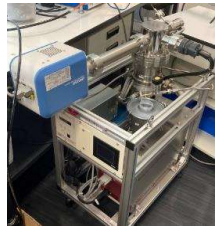
Development of construction material manufacturing system using microwaves

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

Analyzer for gases generated in vacuum

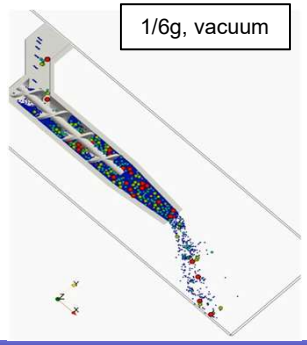


Development of construction material manufacturing system using laser

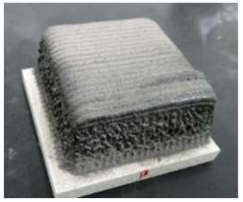
We will examine manufacturing conditions that can improve manufacturing efficiency, flexural strength, etc., and manufacturing methods that can be used in a vacuum.

Laser additive manufacturing test using a robot arm

Powder conveyance simulation in vacuum/low gravity.



Laser additive manufacturing specimen



Development of manufacturing methods other than heat technology

Research is currently being carried out on materials such as lunar concrete, geopolymers, sulfur concrete, and polymer concrete, but we will continue to develop inorganic fibers that are expected to have many uses.

○Technology III : Simple facility

Project name	On-Ground Testbed Development of an Inflatable Lunar Habitat Module
Practitioner	**Representative: Shimizu Corporation** Co-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】

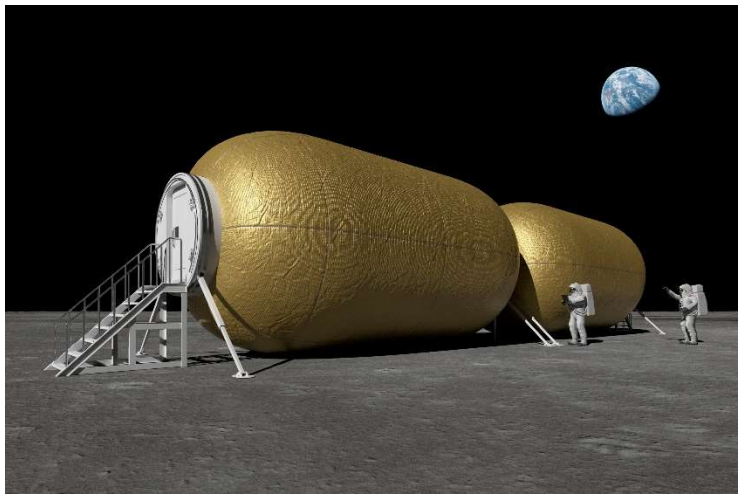
Based on the technical issues identified in the 2021 feasibility study phase, our team will develop (1) a high-strength flexible structure that can withstand the severe environment on the moon while maintaining a habitable room, (2) an autonomous decentralized status monitoring and shape control system,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

Project name	Requirement Definitions of Deployable Structures and R&D of Unmanned Setup System on Lunar Surface
Practitioner	**Representative: Obayashi Corporation** Co-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.

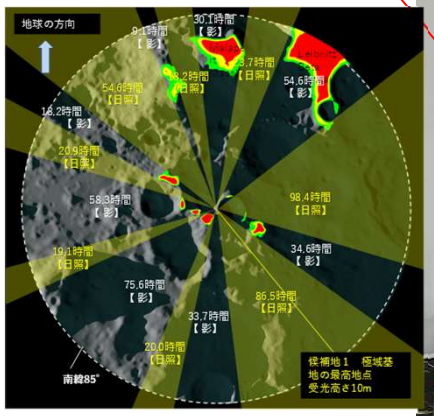
【Non-pressurized structure】

The development target in a non-pressurized structure type is a self-deployable multipurpose tower using CFRP bistable booms. The deployable function has been confirmed by a bread board model, and further study and real size fabrication tests are undergoing.

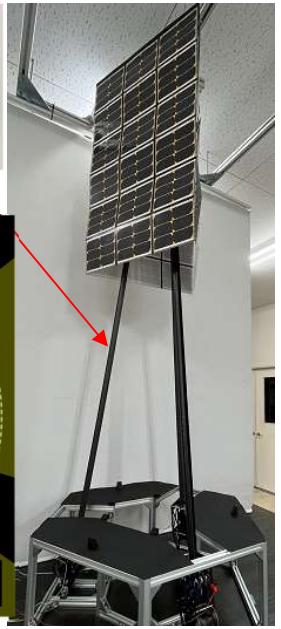
【Pressurized structure】

The development target in a pressurized structure type is a self-deployable membrane structure buried under the Lunar regolith.
The unmanned construction methods and self-deploying procedures have been contentiously studied using a Lunar surface digital twin model.

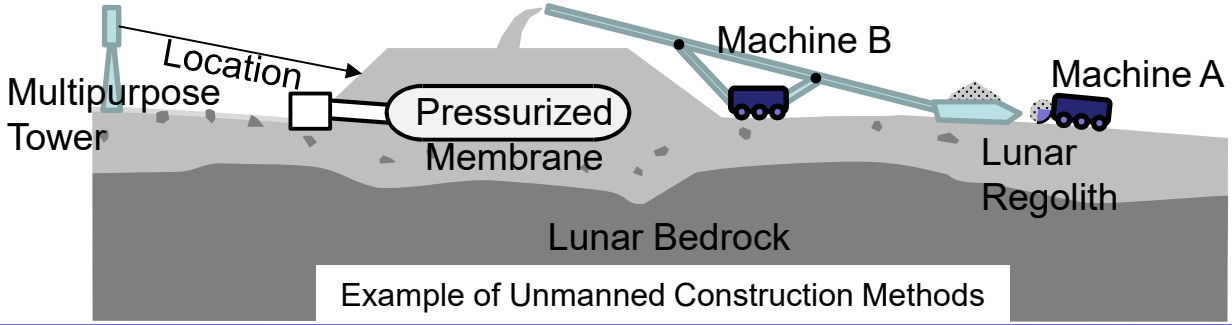
CFRP Bistable Boom



Sunshine Simulation for Solar Panel Locating



Bread Board Model of the Deployable Tower



Example of Unmanned Construction Methods

○Technology III : Simple facility

Project name	**Minimal Composition and Deployment Mechanisms for the Base Camp Embedded into the Lava Tube on the Moon**
Practitioner	**Representative: The University of Tokyo** Co-implementer: Kyushu University, Japan Aerospace Exploration Agency (JAXA)

【Objective・Summary】

The initial base camp on the moon can be composed as a minimum and deployable for quick establishment.
The camp supports remote construction that prepares the equipment for the long stay.
The dropping test using a mini mock-up can also be supposed.

【Content・Point】

A habitat module is installed into a lava tube, while infrastructures are installed on the surface. Each module is packed while transported, deploys passively, and touchdowns onto bumpy terrain. Cramped space is filled up with dense vegetation.
The full scale update will include the dimpled envelope, lifted floor, adjustable legs that deploy simultaneously, a cable lift, and earwig wing fanning panels.