Automated Site Preparation – ASPECT

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Introduction

Plans to return humans to the Moon involve landing large rockets on the lunar surface repeatably in the same area [1]. The exhaust plume of rocket landings on the natural lunar surface will eject regolith at high velocity and excavate material. The removal of material excavated grows rapidly with rocket size. At the size of anticipated human lunar landers, the rocket plume effect on the natural lunar surface is anticipated to pose a hazard to the lander and nearby structures. To mitigate these effects, it is expected that landing pads will be constructed.

The first step in construction on Earth and on the Moon is to clear, level, and compact the surface. The ASPECT project, Automated Site Preparation, Excavation, Compaction, and Testing, was selected by NASA LuSTR 2021 [2], has the goal to develop and demonstrate site lunar surface site preparation.

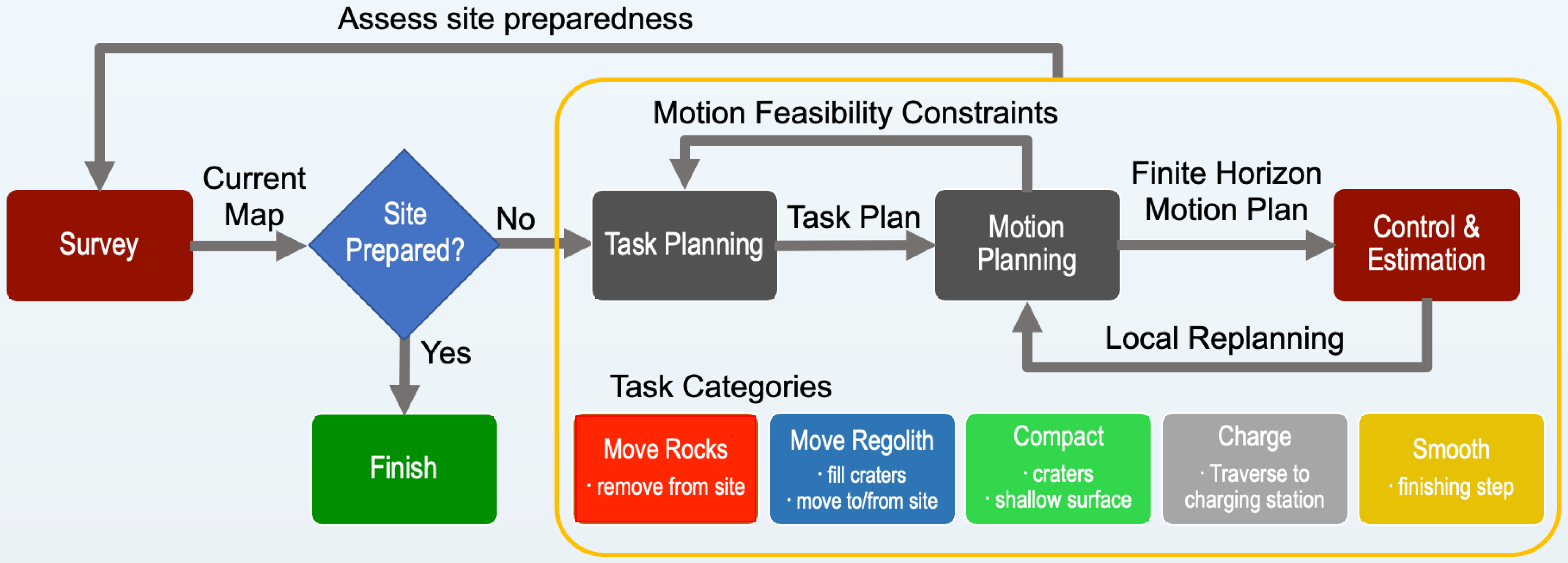
The lunar surface has been altered by meteorite impacts for billions of years. The surface is a fine-grained regolith that poses challenges for terramechanics, grading, and compaction. Lunar surface topography is highly variable over a wide range of length scales due to impact craters. Site preparation on the Moon will require the movement of regolith from high points to craters, the compaction of the regolith to a density suitable for load bearing and rendering the finished surface level and smooth.

Conops

ASPECT begins with a survey of the site and assessment of the deviation from preparation requirements (Figure 1). Task and motion planning algorithms formulate a plan, choosing a sequence of tasks Move Rocks, Move Regolith, Compact Surface, Charge, and Smooth Surface. When a task is complete site preparedness is surveyed again and the process repeats.

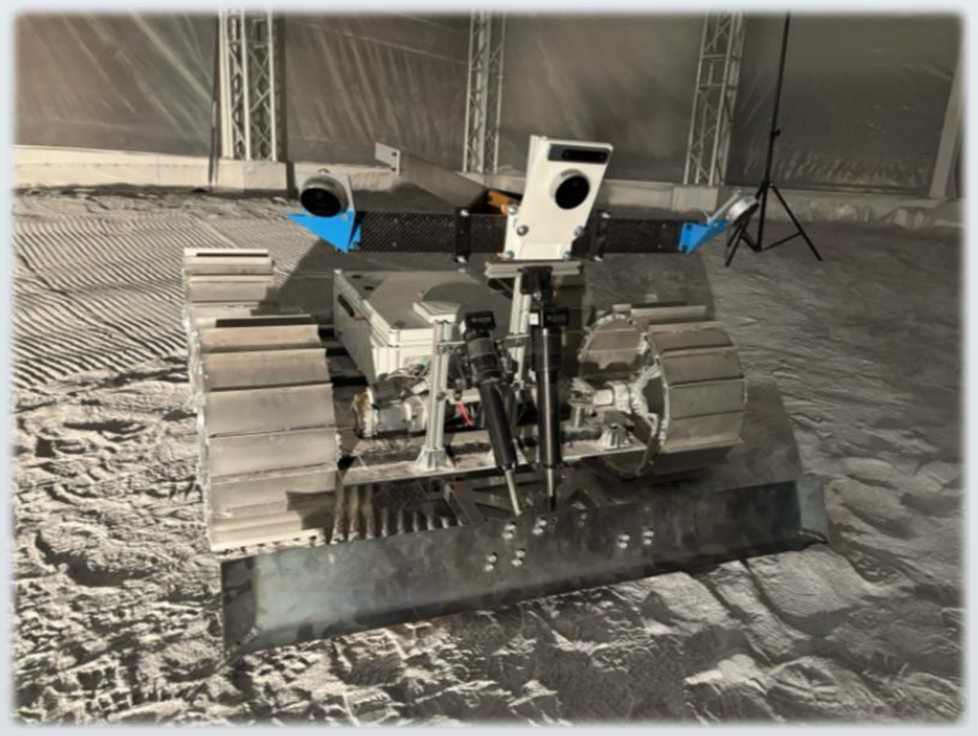
The LuSTR21 solicitation set several specific goals for the finished site:

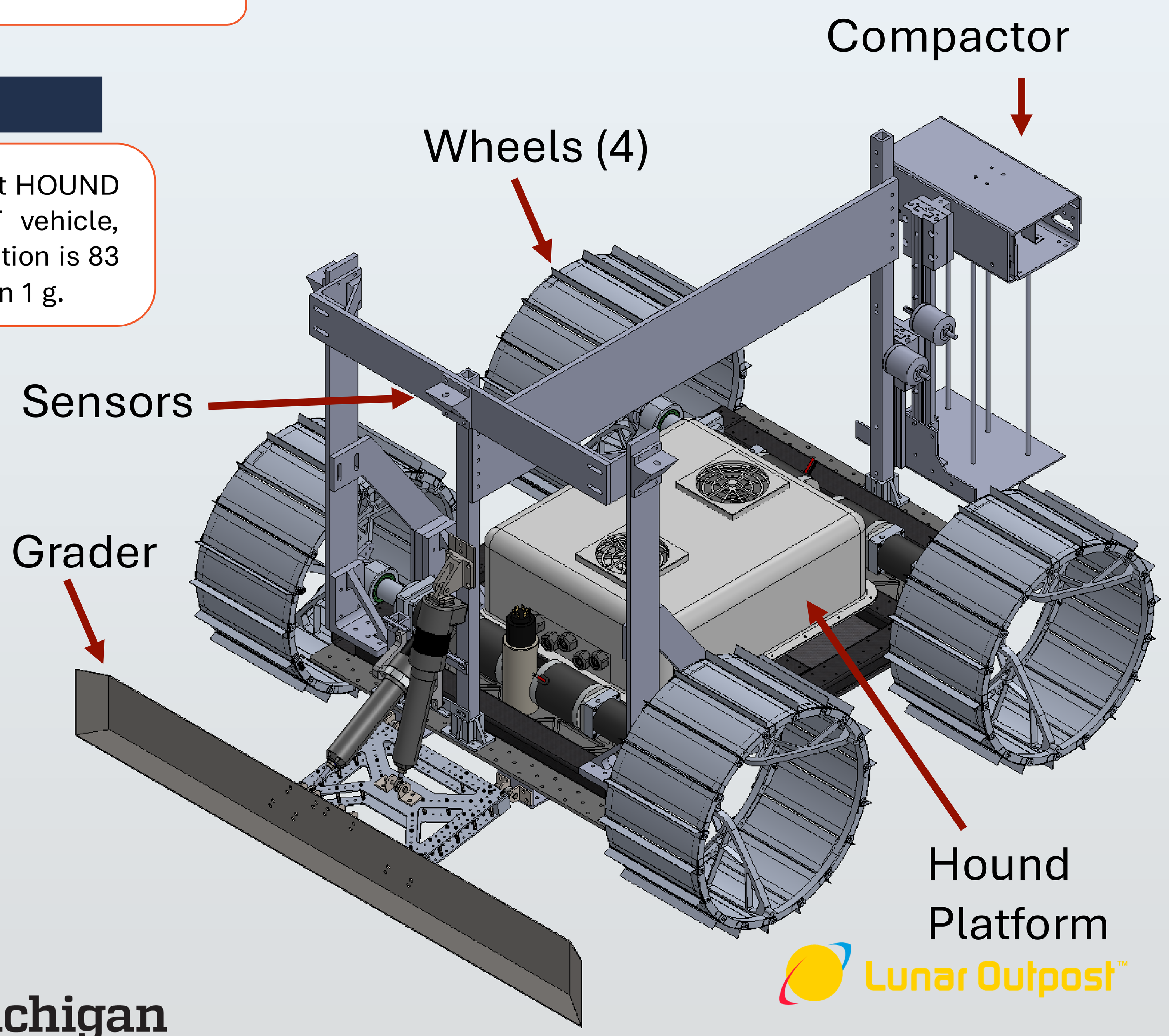
• Compact to 90% relative density to 30cm depth. • Level to within< 1 degrees. • Smooth to <1 cm RMS. • Demonstration of site preparation in a 10 m diameter area. • Prescribed number and size of craters and rocks in the site preparation area.



The ASPECT Rover

The ASPECT mobility platform is based on a Lunar Outpost HOUND with light weight modifications, Figure 2. The ASPECT vehicle, including regolith/rock manipulation, sensing, and compaction is 83 kg to simulate a 500 kg vehicle in lunar gravity while testing in 1 g.

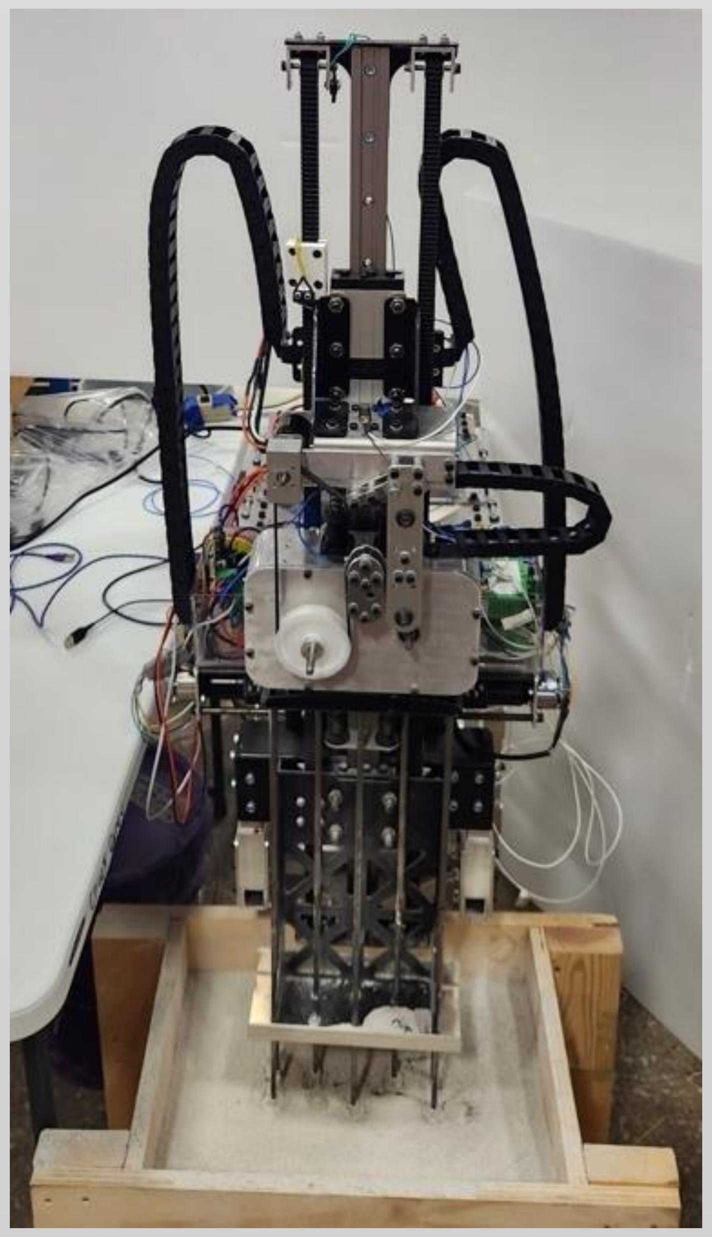




Compaction

The regolith is to be compacted to 90% relative density using a series of pins pressed into the surface aided with a pressure plate. Vibration of the pins causes the regolith particles to move more freely and the overburden and pressure result in compaction. The system is designed to automatically retract as the compaction state achieves the desired compaction level. The required pressure applied by the plate and vehicle mass limit the area that can be compacted per placement of the system. Full site compaction is achieved by repeated placements.

The final onboard system (Figure 3) mass is 22kg, and the system compacts a 200 cm2 area to a 30 cm depth per site. To date testing of compaction system has allowed for a maximum compaction of 87.5% relative density. Testing is ongoing, current efforts are to create a closed loop control utilizing acceleration profiles during testing to improve compaction achieved and improve efficiency.



Sensing and localization Mobility and Planning

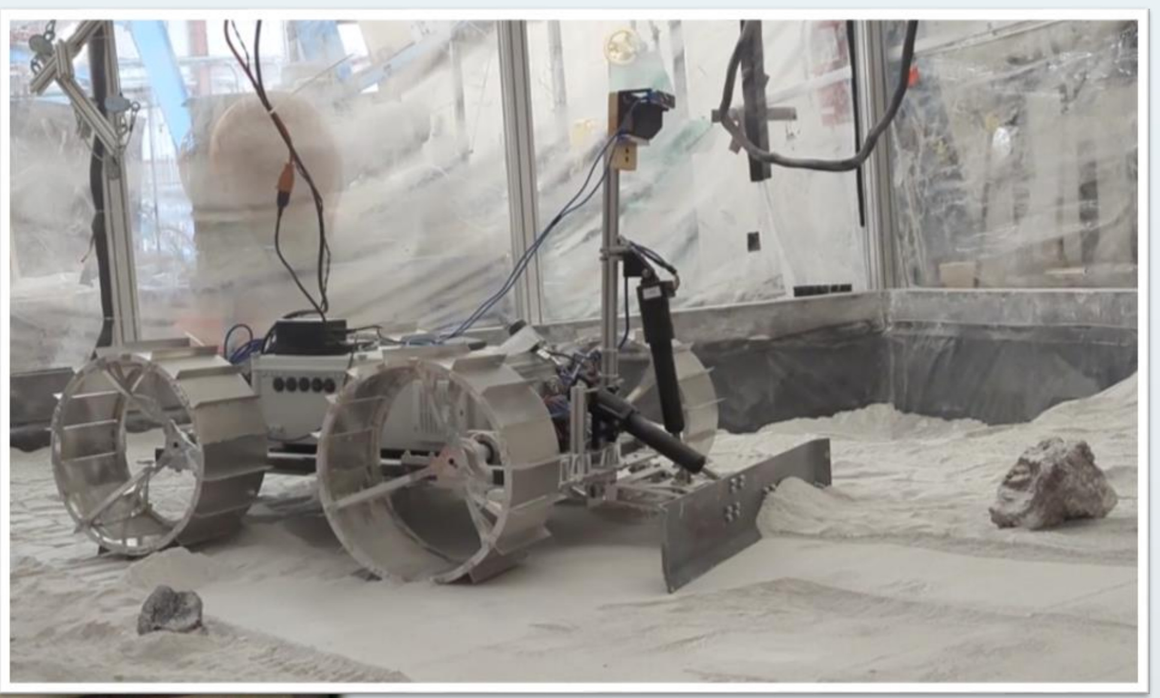
We use ROS to facilitate communication between our planning, control, and mapping systems. The planner operates multiple threads and models the environment as a height map, with separate layers for height and obstacles. It constructs a directed acyclic graph (DAG) to represent tasks and their sequence. A topological sort is used to generate task plans, and the motion planner creates paths, which are sent through ROS to the control system. Control system utilizes modified constant acceleration interpolation to hit all targets and achieve the path set by the task planner.

Task planning and autonomy

The robot must make discrete decisions about ordering of rock removal, regolith manipulation, and compaction, coupled with continuous decisions about motion for each step. We take a Task and Motion Planning (TAMP) [2,3] approach for these decisions. Two domain features enable efficient planning. First, we know initially all task actions to perform (i.e., remove all rocks and compact all areas), so task planning requires only scheduling. Second, we assume an acyclic dependency graph to enable polynomial time scheduling based on topological sorting.

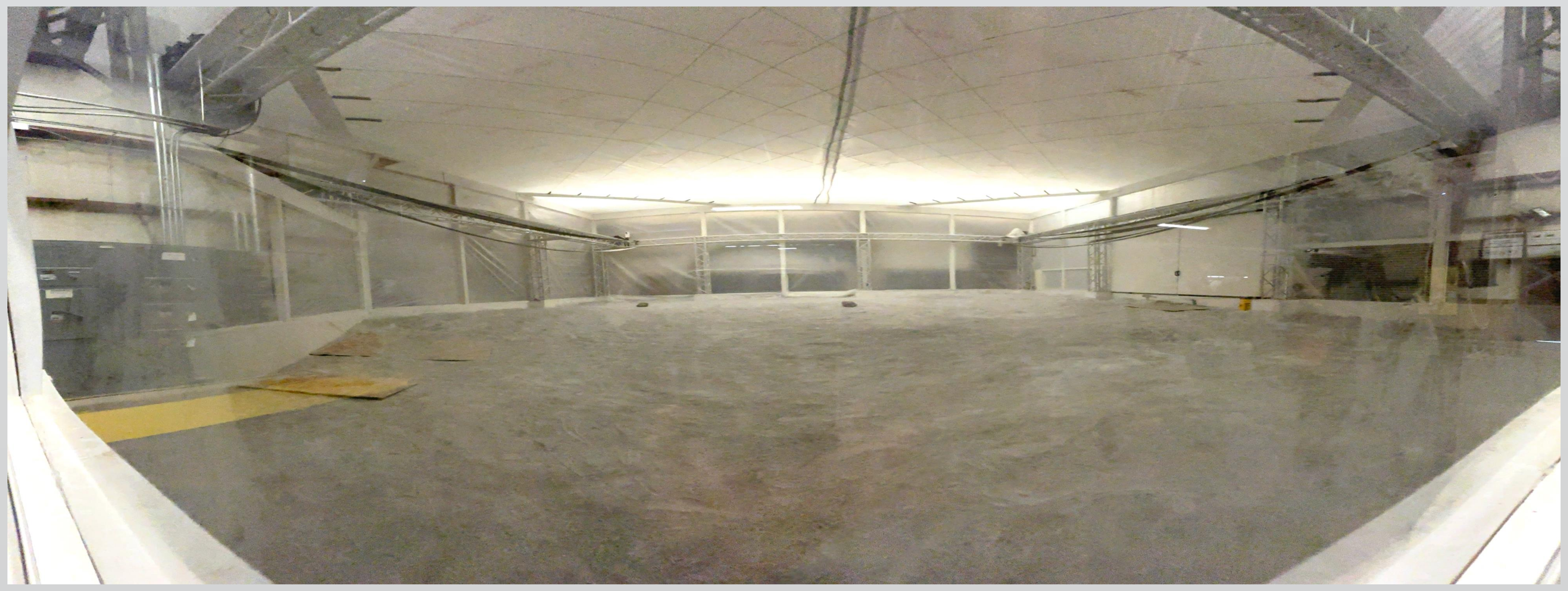
Regolith and Rock Manipulation

A 2 DOF dozer blade is used to move regolith and rock. ASPECT wheels and dozer blade have been designed and tested to work together. Nominally, the ASPECT vehicle will move low density regolith as on the Moon the top 10-15 cm is expected to be low density.



Site Preparation Testbed

The ASPECT system is required to be tested in a 10 m diameter area, which necessitated the construction of over 100 m2 tested, as shown in Figure 4. The Mines Lunar Surface Simulator (MLSS) is filled with a geotechnical quality highlands simulant, CSM-LHT-T.



Conclusions

The ASPECT system involves several challenging individual systems that must function simultaneously to perform the site preparation task. The ASPECT project will be tested in the MLSS testbed in the summer of 2025.

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References: [1] NASA, "Artemis Plan: NASA's Lunar Exploration Program Overview," 2020. artemis_plan-20200921.pdf. [2] NASA, "Lunar Surface Technology Research (LuSTR) 2021," [Online]. https://www.nasa.gov/directorates/spacetech/strg/lustr/2021/ [2] Dantam, N.T.: Task and Motion Planning. Springer Berlin Heidelberg (2020) [3] Garrett, C.R., Chitnis, R., Holladay, R., Kim, B., Silver, T., Kaelbling, L.P., Lozano-Pérez, T.: Integrated task and motion planning. Annual review of control, robotics,and autonomous systems 4, 265–293 (2021)