

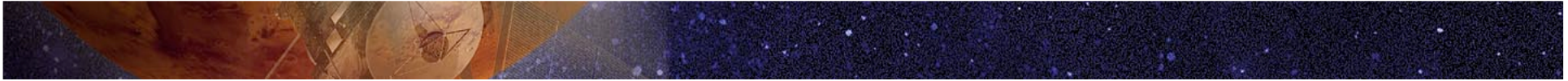
# **TRON – Hardware-in-the-Loop Test Facility for Lunar Descent and Landing Optical Navigation**

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**DLR – Institute of Space Systems, Bremen**



Deutsches Zentrum  
für Luft- und Raumfahrt e.V.  
in der Helmholtz-Gemeinschaft



# Content

- Purpose
- Layout of laboratory
- Description and state of building blocks
- Application of laboratory to DLR project
- Conclusion & Future

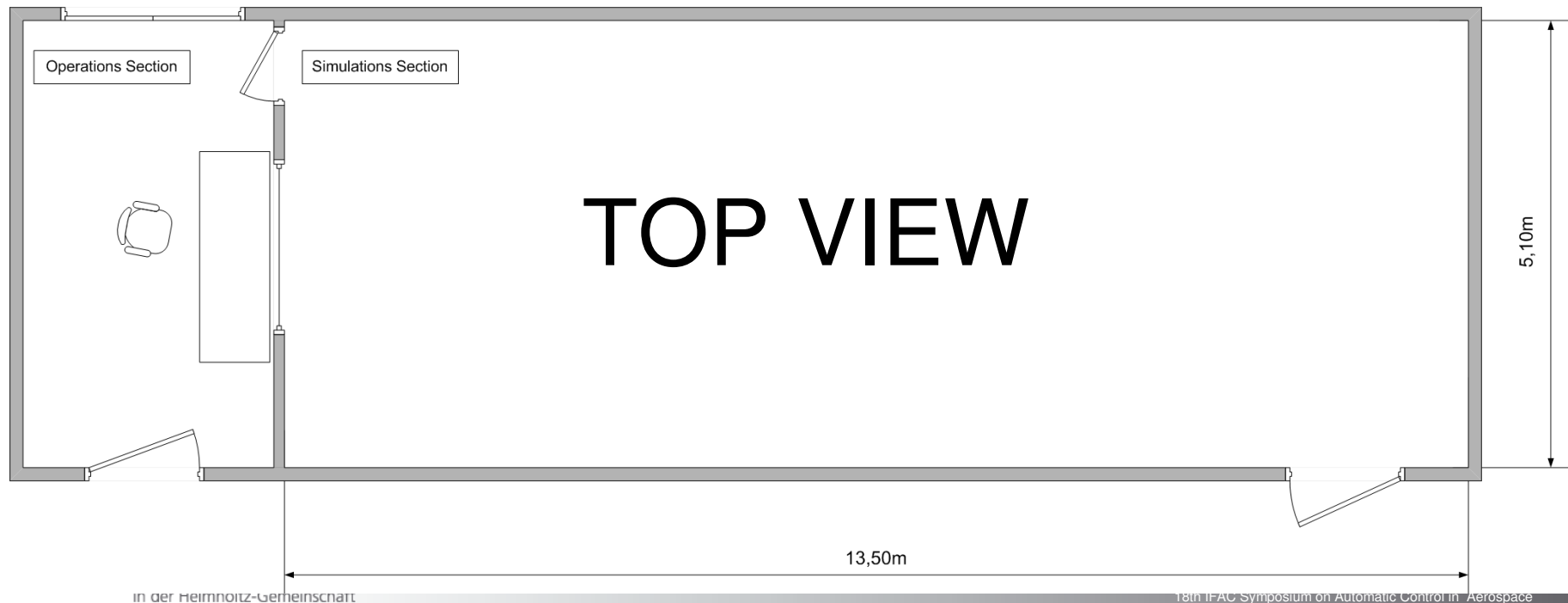


# TRON - Testbed for Robotic Optical Navigation

- Motivation:
  - To support the development of Soft- and Hardware for optical navigation for exploration missions
  - Provide environment to qualify hardware to
    - TRL 4 (breadboard with ad-hoc hardware)
    - TRL 5 (breadboard with flight hardware)
- Approach:
  - Design a laboratory with relevant testing environment
  - Robot system moves sensor over illuminated 3D terrain in real time
  - Application of various models and scales for different mission profiles

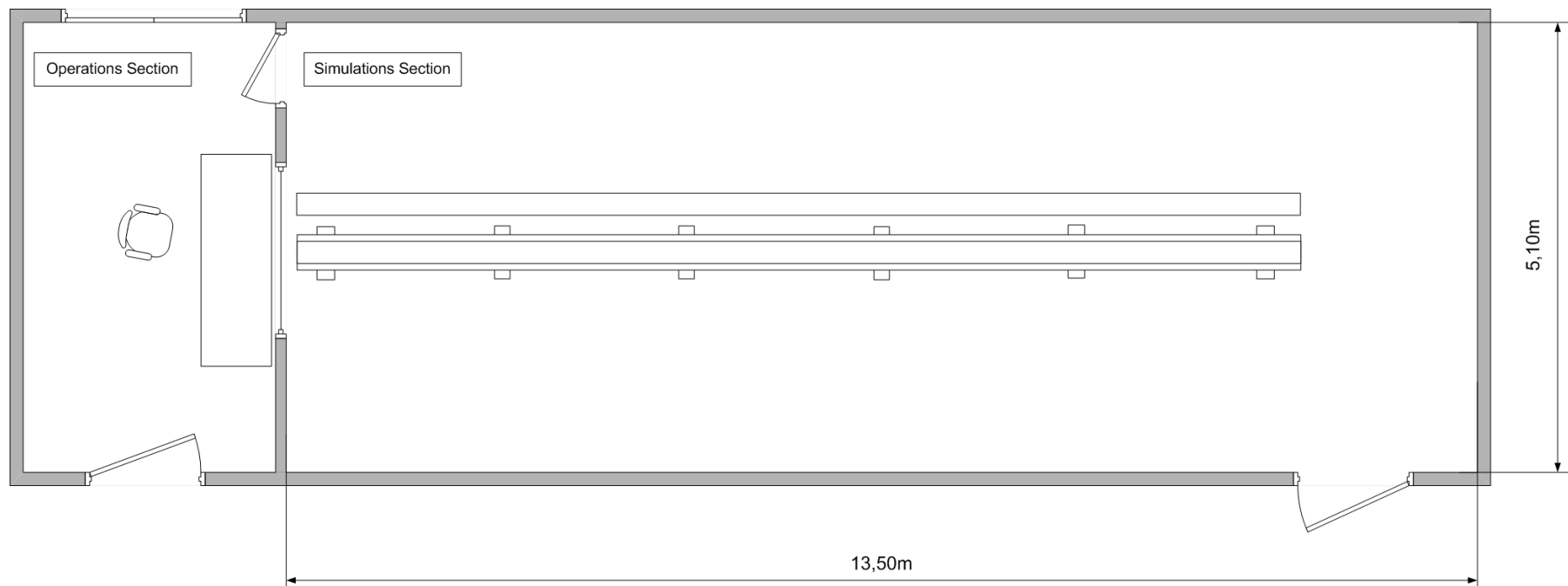
# TRON Layout Dimensions

- Lab situated in DLR Building in Bremen
- operations section for control and observation
- simulations section for provision of the environment



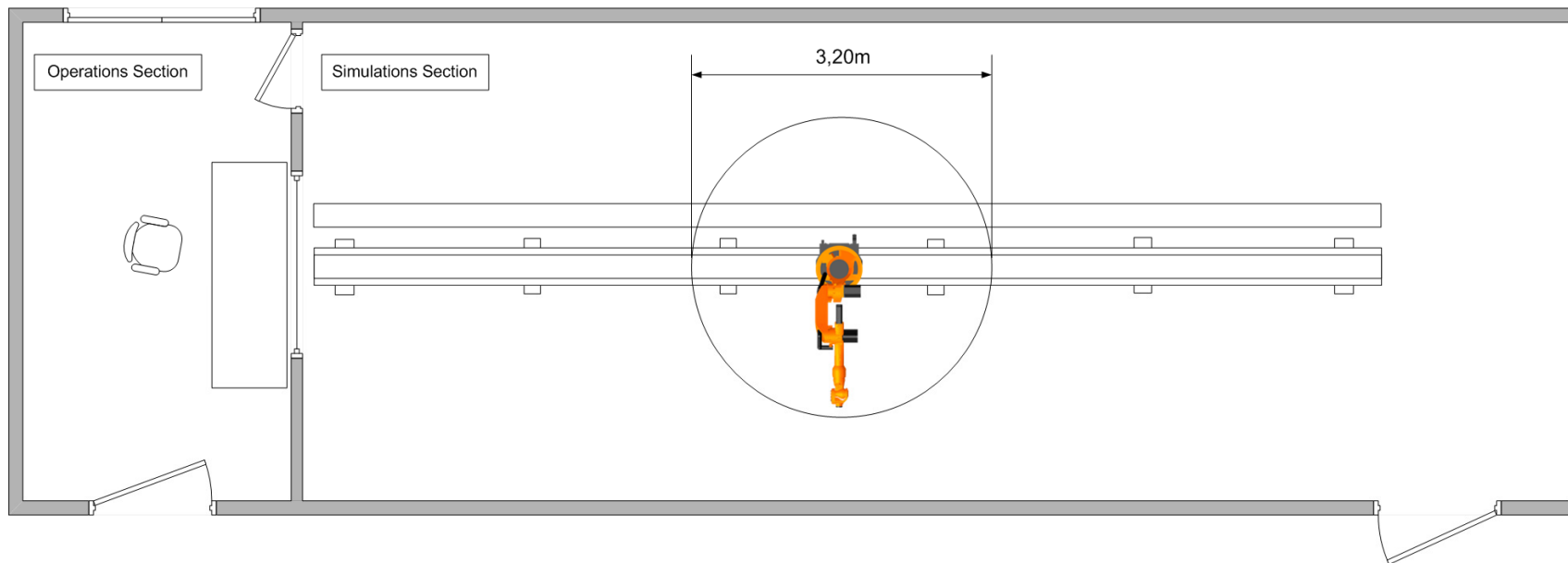
# TRON Layout Simulation of Dynamics

- Installation of a 11 m rail



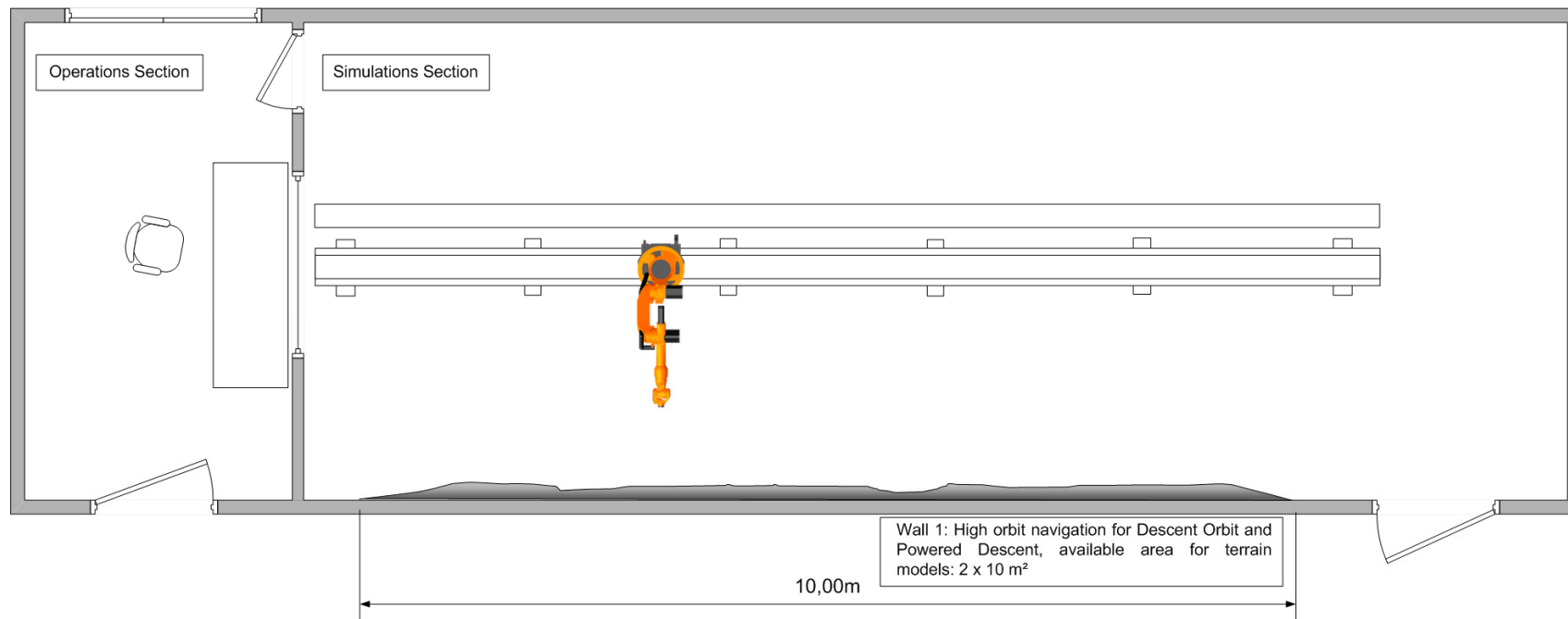
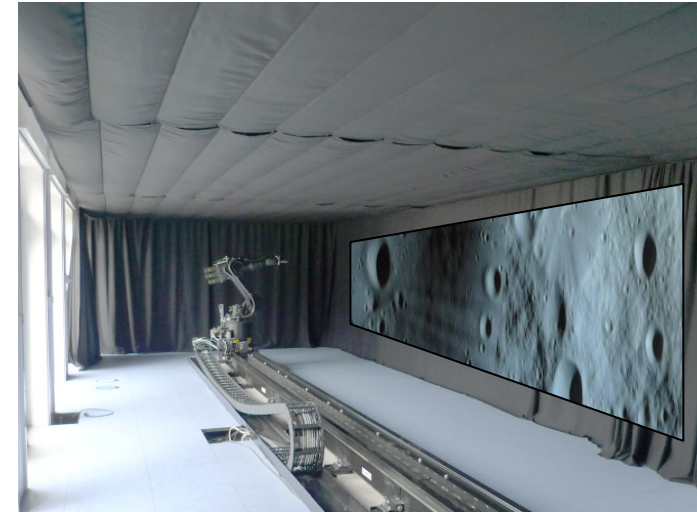
# TRON Layout Simulation of Dynamics

- Installation of a 11 m rail
- Installation of robot on rail (KUKA KR 16)



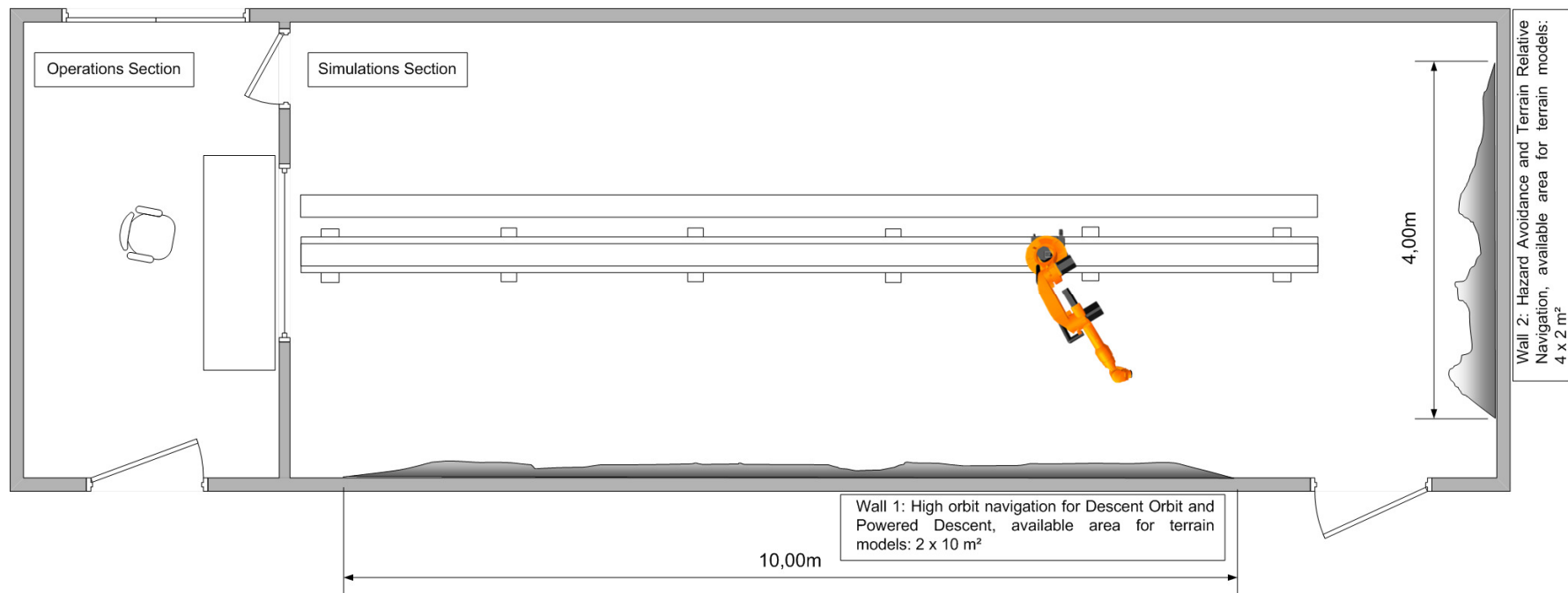
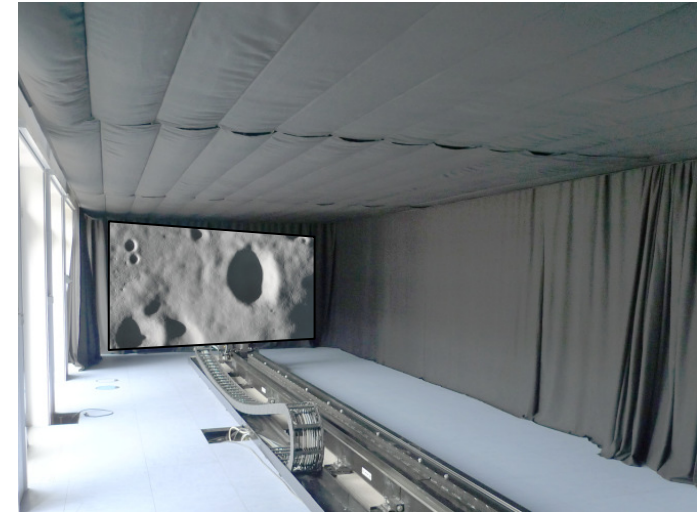
# TRON Layout Simulation of Terrain

- Installation of terrain model at long wall
- Simulation of park orbit, descent orbit, powered descent
- Available space  $\approx 10 \times 2 \text{ m}^2$



# TRON Layout Simulation of Terrain

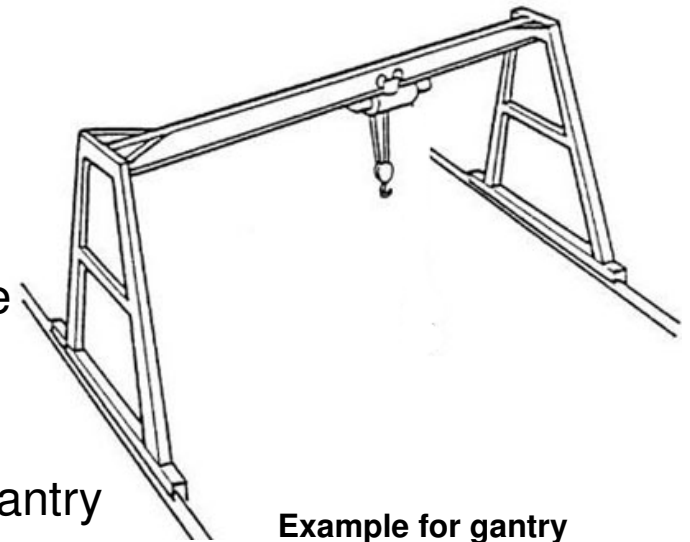
- Installation of terrain model at front wall
- Simulation of approach-manoevre
- Available space  $\approx 4 \times 2 \text{ m}^2$



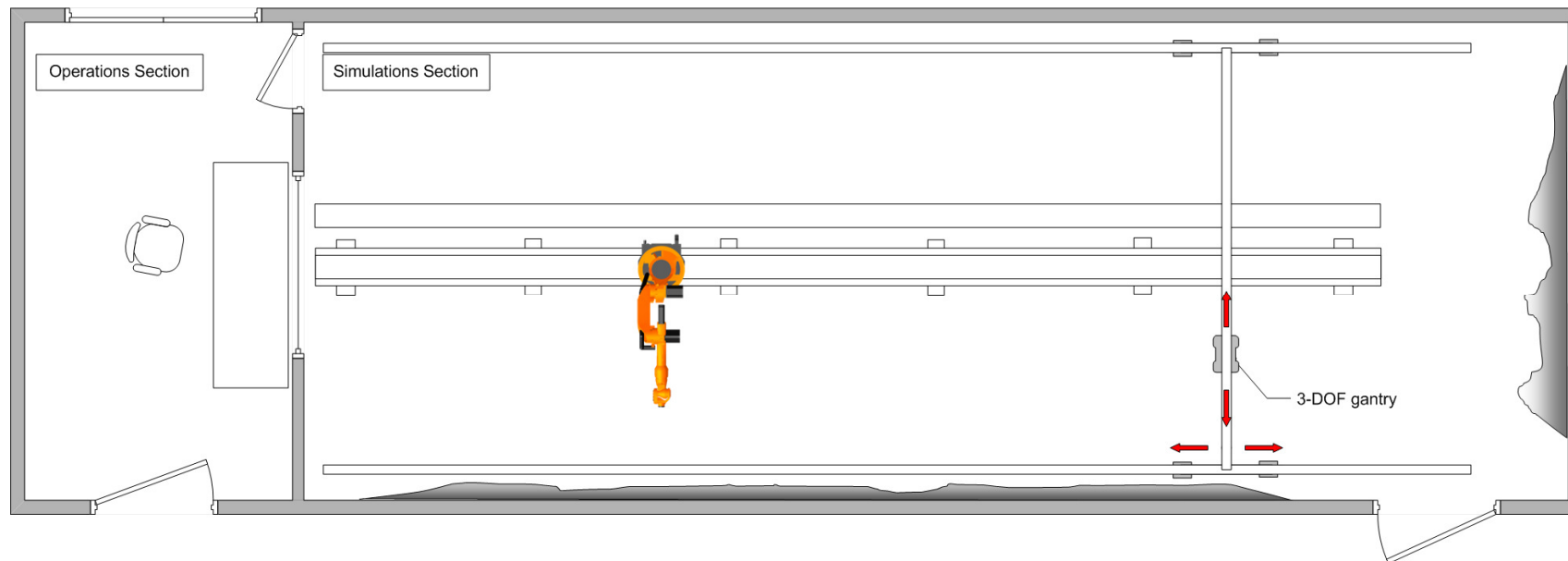
# TRON Layout

## Simulation of sun

- Idea: Simulation of solar radiation by a single moveable light
- Placement of light source on gantry
- 3 DOF by lateral and vertical movement of gantry



Example for gantry



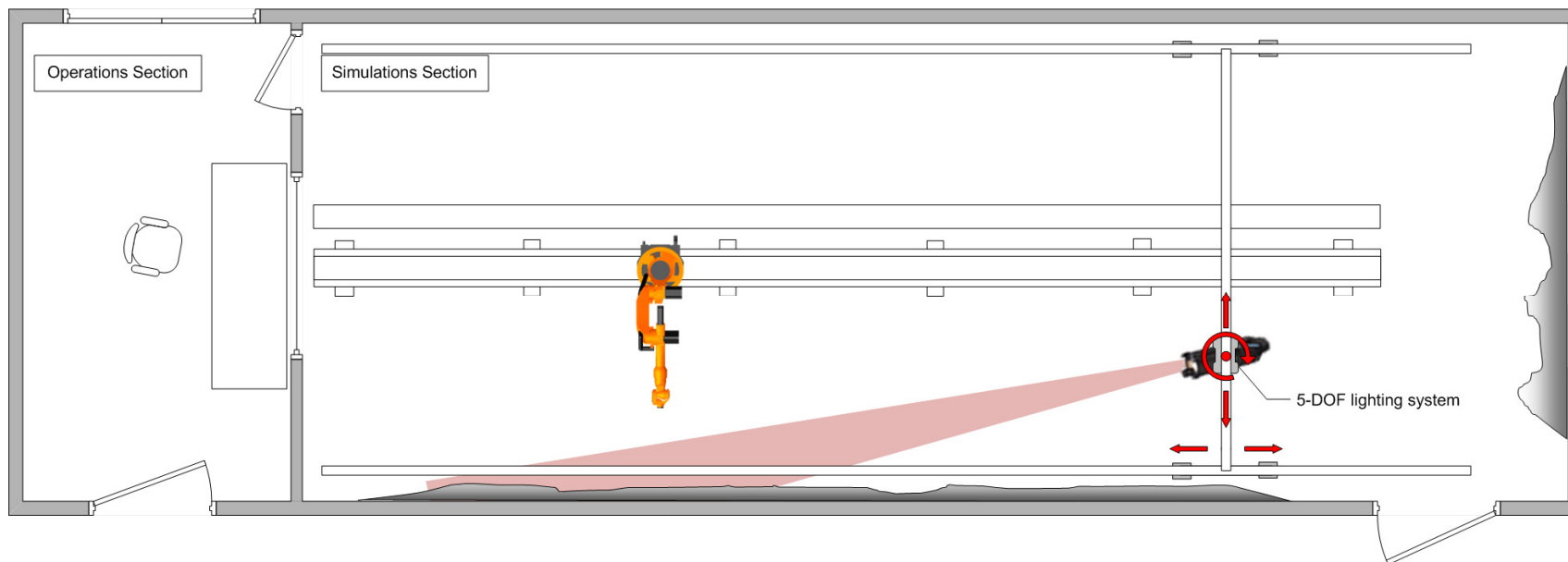
# TRON Layout

## Simulation of sun

- 3 DOF by lateral and vertical movement of gantry
- 2 DOF by lamp, 2-axis rotation



Moving-head lamp



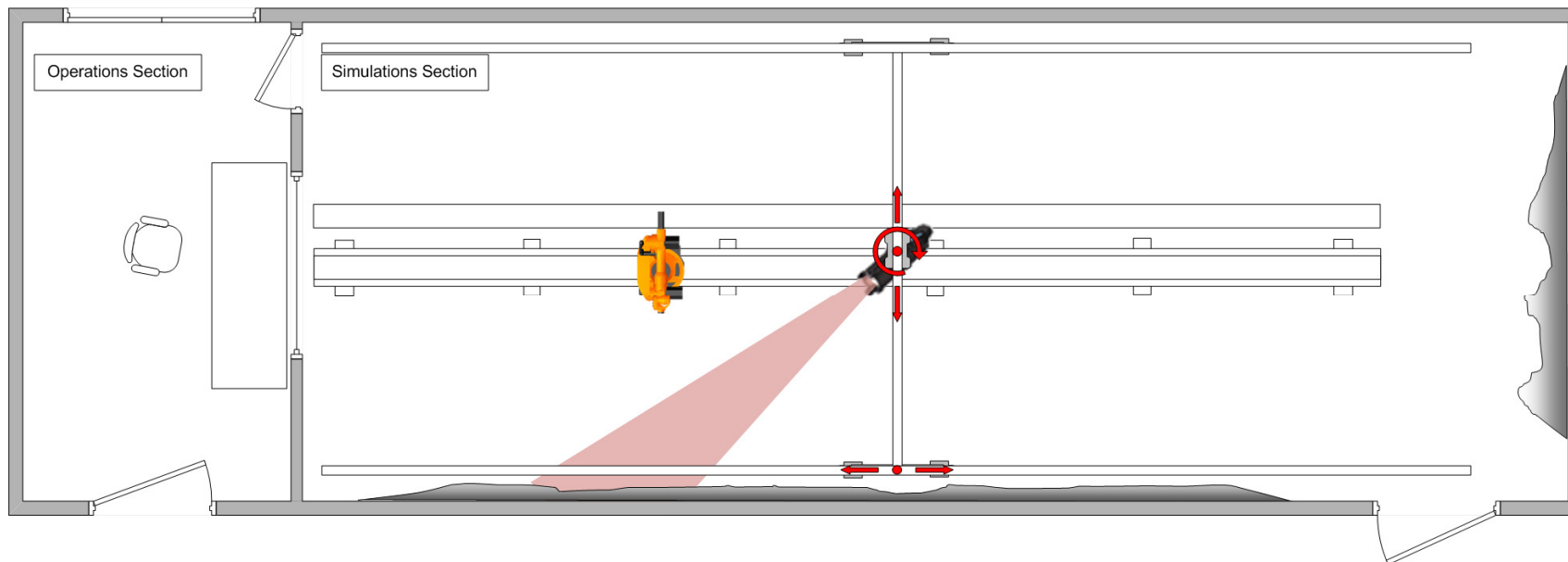
# TRON Layout

## Simulation of sun

- 3 DOF by lateral and vertical movement of gantry
- 2 DOF by lamp, 2-axis rotation
- Result: huge variety of solar irradiation conditions



Moving-head lamp



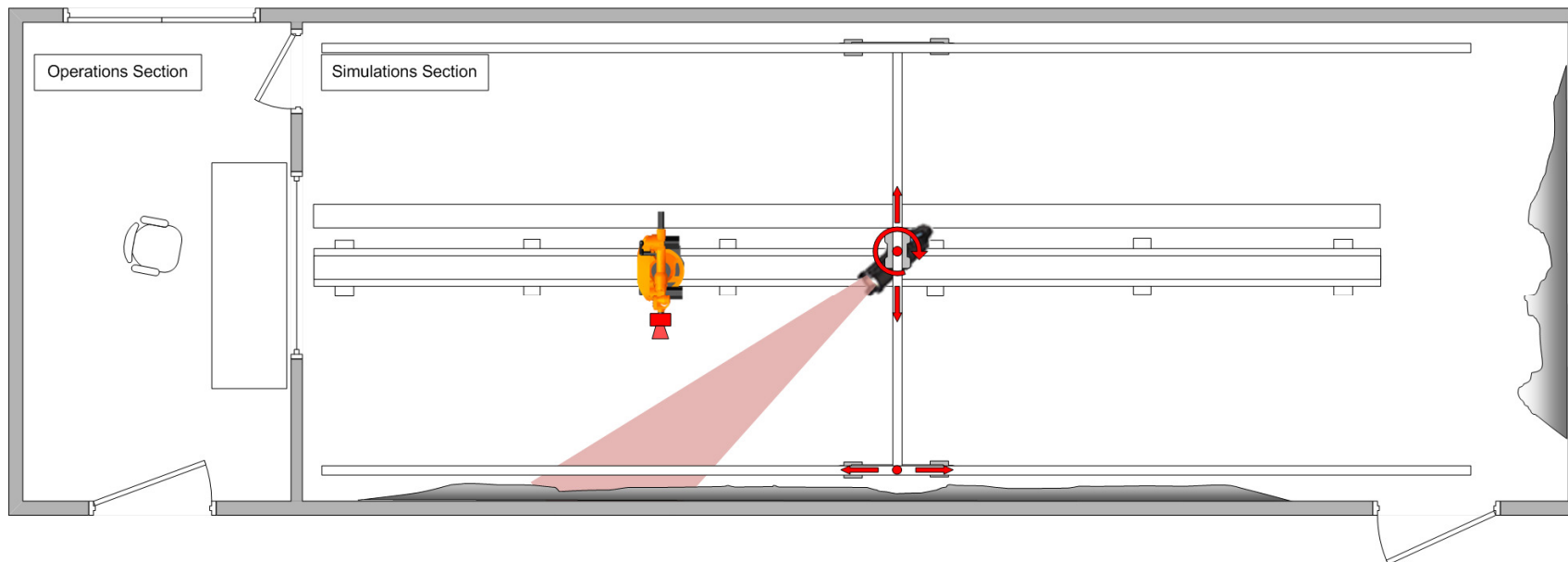
# TRON Layout

## Installation of sensor

- Installation at tool center point of robotic arm



Illuminated terrain model in TRON



# Description of building blocks

## Dynamics

- Movement of sensor by industry robot KUKA KR 16
- Payload at robot hand: 16 kg for sensor
- Supplementary payload: 30 kg for additional hardware (breadboard support)
- Repeatability:  $\pm 0.1$  mm
- Maximum velocity (Tool Center Point): 1.47 m/s
- Control via
  - KRL programs (open loop)
  - Real time via RSI interface, 85 Hz (closed loop)
- Status:
  - Characterisation of dynamics
  - Alignment measurements



KUKA KR16



## Description of building blocks

### Terrain models – production parameters

- After iterations the following production parameters were found
  - Milling resolution: 0.2 mm
  - material: polyurethane based foam
  - Coating: clear coat with matte-powder
- Data basis for production
  - PANGU – DEM generation software
  - Kaguya DEMs
- Status
  - Finished production of Kaguya terrain model
  - Wait for comparison with LRO DEMs

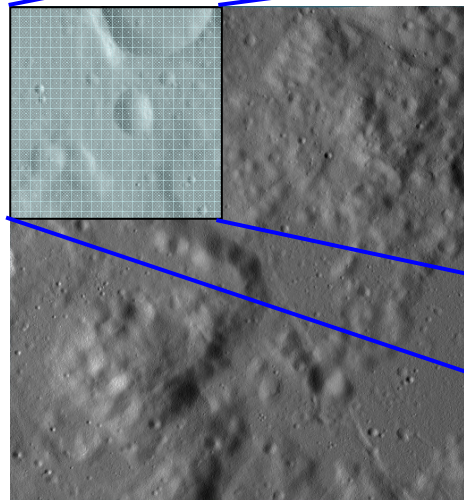
# Description of building blocks

## Terrain models – Kaguya DEM

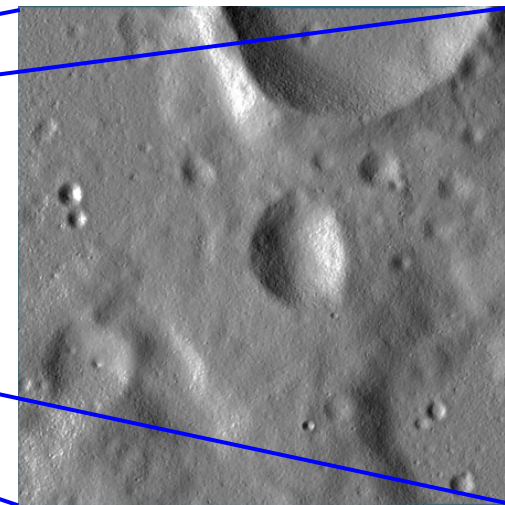
➤ Choice of 2500 x 2500 px from Kaguya patch → 0.5 x 0.5 m<sup>2</sup>



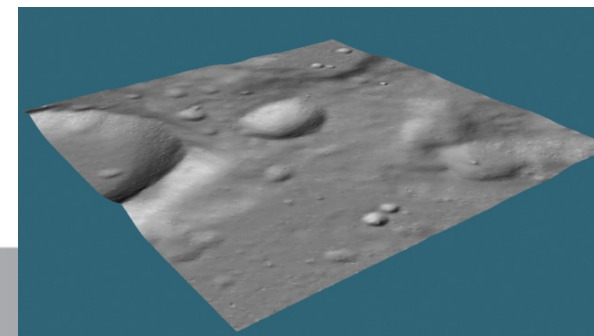
One Kaguya data patch,  
original camera image

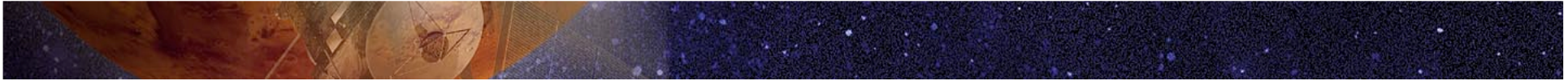


Rendering of elevation data  
in 3dsmax, no radiance



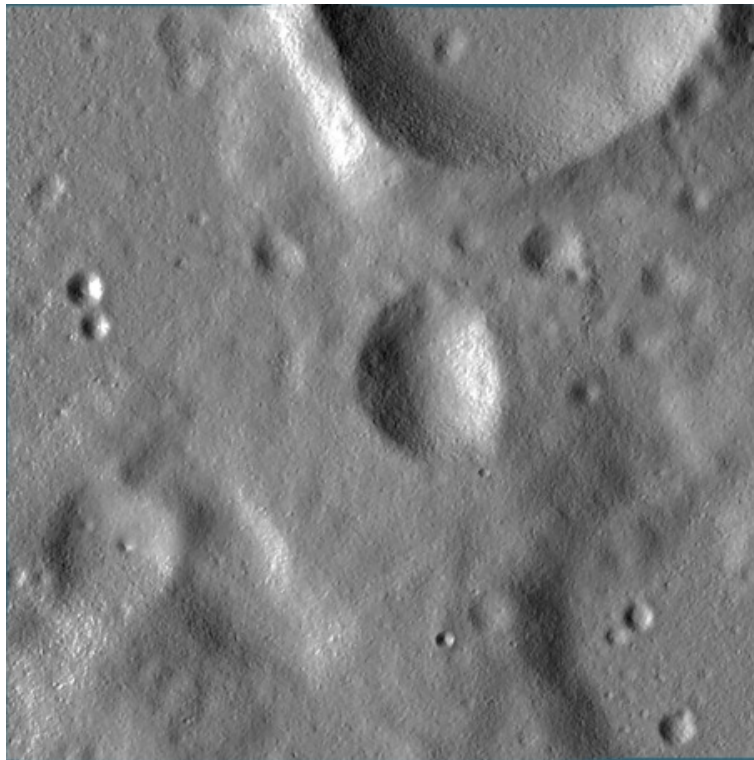
Rendering of  
selection in 3dsmax





## Description of building blocks

### Terrain models – Test with Kaguya based model



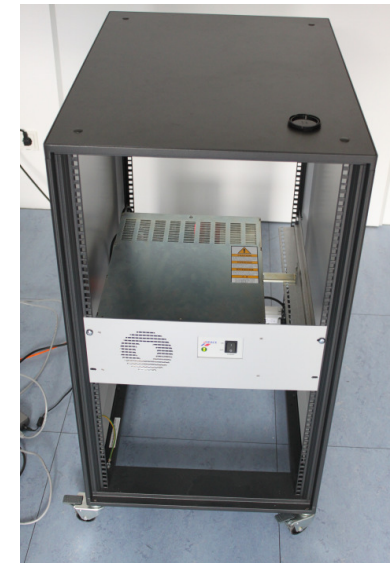
Rendering in 3dsmax



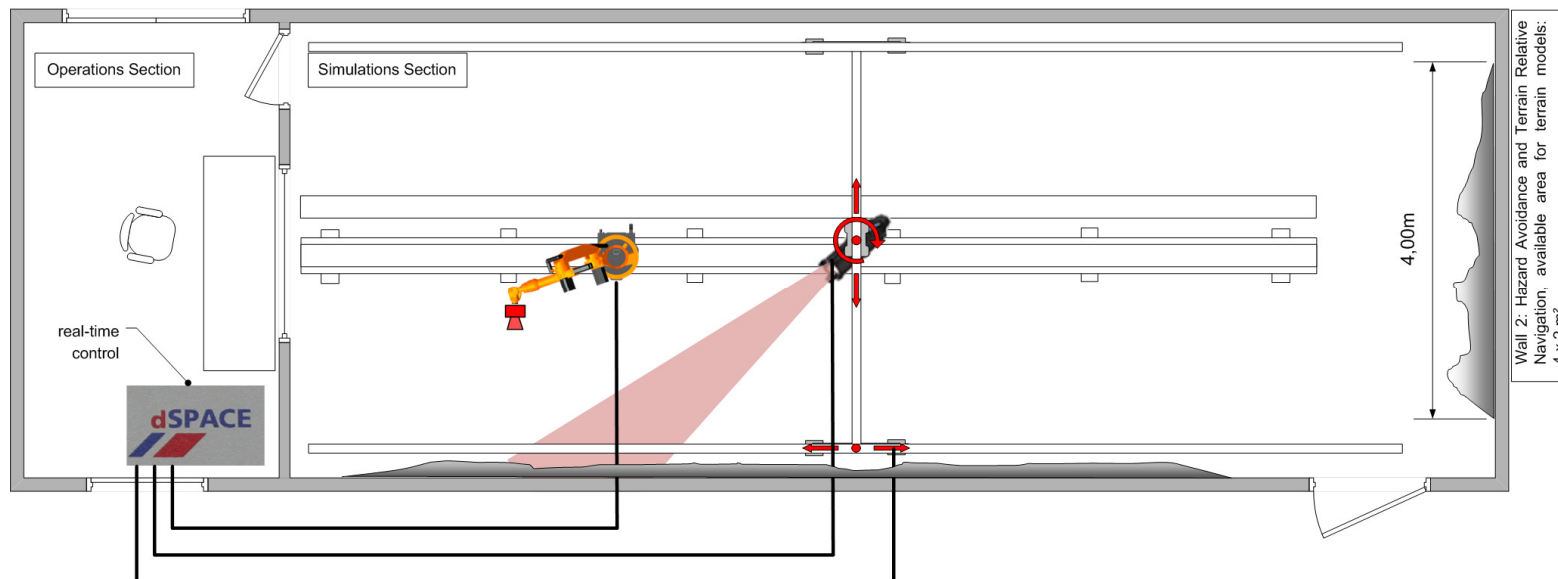
Testmodel in sunlight (0.5 × 0.5 m<sup>2</sup>)

# Description of building blocks Control

- real-time control via dSPACE system:
  - robot (7 DOF), Gantry (3 DOF), Lamp (2 DOF)
- simulation of space craft dynamics



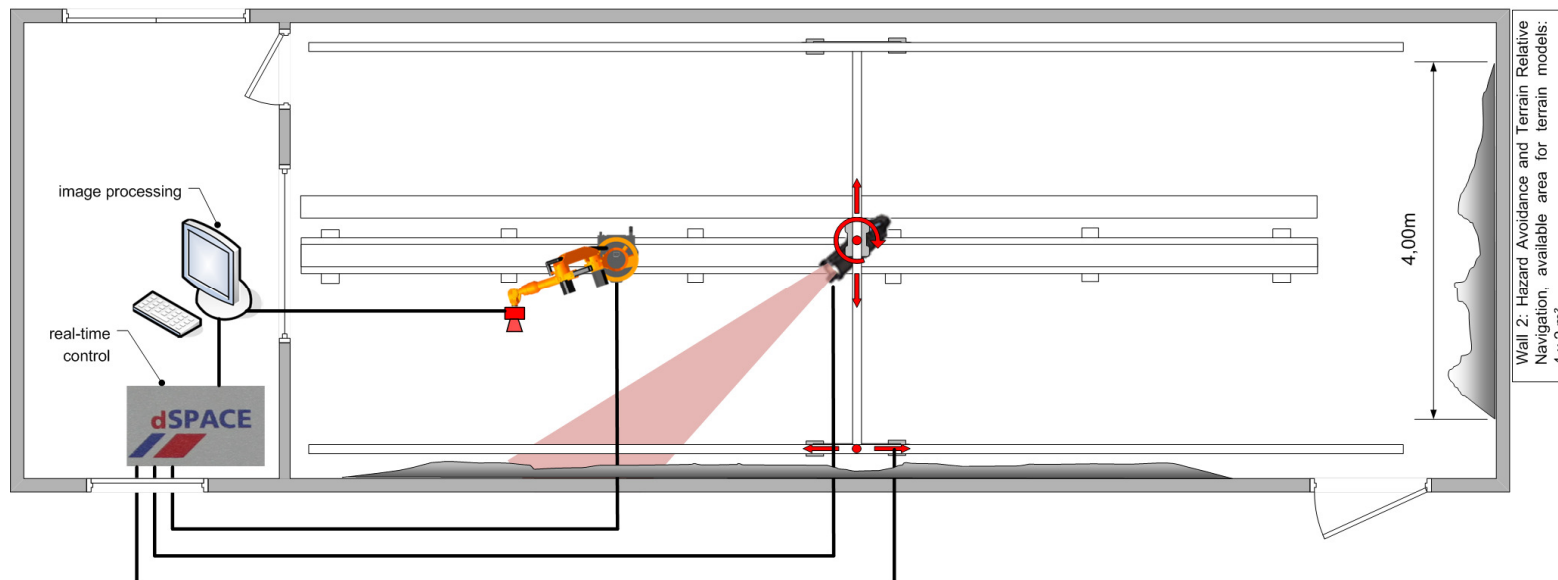
dSPACE system in TRON



# Description of building blocks

## Control

- real-time control via dSPACE system:
  - robot (7 DOF), Gantry (3 DOF), Lamp (2 DOF)
- simulation of space craft dynamics and on-board GNC
- Option for including external hardware (e.g. sensor bread-boards)

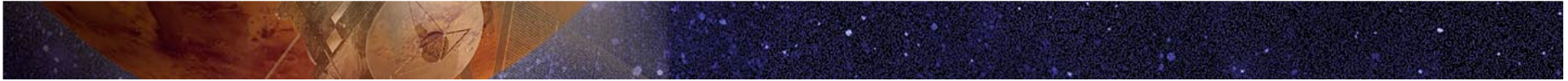




# Application to ATON

## Autonomous Terrain based Optical Navigation

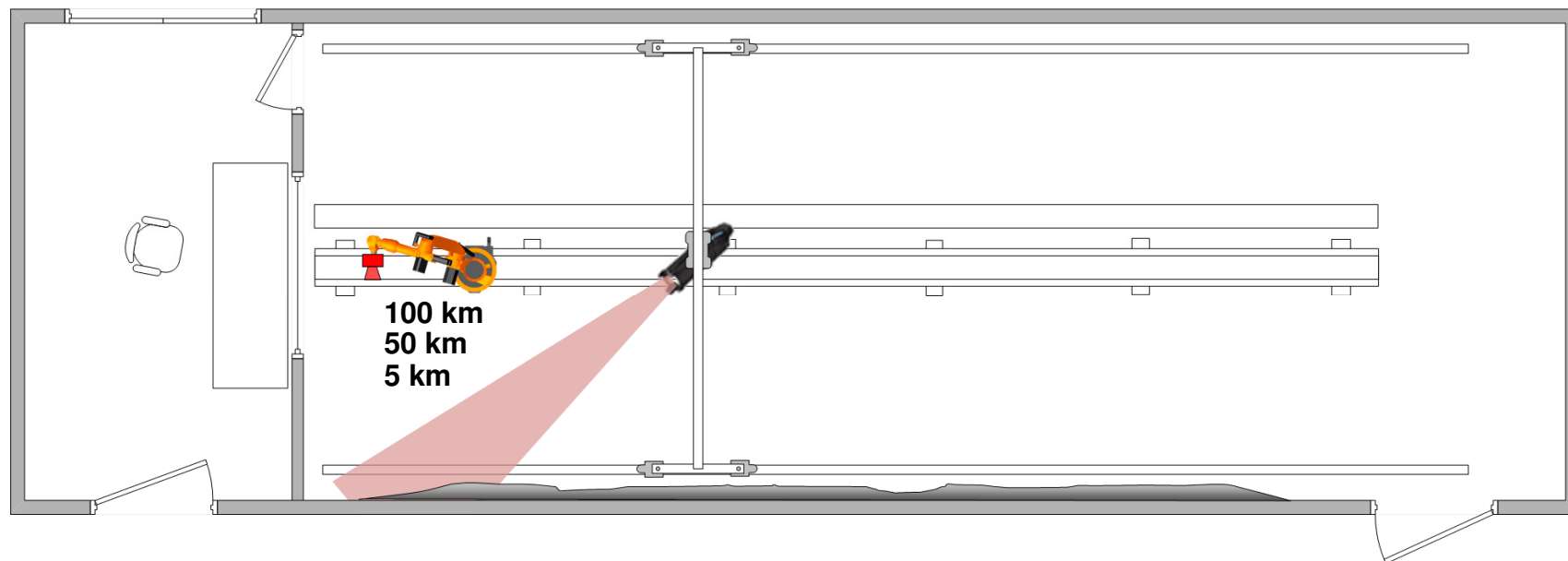
- ATON is a DLR project for development of technology for the autonomous, precise and safe landing on the Moon
- Goal is
  - Develop sensor system bread-board
  - Qualify bread-board to TRL 4 (ad hoc components in relevant environment)
- Project shall be finished by end of 2012
- 3 phases
  - Absolute navigation during descent orbit and powered descent
  - Relative navigation during powered descent
  - Landing site evaluation and TRN during approach



# ATON

## Phase 1 & 2 – Descent Orbit & Powered Descent

- Utilization of long wall for Descent orbit and powered descent
- Utilization of different scales
- Example: 1:50000, 1:25000, 1:2500

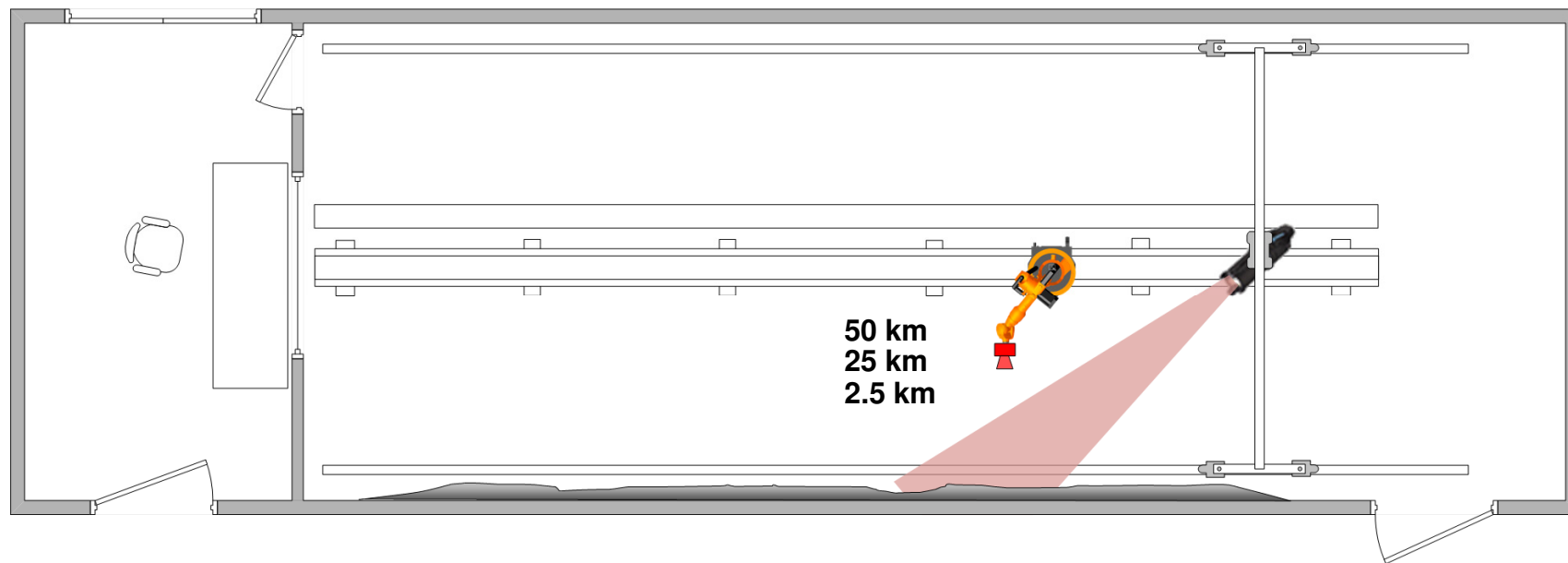




# ATON

## Phase 1 & 2 – Descent orbit & Powered Descent

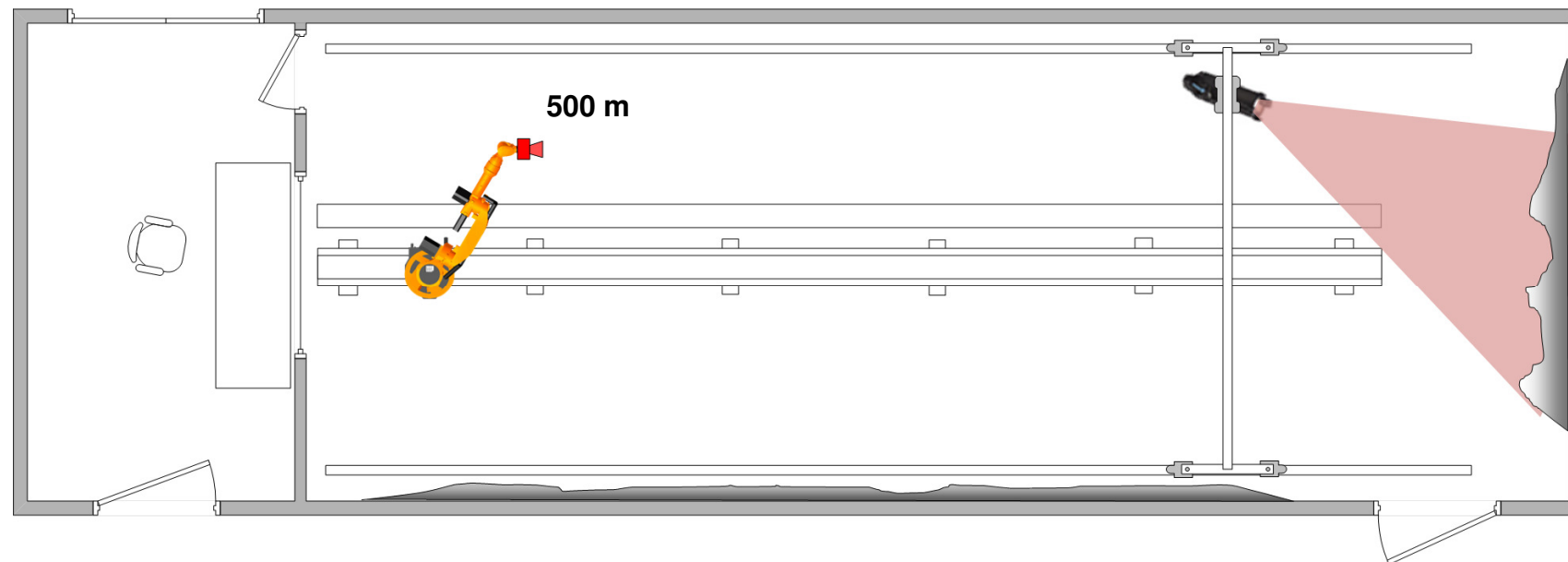
- Utilization of long wall for Descent orbit and powered descent
- Utilization of different scales
- Example: 1:50000, 1:25000, 1:2500



# ATON

## Phase 3 – Landing Site evaluation

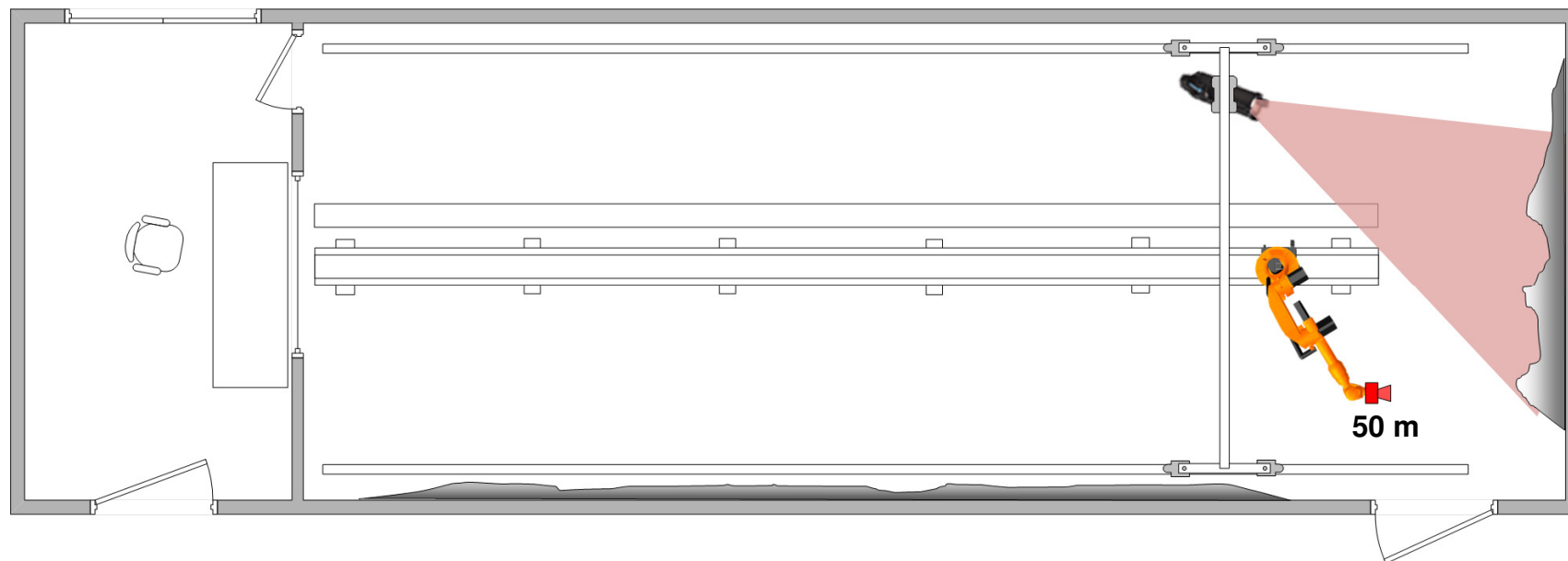
- Utilization of front wall for landing site evaluation
- Example Scale  $\approx 1:50$



# ATON

## Phase 3 – Landing Site evaluation

- Utilization of front wall for landing site evaluation
- Example Scale  $\approx 1:50$

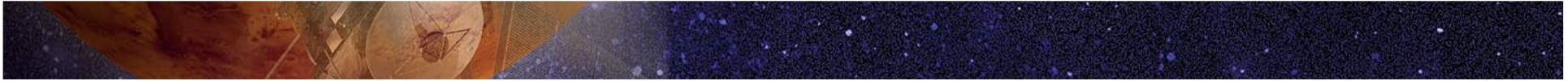




## Conclusion

### Ongoing assembly & Future

- Ongoing assembly of TRON
  - Finished lighting system by end of year
  - Characterisation of robot and lighting system performance
  - Full terrain model by mid of 2011 (LLB1)
- Future projects
  - Qualification of ATON sensor system to TRL 4
  - Test of european flash lidar system (FOSTERNAV)
  - Test of navigation sensor for Lunar Lander Phase B



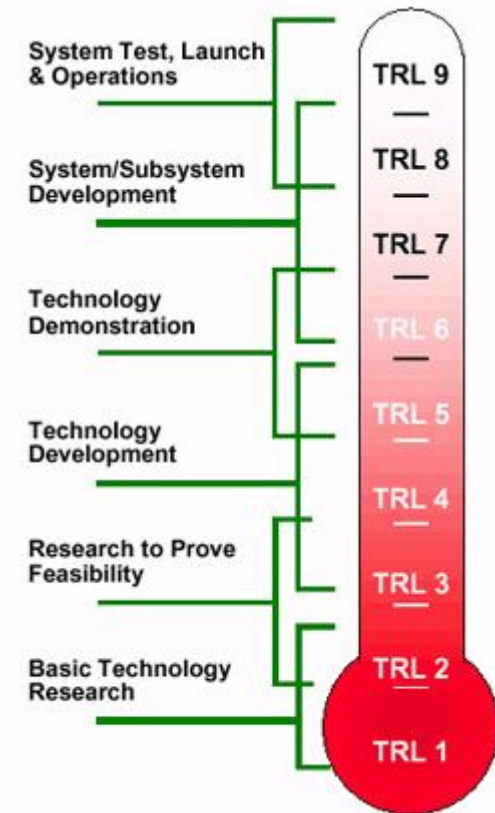
# Thank you



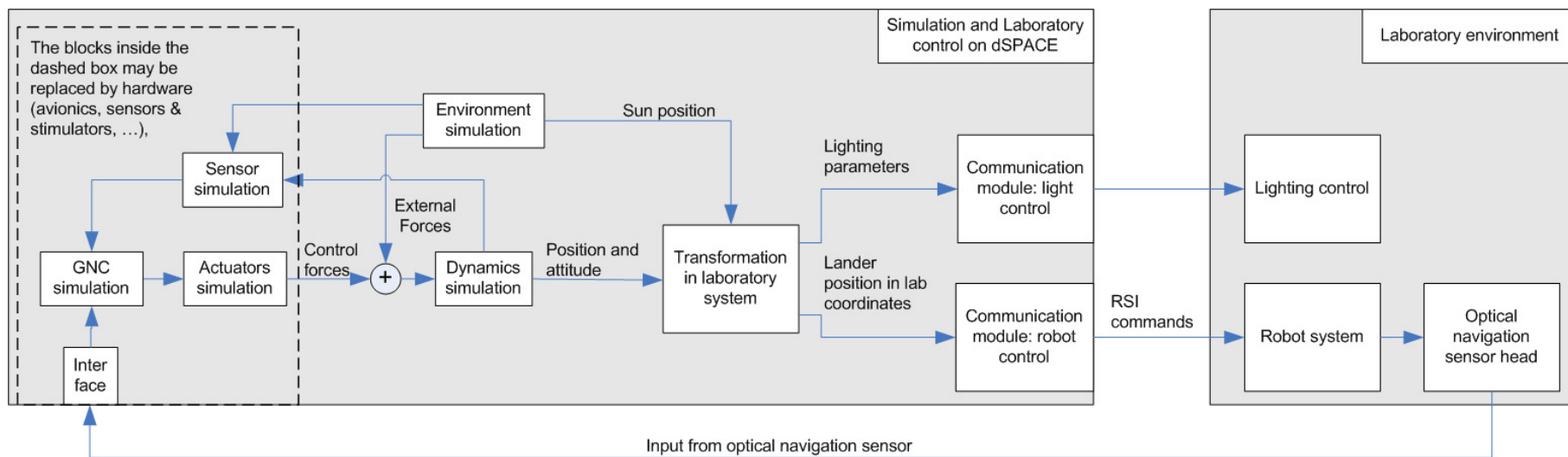
# Backup

## TRL

- Cover whole phase of technology development
- Cover major part of Technology demonstration
- TRL 4: it could be composed of ad hoc discrete components in a laboratory (Wikipedia)
- TRL 5 (Wikipedia):
  - the fidelity of the component and/or breadboard being tested has to increase significantly
  - tested in a 'simulated' or somewhat realistic environment

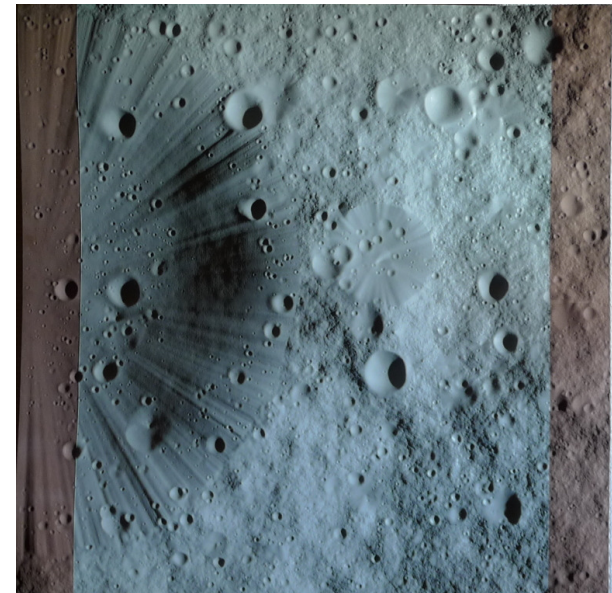
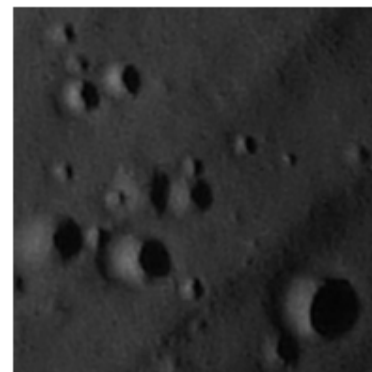
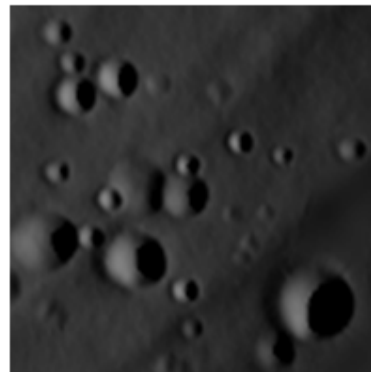
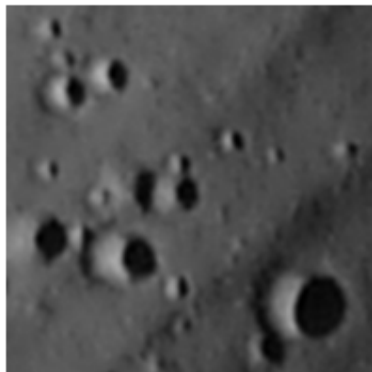
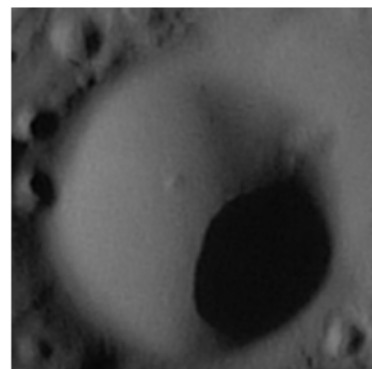
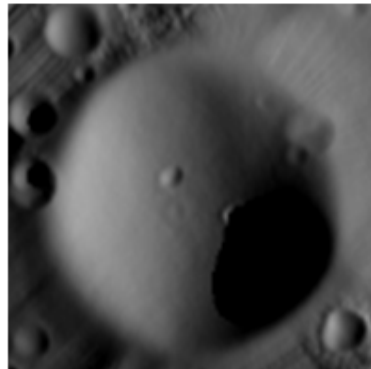
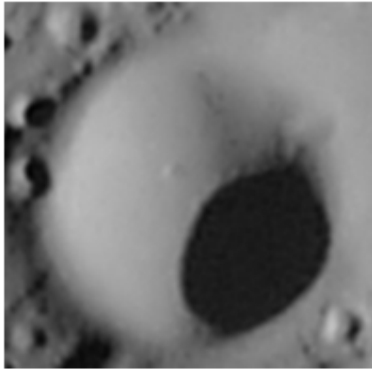


# Description of building blocks HITL concept



# Description of building blocks

## Geometry - Test with PANGU model



**Whole model (sunlight)**  
**0.5 x 0.5 m<sup>2</sup>**

10 mm

**Testmodel  
in TRON**

**Digital model in  
PANGU**

**Testmodel under  
sunlight**



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