LUNASCAPE

1:1 Interactive Architecture Prototypes
TU Delft
Q3 2023/24

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Lilian **Le**
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Lowie **Swinkels**

1 _ LOCATION AND SITE

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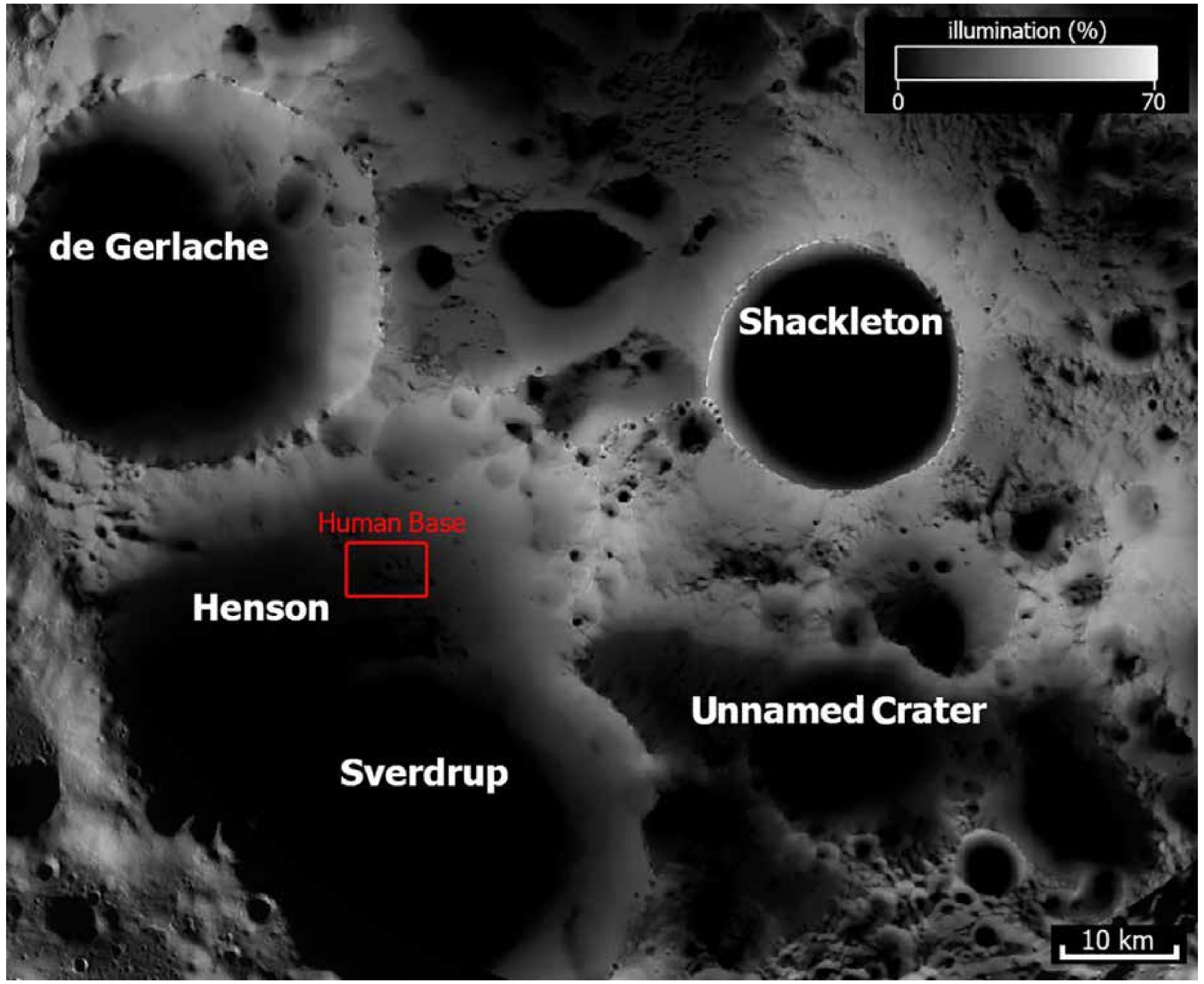
SITE ANALYSIS

Lunar South Sverdrup-Henson crater (location 1)

•Approximately **5 km² of area**.
•Flat topography inside the crater.
•Abundant water supply, nearby shaded areas have more ice and materials.
•Parts of the crater are covered by **sunlight all day long**, which is suitable for solar power generation.
•The terrain is **suitable to build ground antennas** for connection with the Earth.



Map of the studied location for the human base

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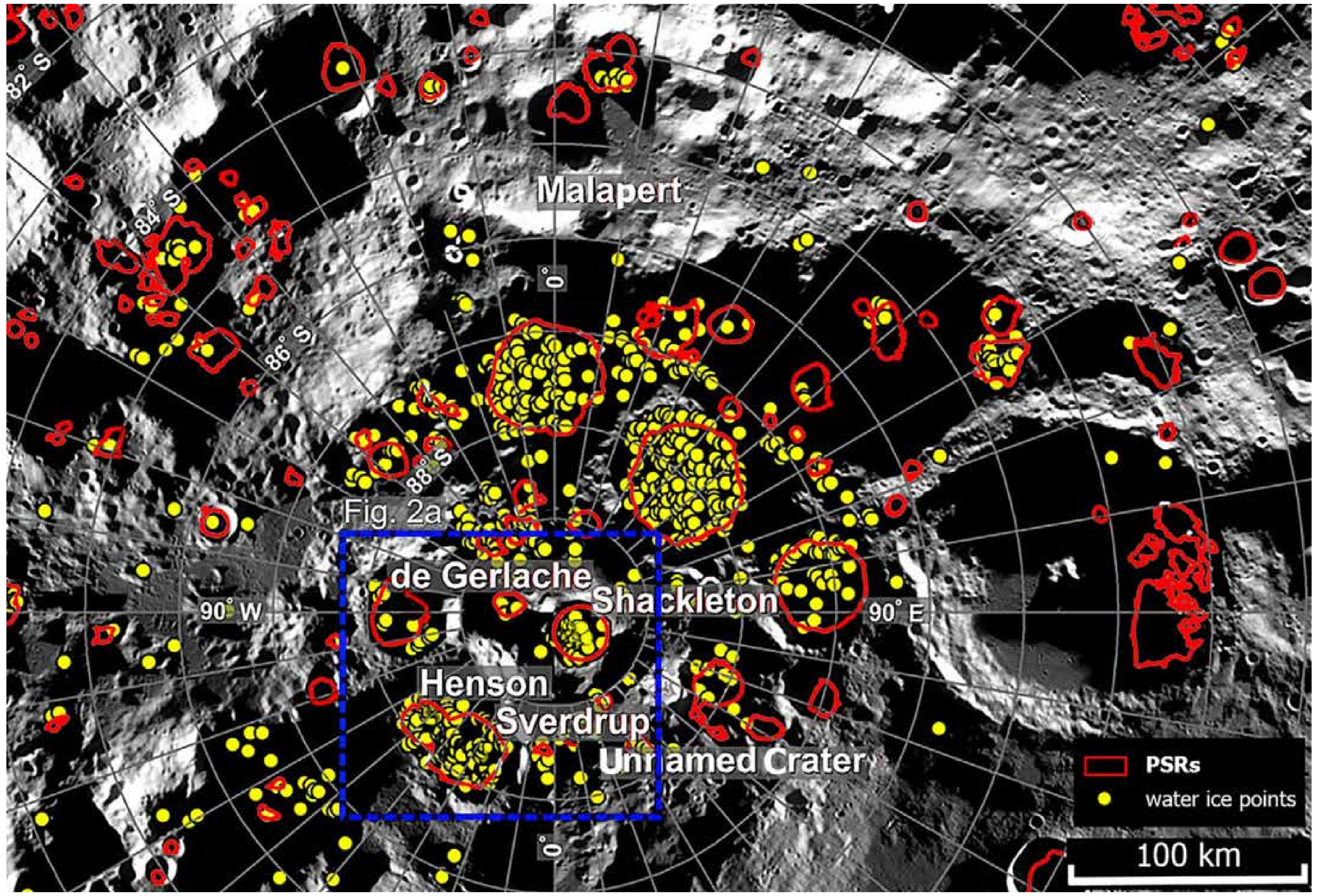
PSRs and water ice points

The image shows the **water ice points available in the area**. As it can be seen, the reason why the Lunar South Pole is such a strong candidate for a Lunar settlement is the **large concentration of these points. PSR is an acronym for permanently shadowed regions.** Of course, surface water ice points are located mainly in the PSRs, as they would evaporate if they became in contact with the sun.



Map of the studied location for the human base

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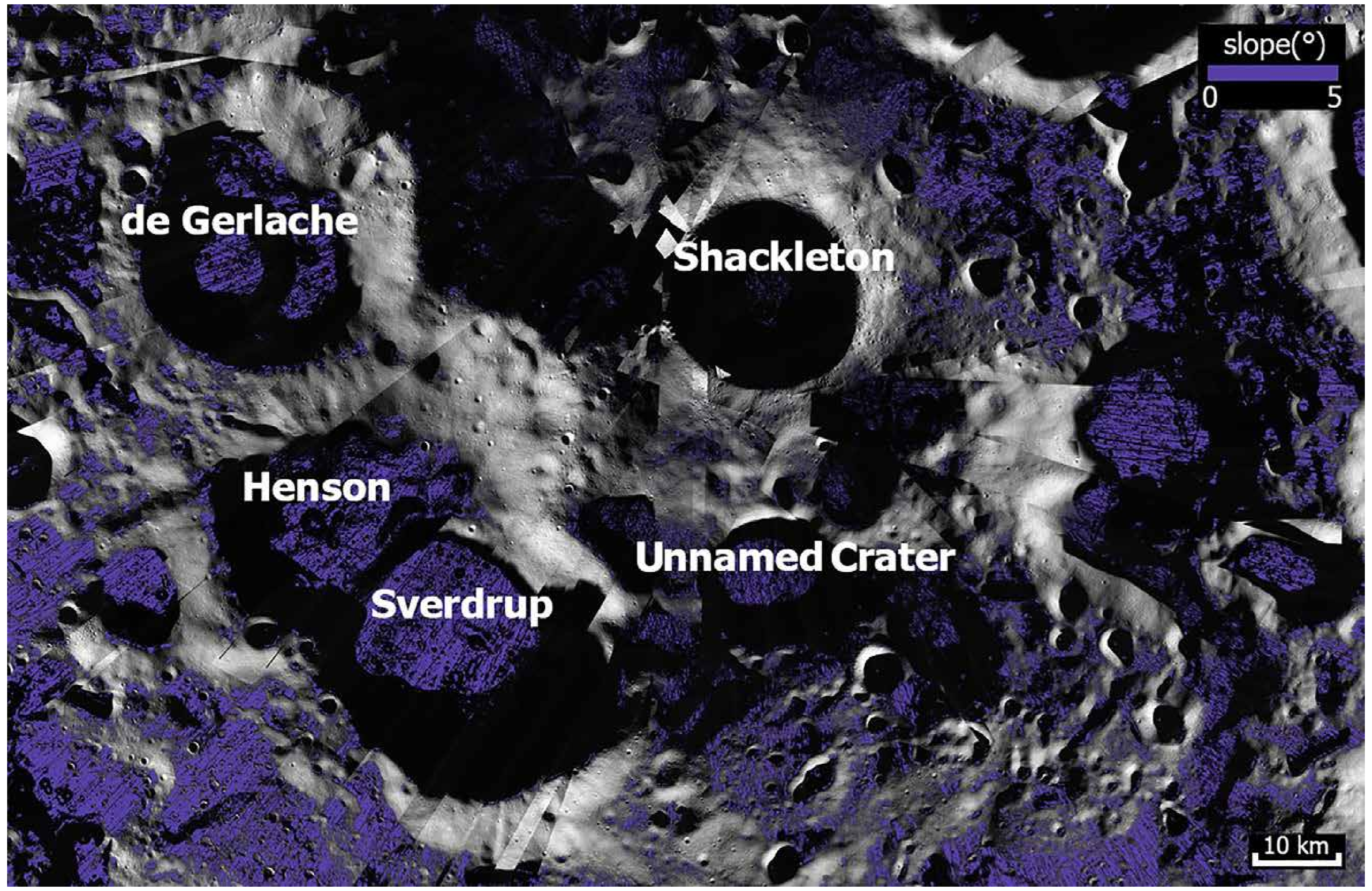

Slope of the terrain in the considered area.

Terrain slope

The slope of the terrain is also very suitable. Ideally, a flat surface would be the most desirable, but **moderate slope angles may still be considered relatively safe**, depending on the task. For example, a slope of **7° allows spacecraft landing**, and mobile surface operations are safe on an angle of up to 15°. The image shows the slopes between 0° and 5° in the area.

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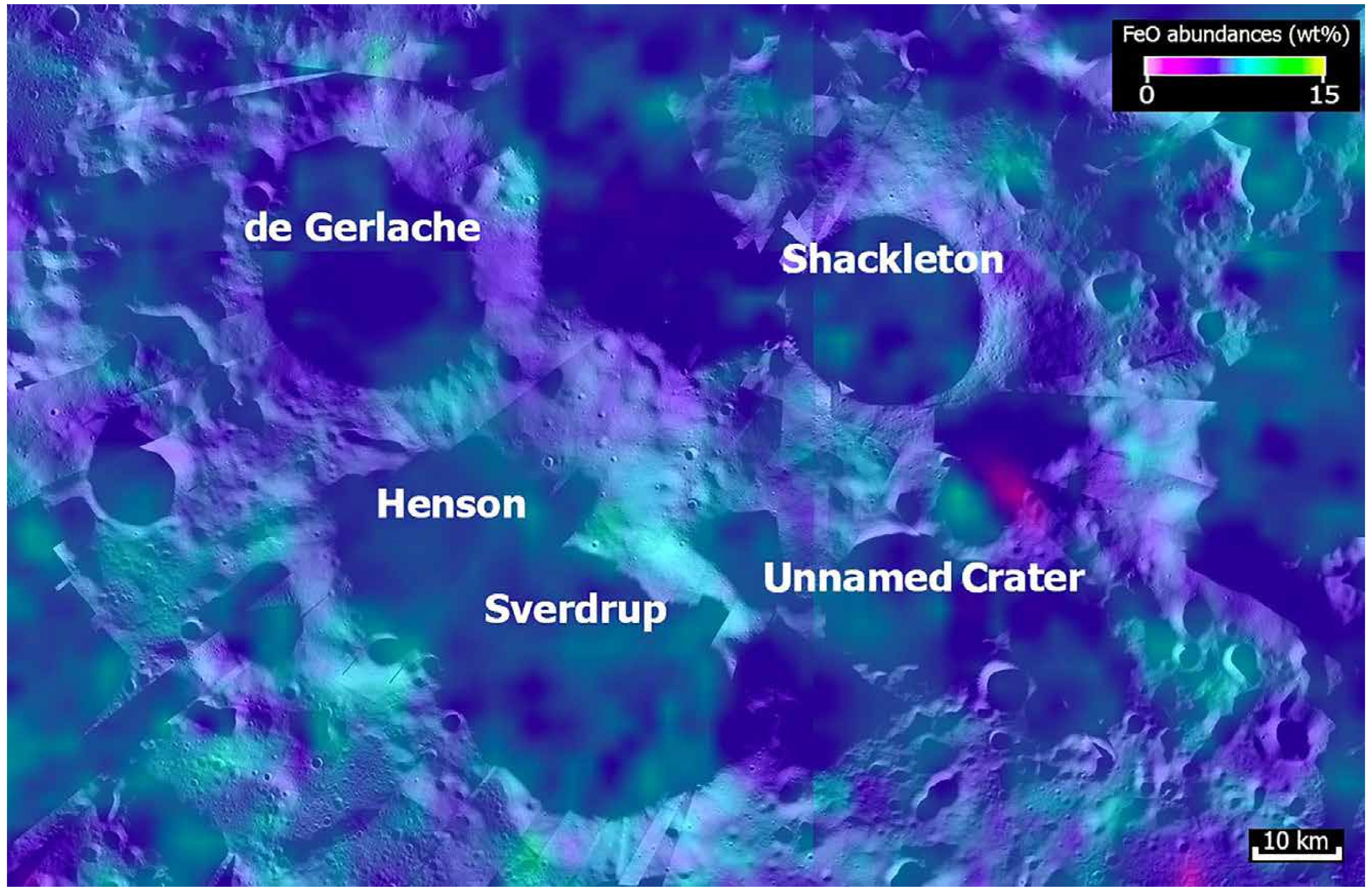

*Map of **iron oxide** abundance*

Available mineral resources

Another crucial factor involves the **availability of mineral resources** essential for constructing technological equipment through **In-Situ Resource Utilization (ISRU)**. Notably, **iron and titanium oxides**, as well as **rare earth elements**, play a key role. These materials are prominently found in the Oceanus Procellarum KREEP Terrane (PKT), particularly in the eastern part of the Em4 geological unit, but recent sampling has provided insights into this region. Additionally, the area is rich in rare earth elements, with concentrations of up to 4.6 wt. % **yttrium** and up to 0.25 wt. % **neodymium**.

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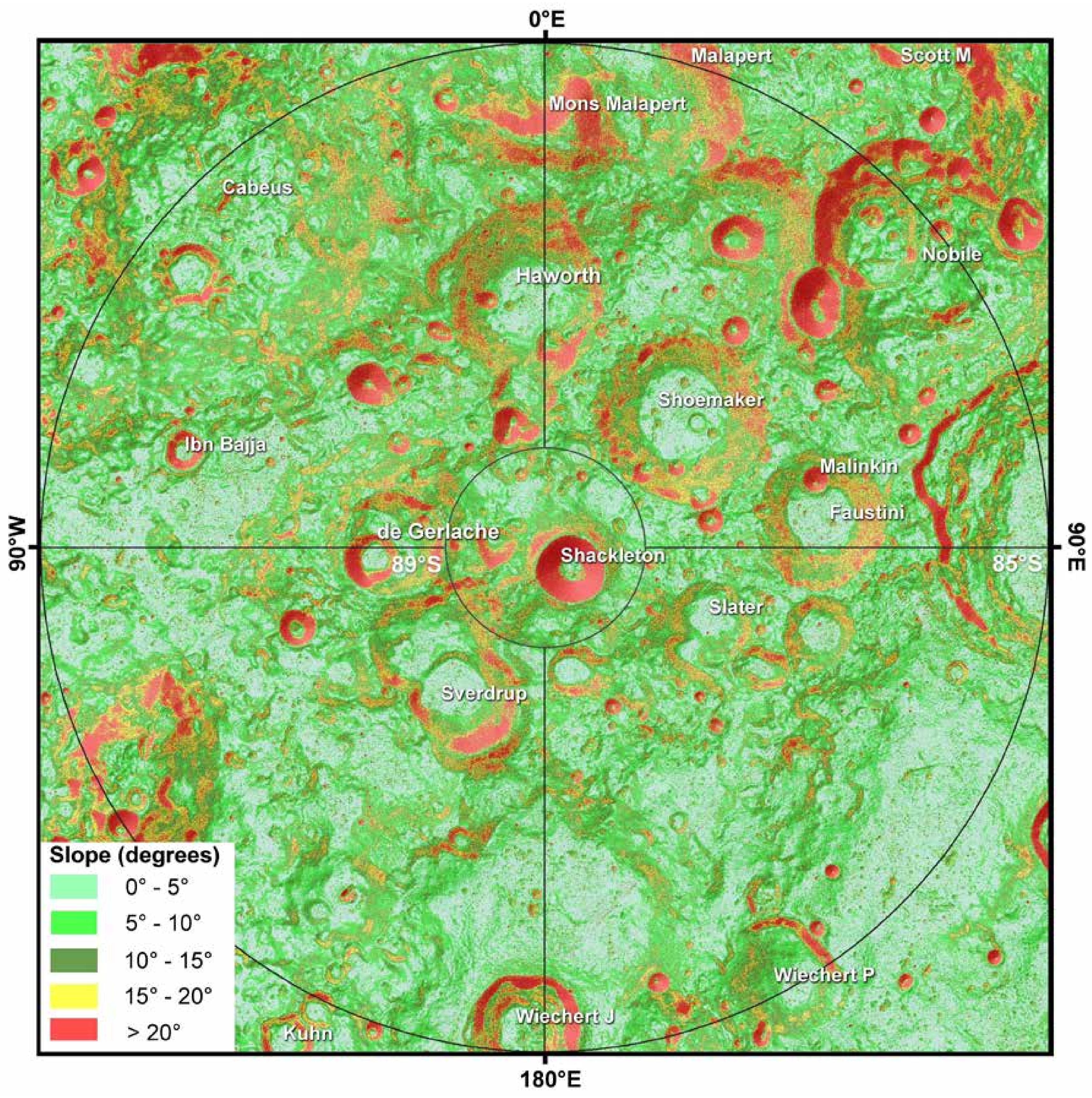
CARTOGRAPHIES

From the Lunar South Pole Atlas

The following slides show some interesting and relevant cartographic maps developed by the **Center for Lunar Science and Exploration**. They showcase **high quality,** relevant site data such as elevation, slope, and near surface temperatures, among others, of the investigated area.



Detailed slope map, in 5 degree breaks

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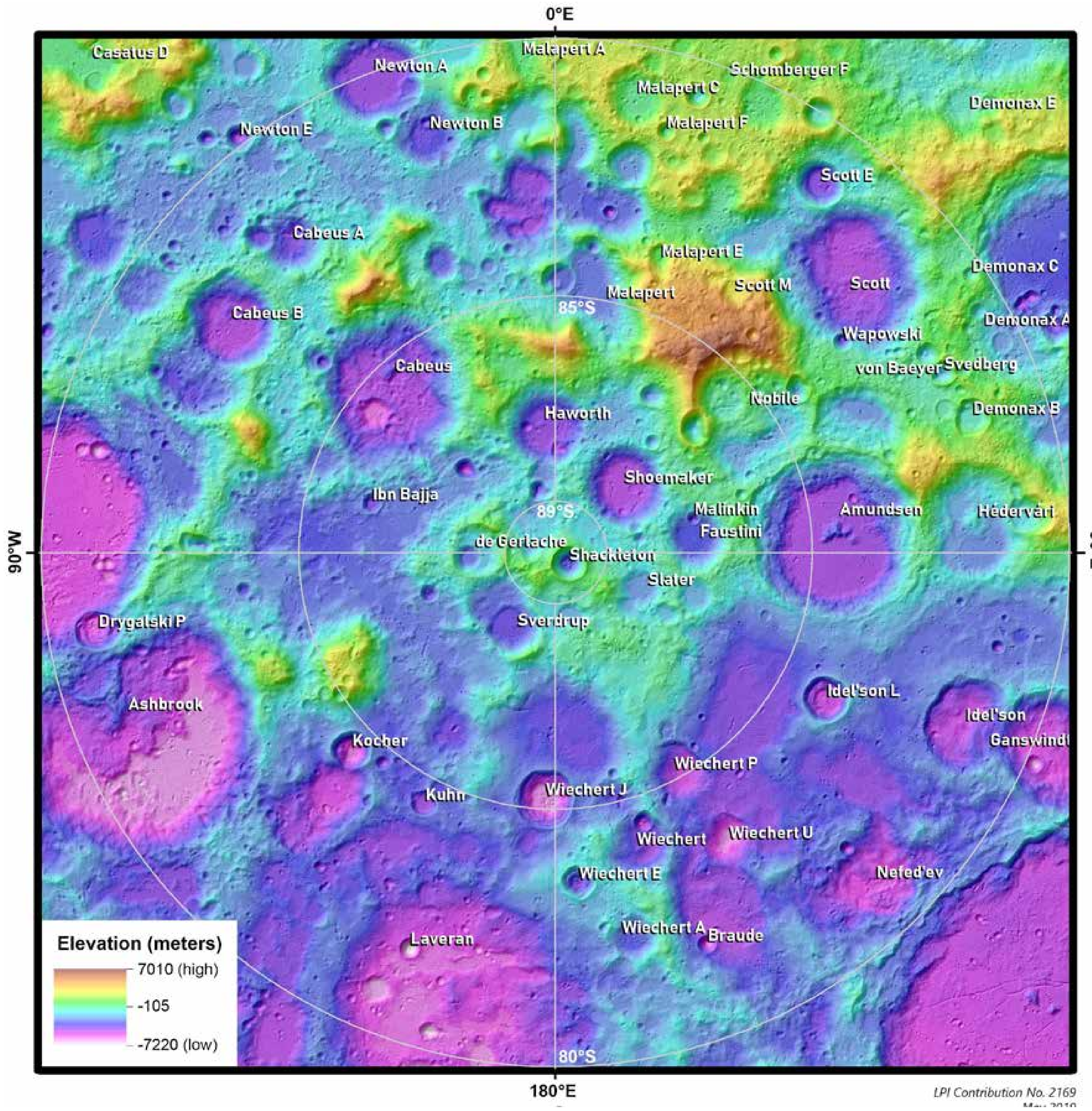
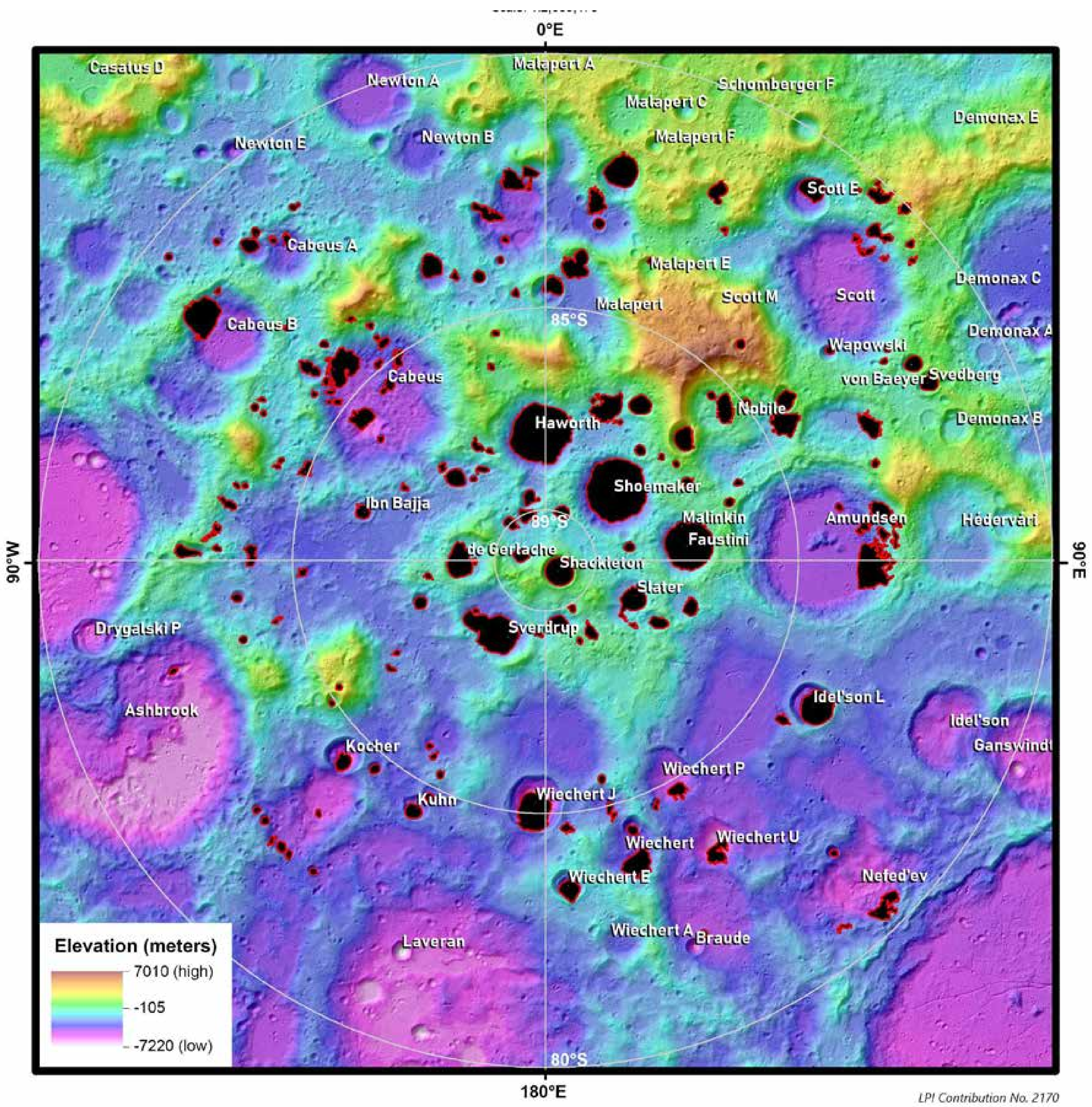


*Elevation map, in meters. The height difference is **greater than 14000 meters** between the highest and lowest points.*



*The **permanently shadowed regions (PSRs)** overlayed on the elevation map.*

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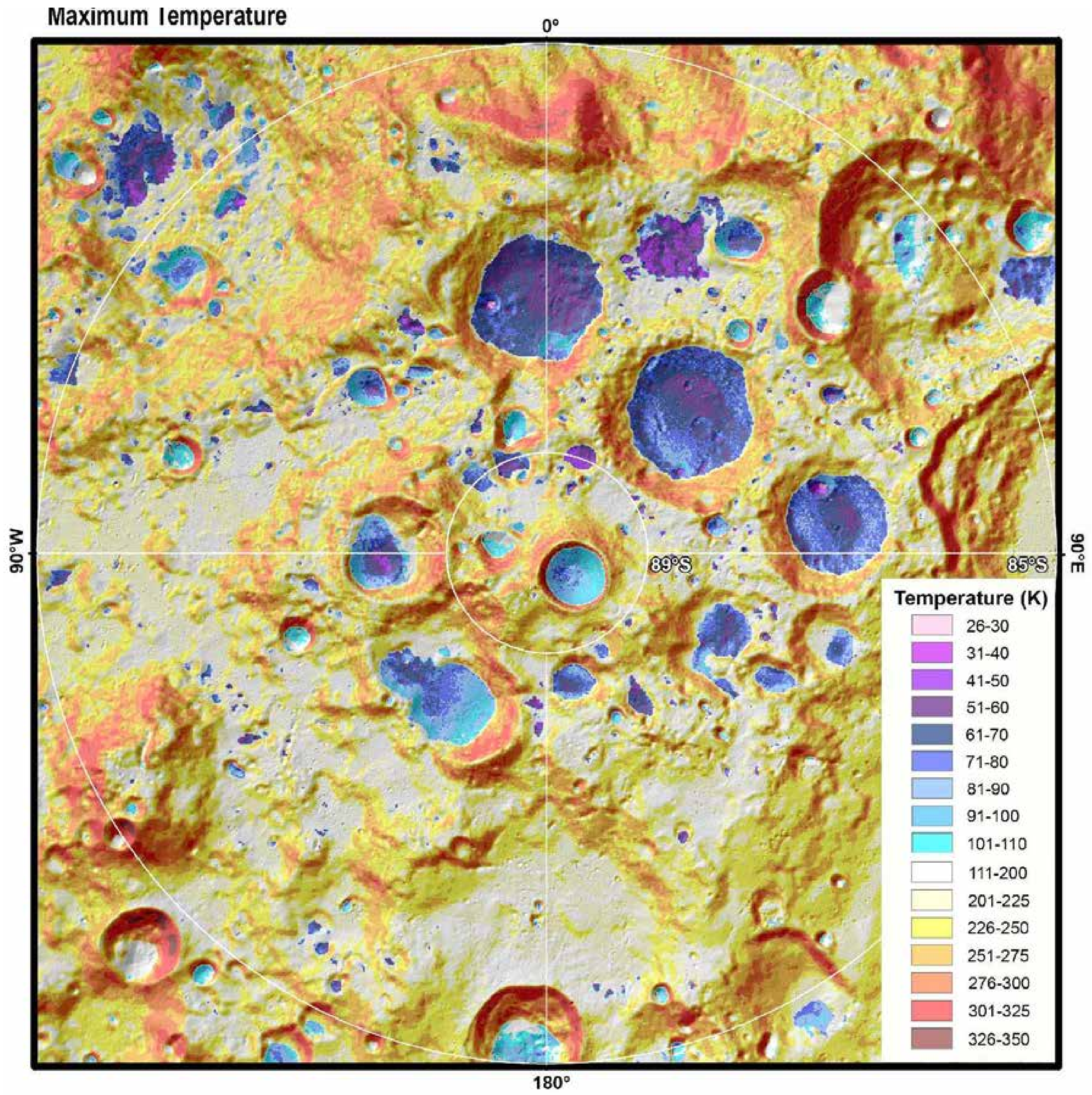
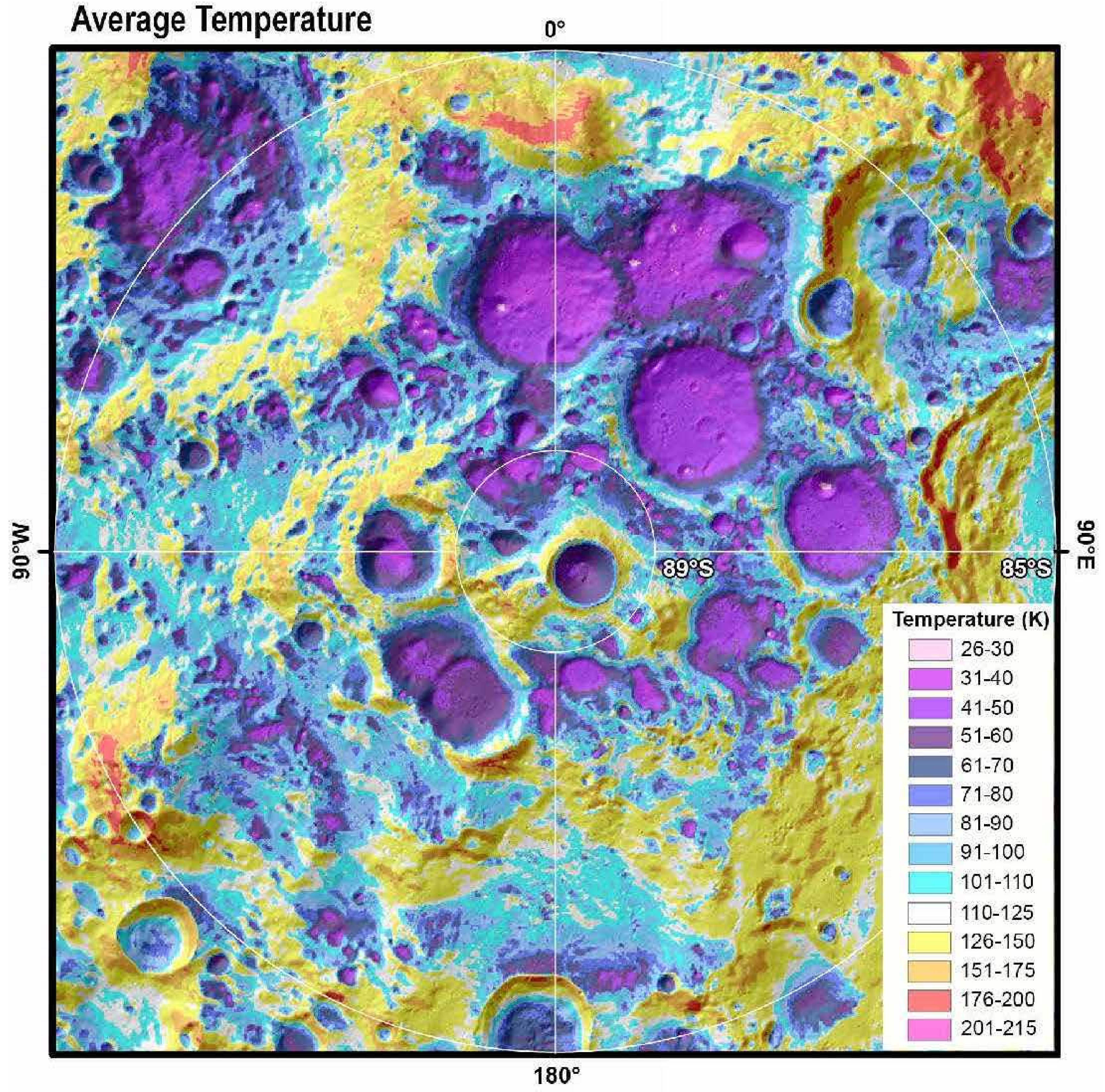
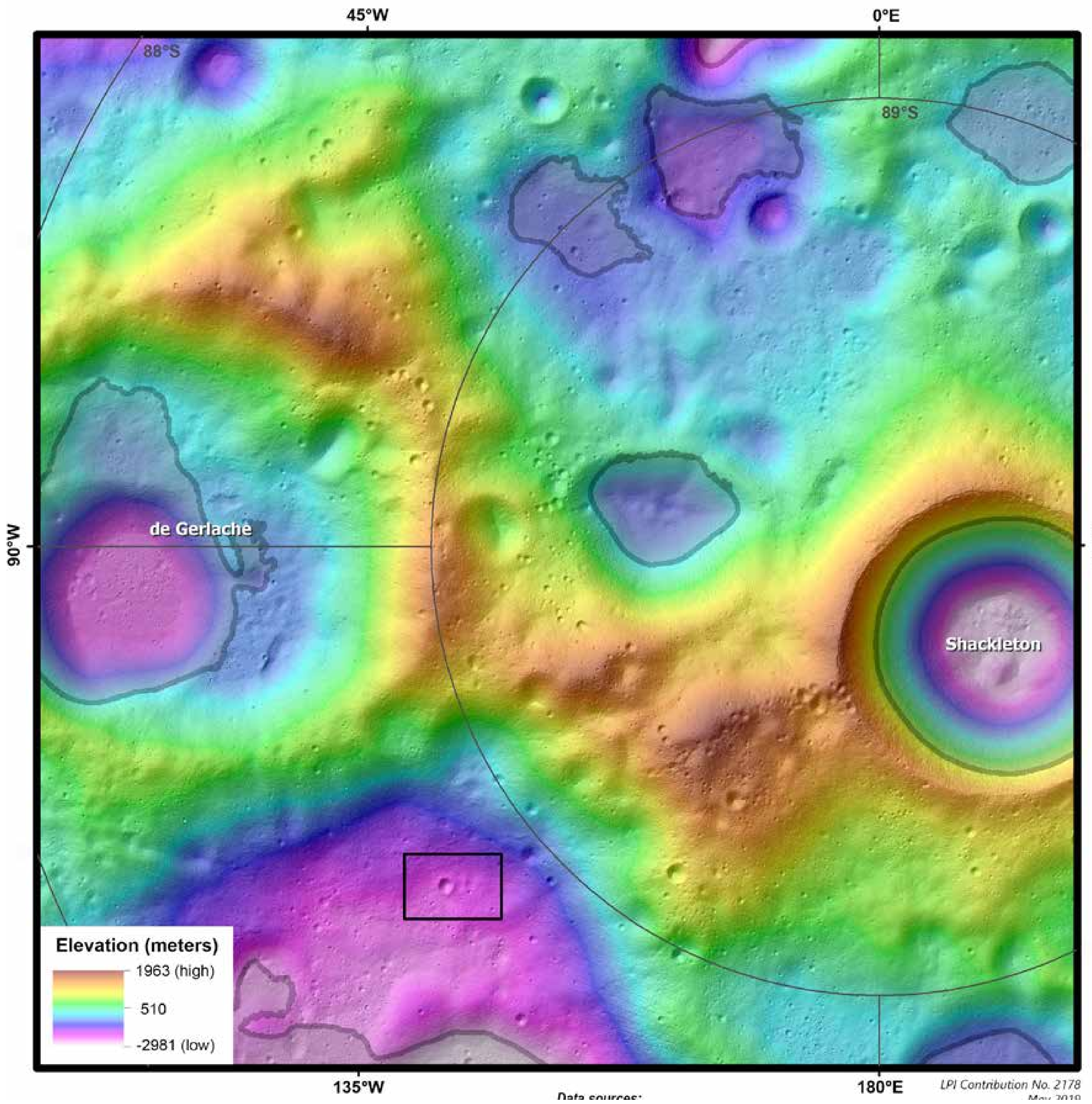


***Maximum temperatures** map, **in Kelvin**. They're notably lower on craters and PSRs.*

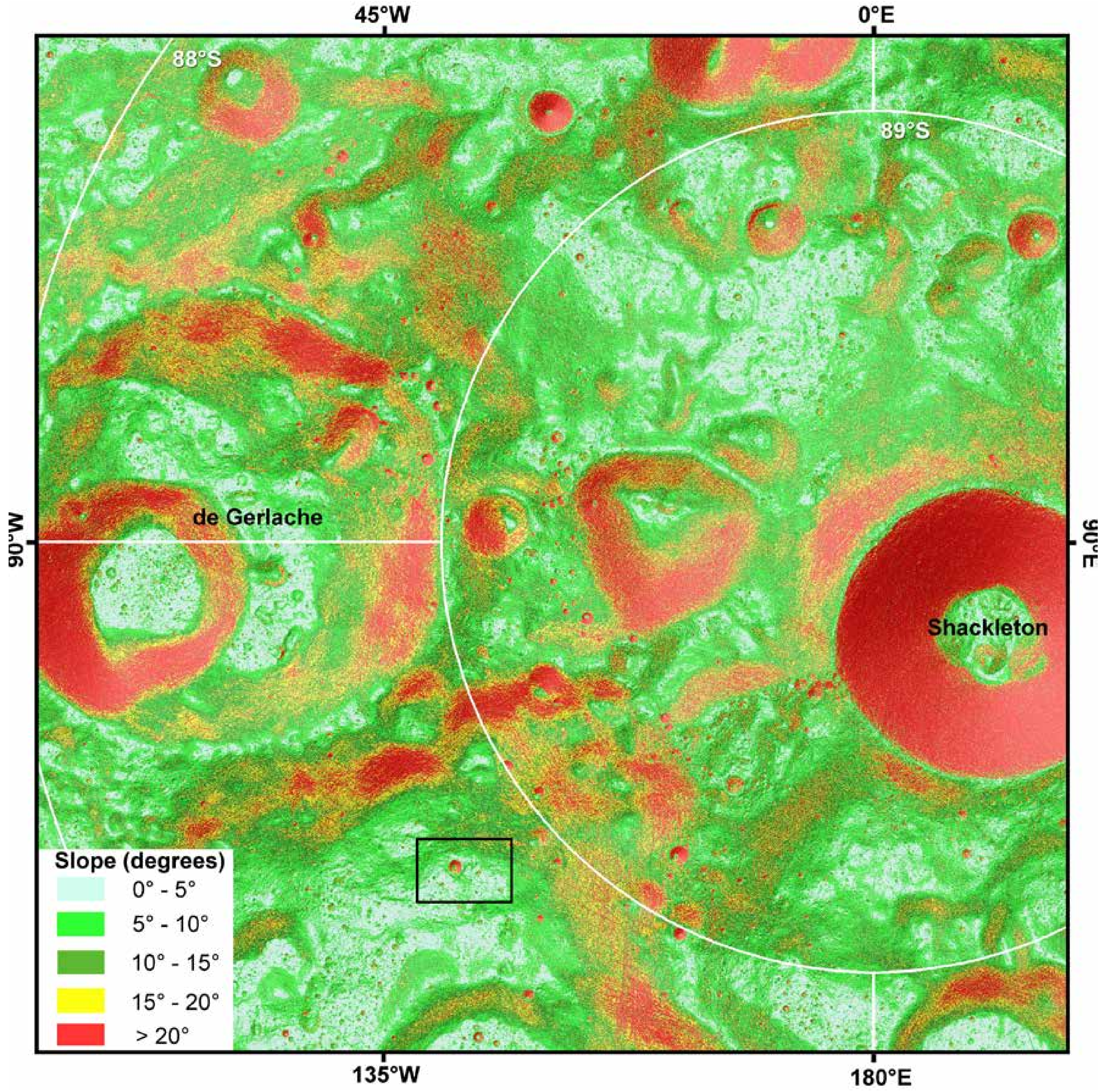


***Average temperatures** map, in Kelvin*

Site-overlaid close up cartographies:



Detailed slope map, in 5 degree breaks



Detailed slope map, in 5 degree breaks

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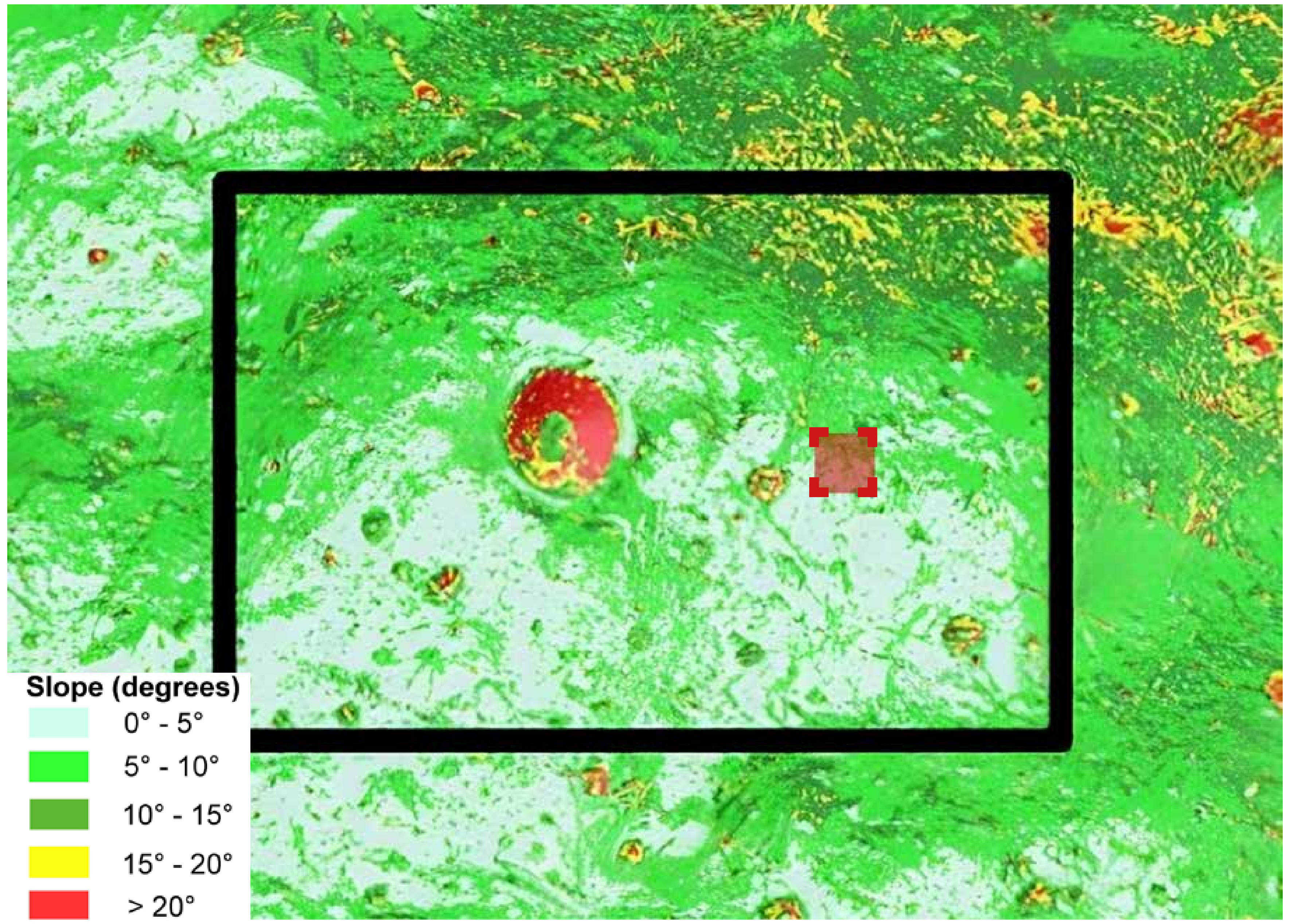
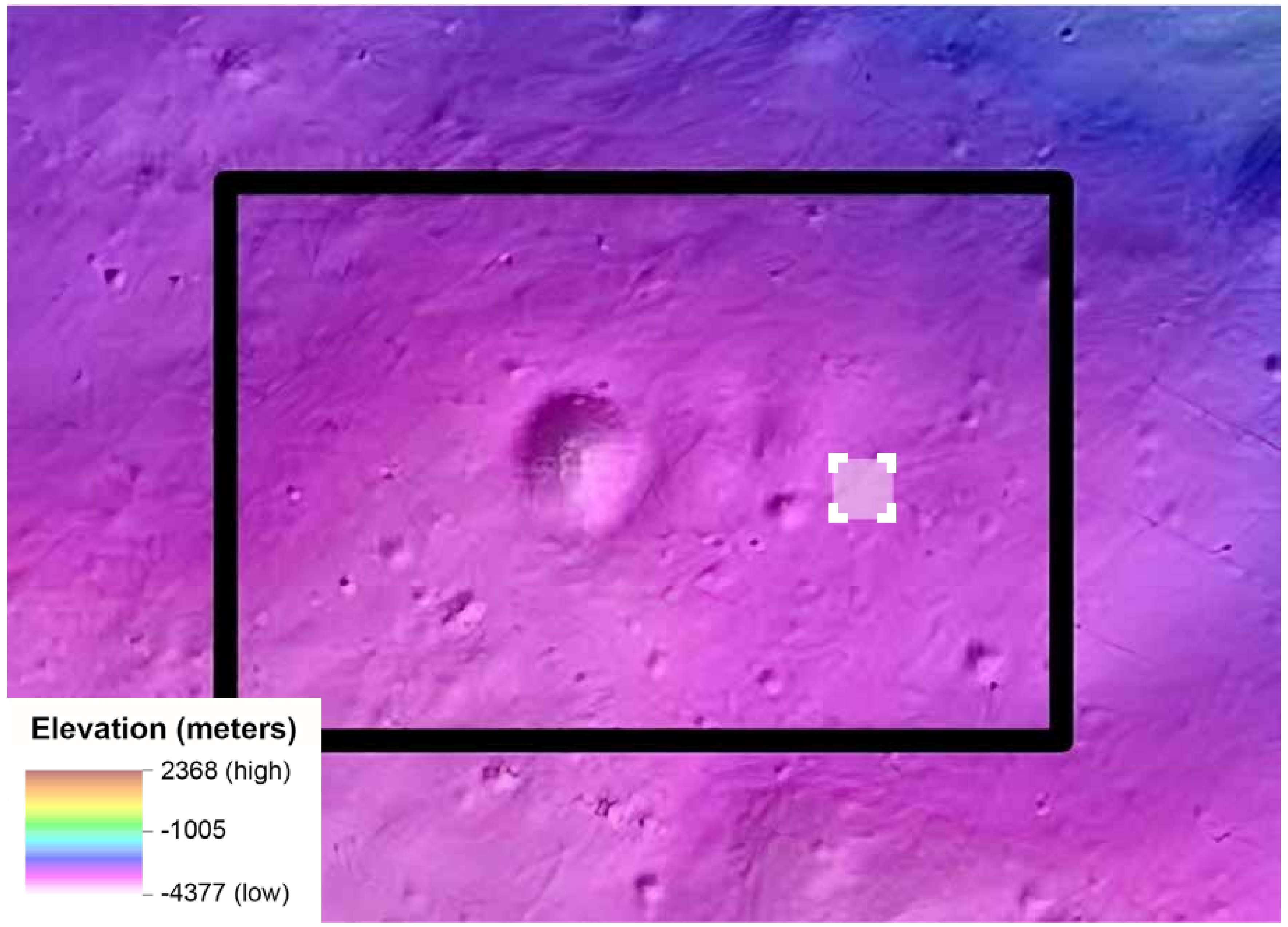


Slope map with site location



Slope map with site location

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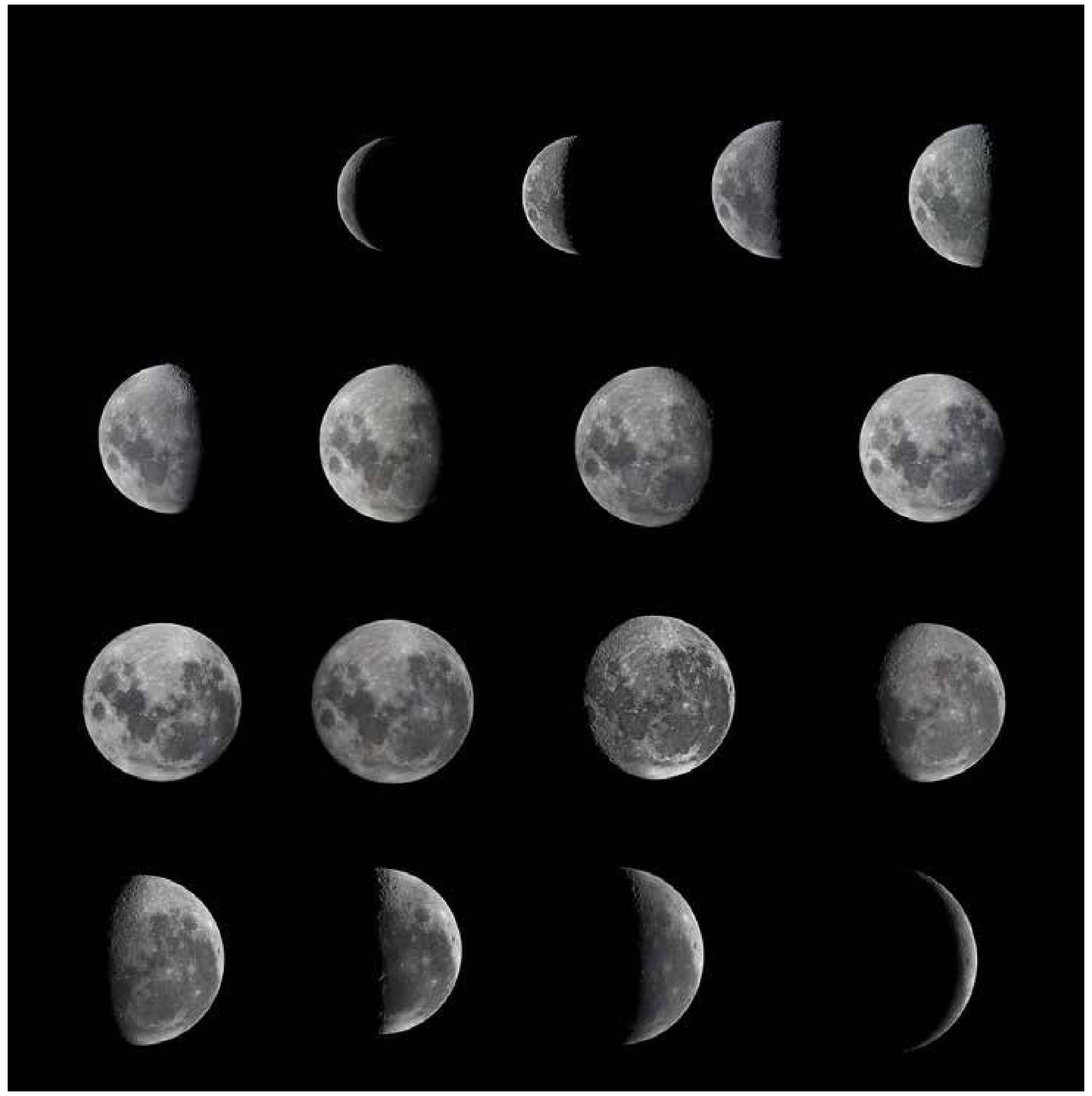
CLIMATIC ANALYSIS

•**Extreme temperature conditions** (from +127 ºC to -173 ºC). **In the PSRs** the temperature can be even lower, as temperatures of **up to -246 ºC** have been recorded.
•**Radiation from the Sun is very intense**, more than a hundred times that of Earth: the measured surface radiation in the Moon is 60 μSv/hr, while on Earth it usually remains below 0.2 μSv/hr.
•**Gravity is 1.62 m/s², one sixth of Earth's**.
•**A Lunar day**, that is, the time it takes the Moon to complete on its axis one synodic rotation, **takes 29.5 Earth days**. That means approximately **350 hours of continuous Sun** exposure and heating and **another 350 hours of darkness and cold**.



Lunar day cycle

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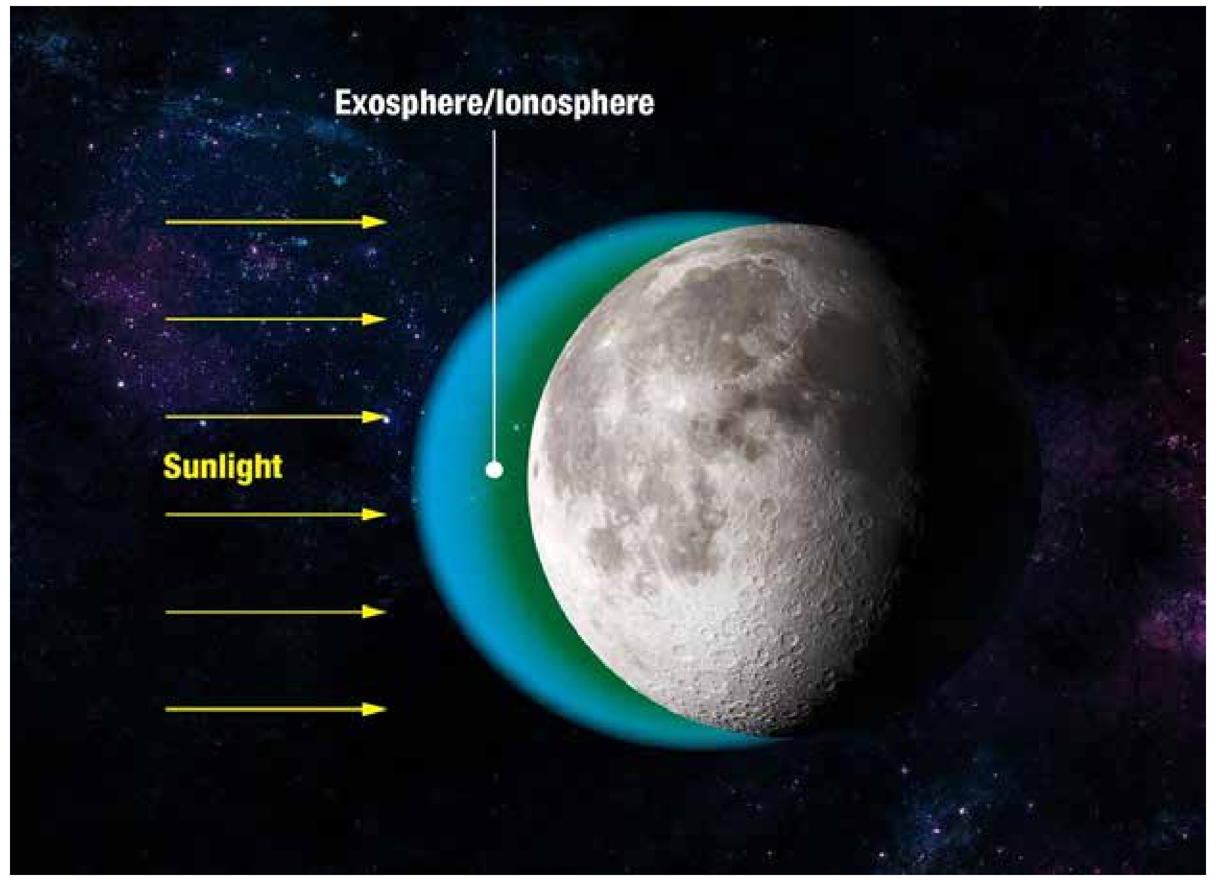
• **Micrometeoroids**, and sometimes larger space objects, **impact the lunar surface on a regular basis**. This dry shower of debris shuffles materials in the Moon's exterior layers, exposing fresh material in a process known as **impact gardening.**

• There is a very thin type of atmosphere on the Moon, known as an **exosphere**, which contains **helium, argon, neon, ammonia, methane and carbon dioxide.** The exosphere is **not breathable**, and **in the cold lunar night it falls to the ground.**



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2 _ PROGRAMS AND NEEDS

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BERTHING	RECREATION	WORKSPACE	EXERCISE	HYGEINE	STORAGE	SAFETY BUNKER
Docking station for vehicles	Sleeping pods (private)	Multifunctioning laboratories	Multifunctioning exercise spaces	Bathing and bathroom spaces (communal)	Multi-use storage zone	Self-contained underground bunker in case of emergency
Emergency exits	Dining space (communal)	Hydroponics				
	Lounging spaces (communal)					

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BERTHING

DOCKING STATION

EMERGENCY EXIT ZONE

VOLUME	TIME SPENT USING SPACE	ABOVE OR BELOW GROUND	INTERNAL RISK RATING	EXIT POINTS BASED ON INTERNAL RISK
60 m^3	Variable time Docking procedures can last from several minutes to a few hours. 15 mins - 3 hrs	Above ground Easy access for shipping deployments	2	Docking Station: 2+ exits Emergency Exit Zones 2+ exits

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RECREATION

SLEEPING PODS (PRIVATE)

DINING SPACE (COMMUNAL)

LOUNGING (COMMUNAL)

VOLUME	TIME SPENT USING SPACE	ABOVE OR BELOW GROUND	INTERNAL RISK RATING	EXIT POINTS BASED ON INTERNAL RISK
Sleeping Pods - 45 m^3 total 9 m^3 / person Dining - 20 m^3 Lounging - 20 m^3	Sleeping - 8 hrs Dining - 30 mins to 1 hr per meal, max 3 hrs per day Lounging - variable time, estimate 3 hrs	Below ground High security	Sleeping - 1 Dining - 2 Lounging - 1	Sleeping Pods 1 exit Dining Space 2 exits Lounging Spaces (Communal) 2 exits

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WORKSPACE

MULTIPURPOSE LABORATORIES

HYDRAPONICS GREENHOUSE

VOLUME	TIME SPENT USING SPACE	ABOVE OR BELOW GROUND	INTERNAL RISK RATING	EXIT POINTS BASED ON INTERNAL RISK
Laboratories 100 m^3 Hydroponics Greenhouse 80 m^3	Variable time Laboratories - 5 hrs Hydroponics - 5 hrs In conjunction with Lunar Surface Activities - 5 hrs	Sub-level - analysis of upper surface and controlled labs beneath the surface Controlled space - high-security	Laboritories - 3 Hydroponics - 2	Laboritories 2 exits Hydroponics 2 exits

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EXERCISE

MULTI-PURPOSE EXERCISE SPACES (COMMUNAL)

VOLUME	TIME SPENT USING SPACE	ABOVE OR BELOW GROUND	INTERNAL RISK RATING	EXIT POINTS BASED ON INTERNAL RISK
40 m^3	1-2 hrs a day	Above ground Interaction with sunlight	1	2 exits

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HYGEINE

BATHROOM AND BATHING SPACES (COMMUNAL)

VOLUME	TIME SPENT USING SPACE	ABOVE OR BELOW GROUND	INTERNAL RISK RATING	EXIT POINTS BASED ON INTERNAL RISK
30 m^3	1 hr a day	Below ground Controlled space	1	Bathroom 1 exit Bathing 1 exit

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STORAGE

MULTI-PURPOSE STORAGE FACILITY

VOLUME	TIME SPENT USING SPACE	ABOVE OR BELOW GROUND	INTERNAL RISK RATING	EXIT POINTS BASED ON INTERNAL RISK
40 m^3	Variable time Estimate 2 hrs Access as needed	Below ground Highly controlled space High security	2	2 exits

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BUNKER

UNDERGROUND
EMERGENCY
BUNKER
SELF-CONTAINED

VOLUME	TIME SPENT USING SPACE	ABOVE OR BELOW GROUND	INTERNAL RISK RATING	EXIT POINTS BASED ON INTERNAL RISK
100 m^3	Variable time In case of emergency Estimate of 8 hrs	Below ground High security	2	2 exits

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3 _ ASSEMBLY AND CONSTRUCTION

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LUNAR CHALLENGES

LUNAR SOIL IS DANGEROUS

Potential of acute and/or chronic multiorgan toxicities
No direct wall contact, no regolith can be carried inside

ASSEMBLY MUST BE AIRTIGHT

1 bar pressure and breathable atmosphere

OPTIONS
Binder, Spray/Glaze, Membrane, Tiles, Tube that can be extended

Pohlen, M., Carroll, D., Prisk, G.K. et al. Overview of lunar dust toxicity risk. npj Microgravity 8, 55 (2022). https://doi.org/10.1038/s41526-022-00244-1

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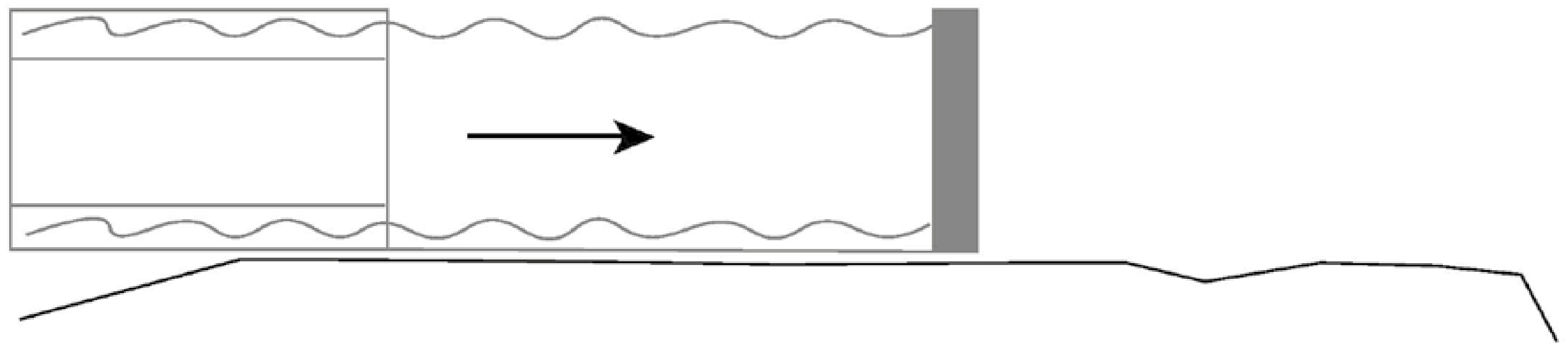
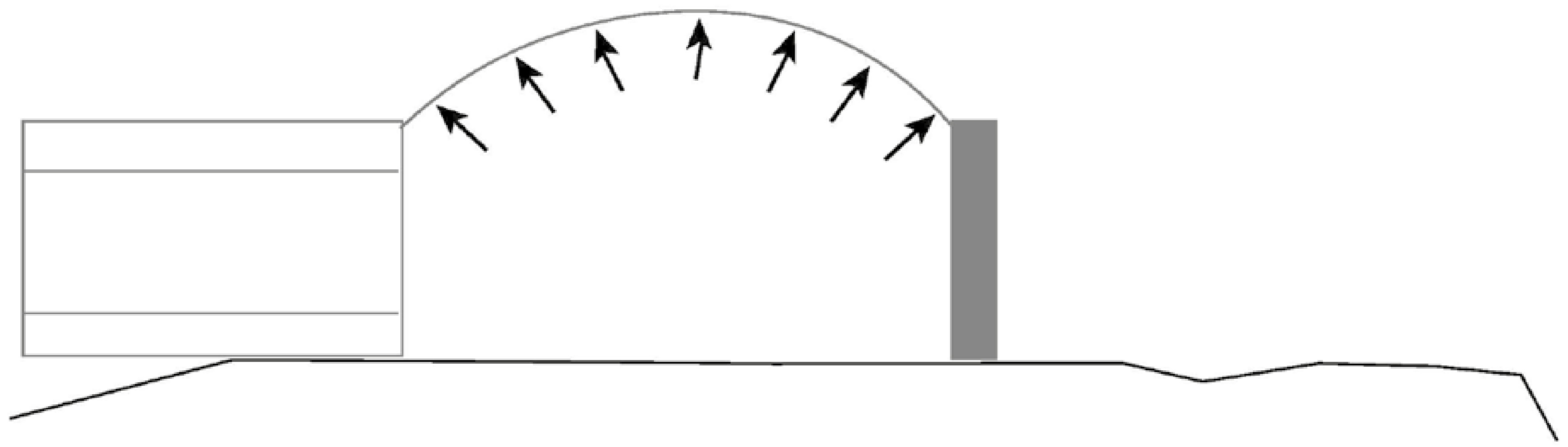
Assembly Process

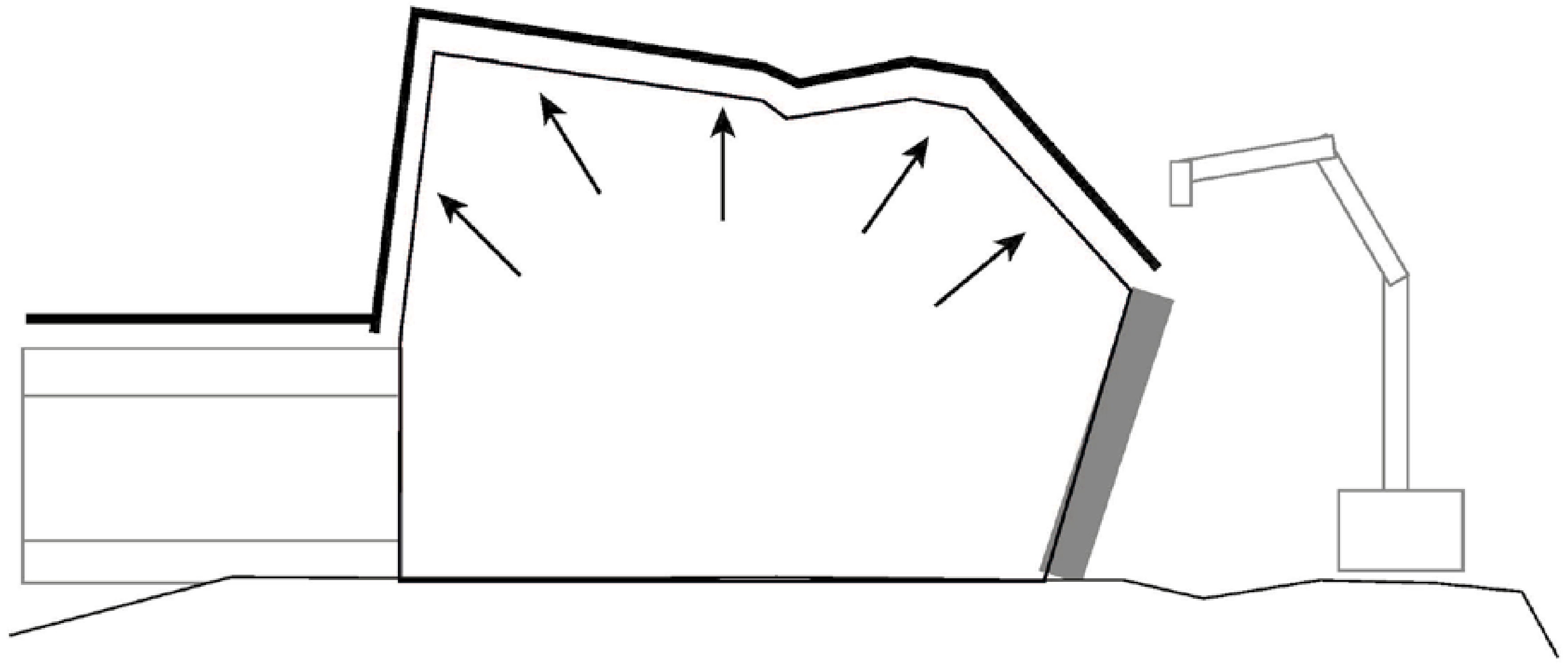
Step 0: Airlock



Step 1: Opening process



Step 2: Membrane inflation



Step 3: Voronoi-shell printing and connecting it to membrane

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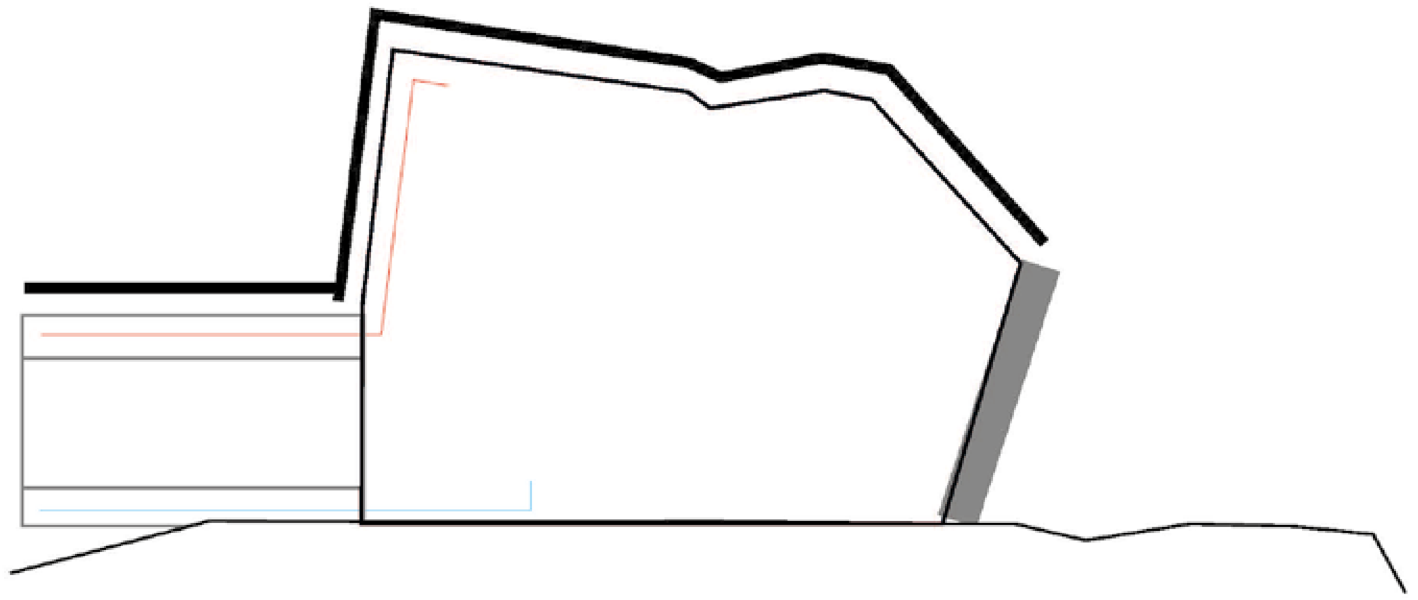
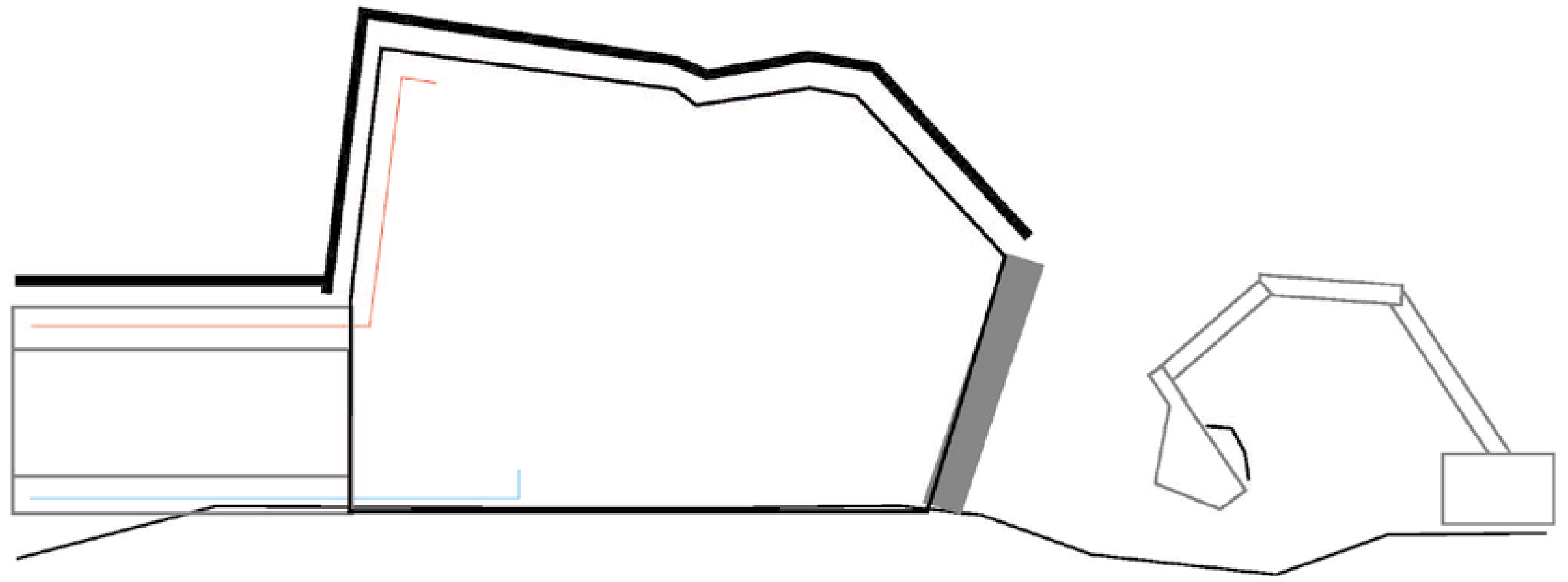
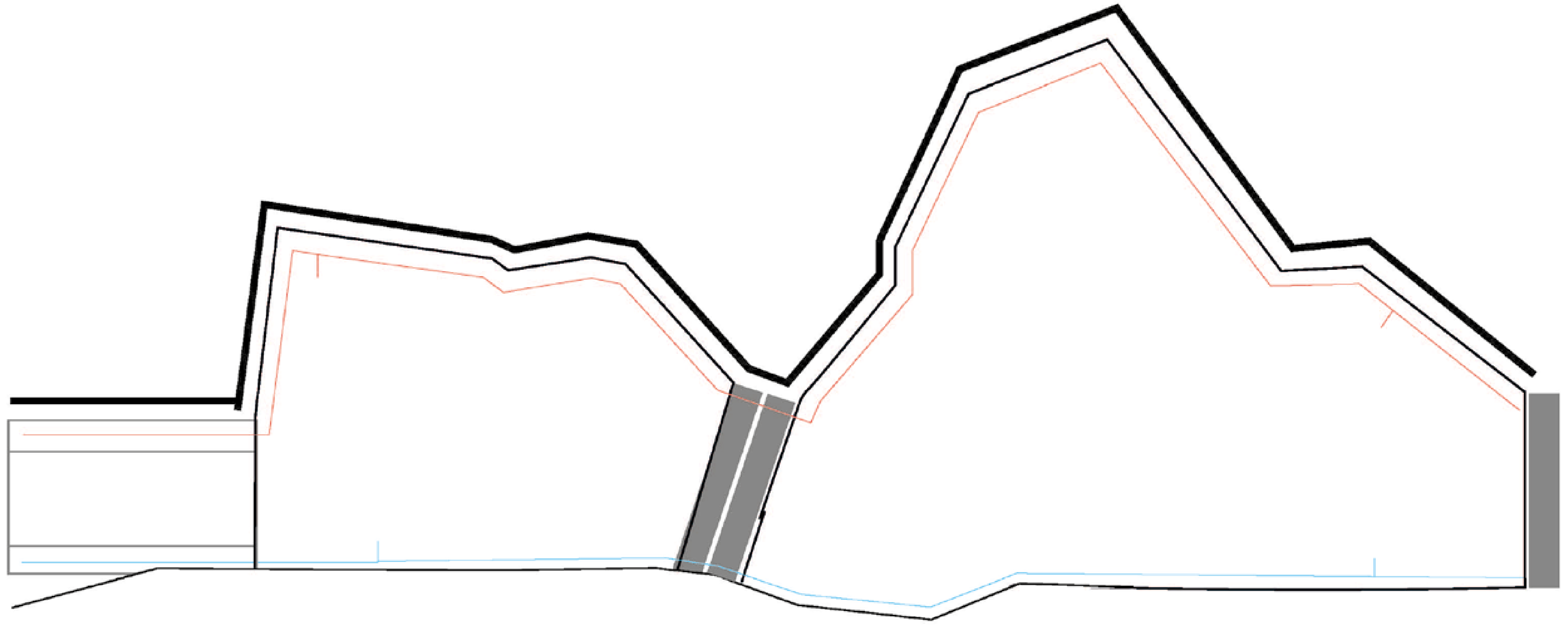
Assembly Process



Step 4: Connecting/launching LSS



Step 5: Underground extraction



Step 6: Repeating the process for the next module

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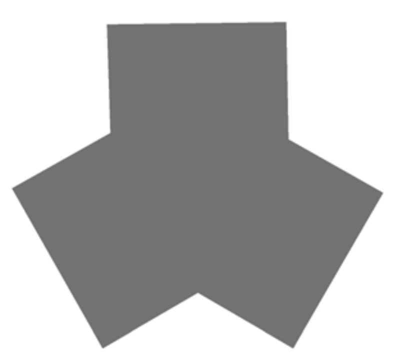
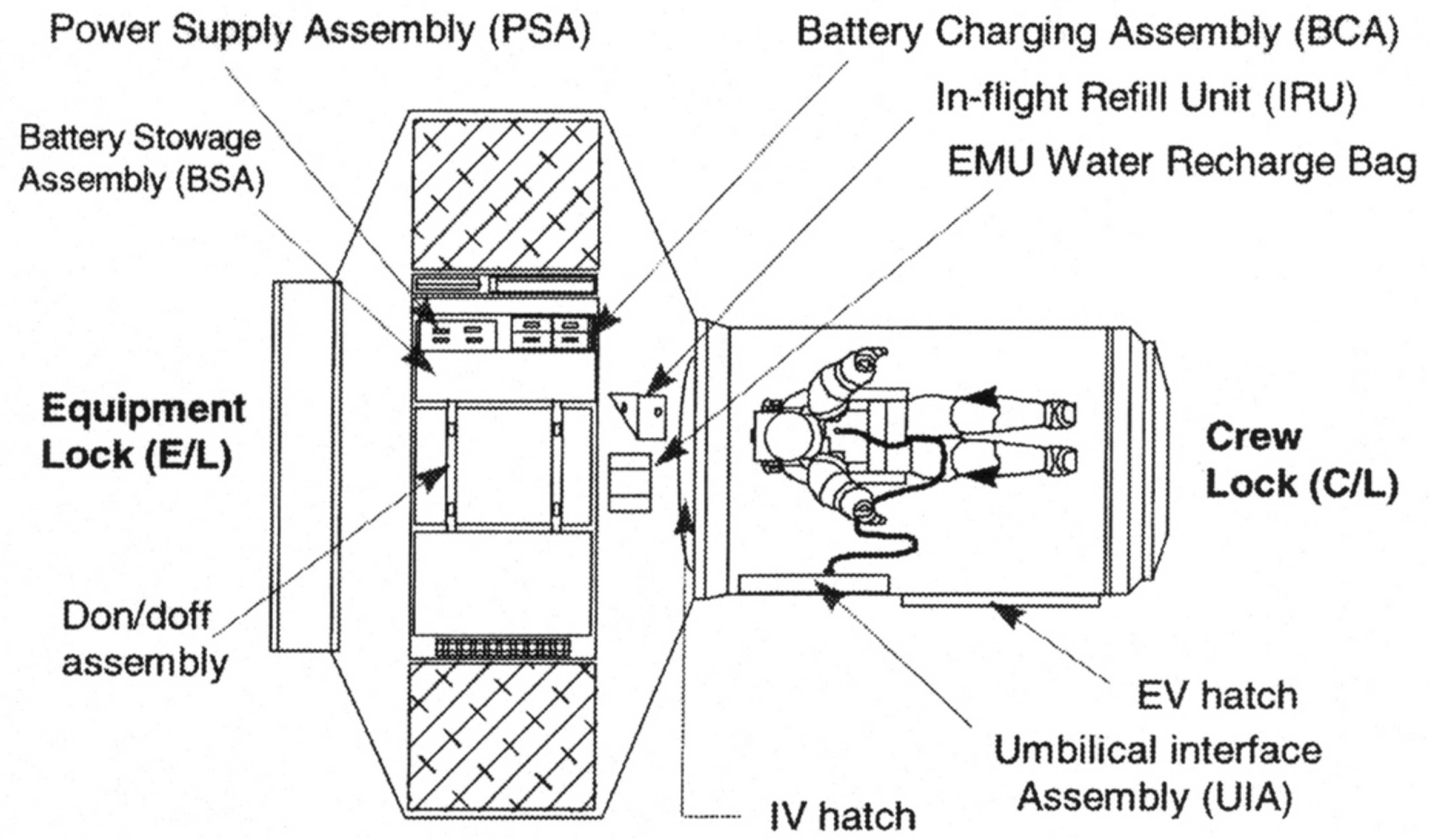
Components - Airlock



Geometry and Dimensions:
Isotoxal-star-form with three entrances to ensure modular connectivity, safe emergency routes and pollution-free entering/leaving the module

Entrance:
Voroni- module entrance: always the same shape as airlock

Functionality:
holds the LSS
provides electricity access
seals habitat
prevents habitat from regolith pollution



https://www.lpi.usra.edu/lunar/artemis/Mary-2018-EVA%20Airlocks-And-Alternative-Ingress-Egress-EVA-EXP-0031.pdf

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Components - Membrane

Adaptable Geometry:
Flexible fabric that can fit modules of x m3 (large membrane) or y m3 (small membrane)

Integrated Sensor Array:
Oxygen, Carbondioxide, Particles, Smoke, Temperature

Radiation Protection and Airtightness:
While the 3D print is still wet, the mebrane can be attached to the shell with the help of the soft spikes that can be pressed into the regolith layer

https://arstechnica.com/science/2019/08/one-could-fly-to-mars-in-this-spacious-habitat-and-not-go-crazy/

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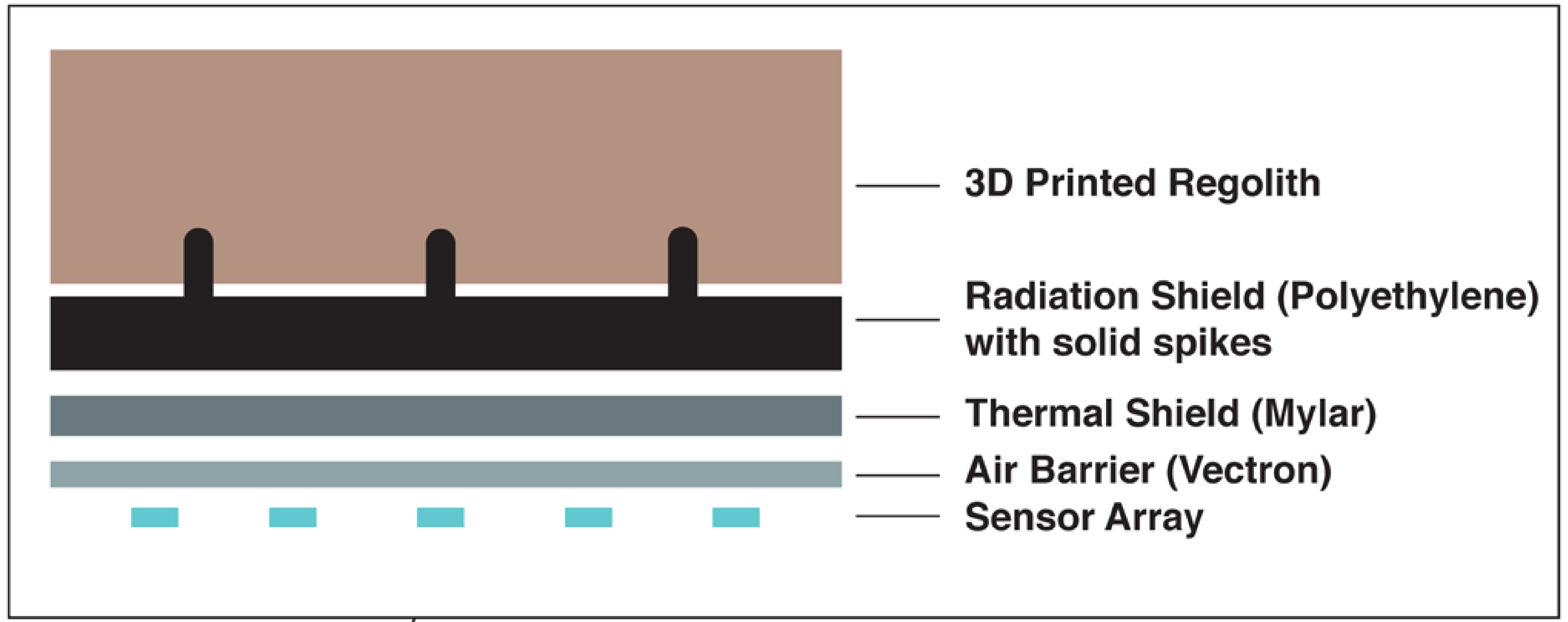
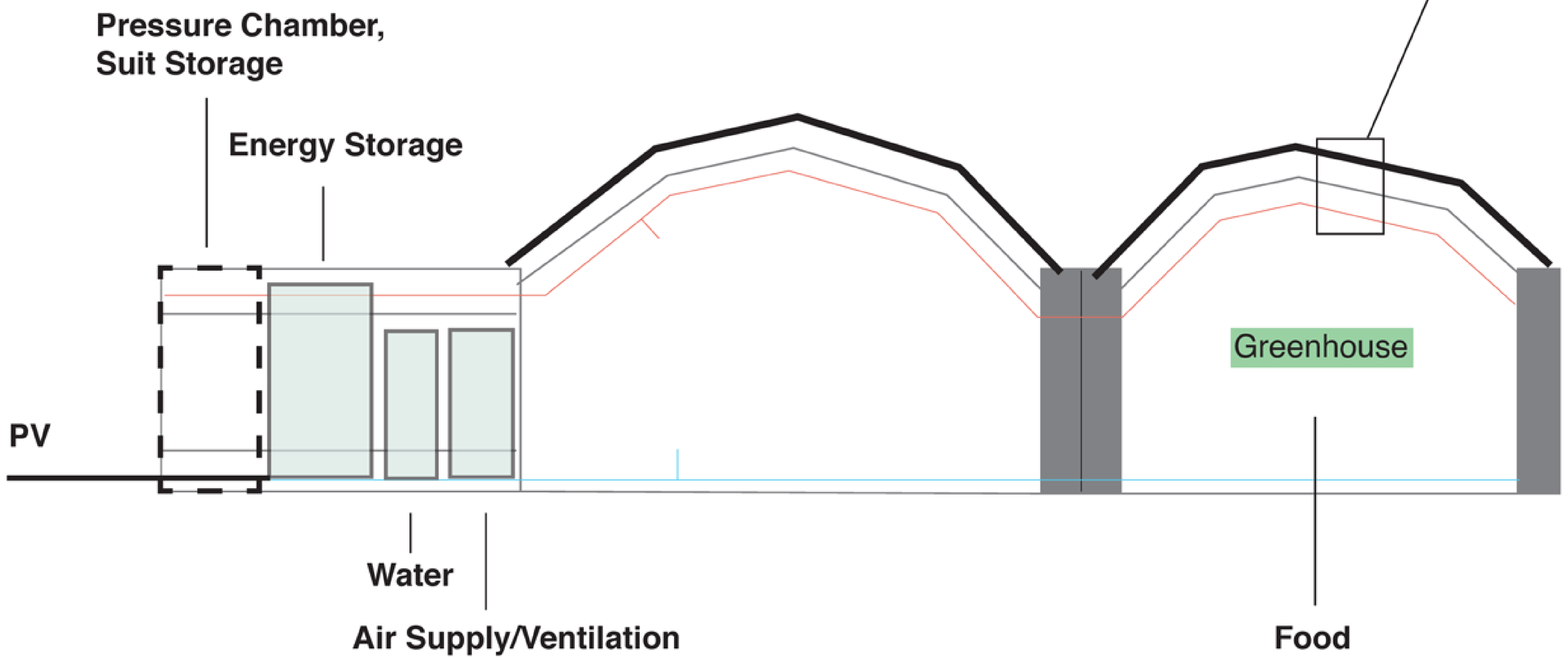
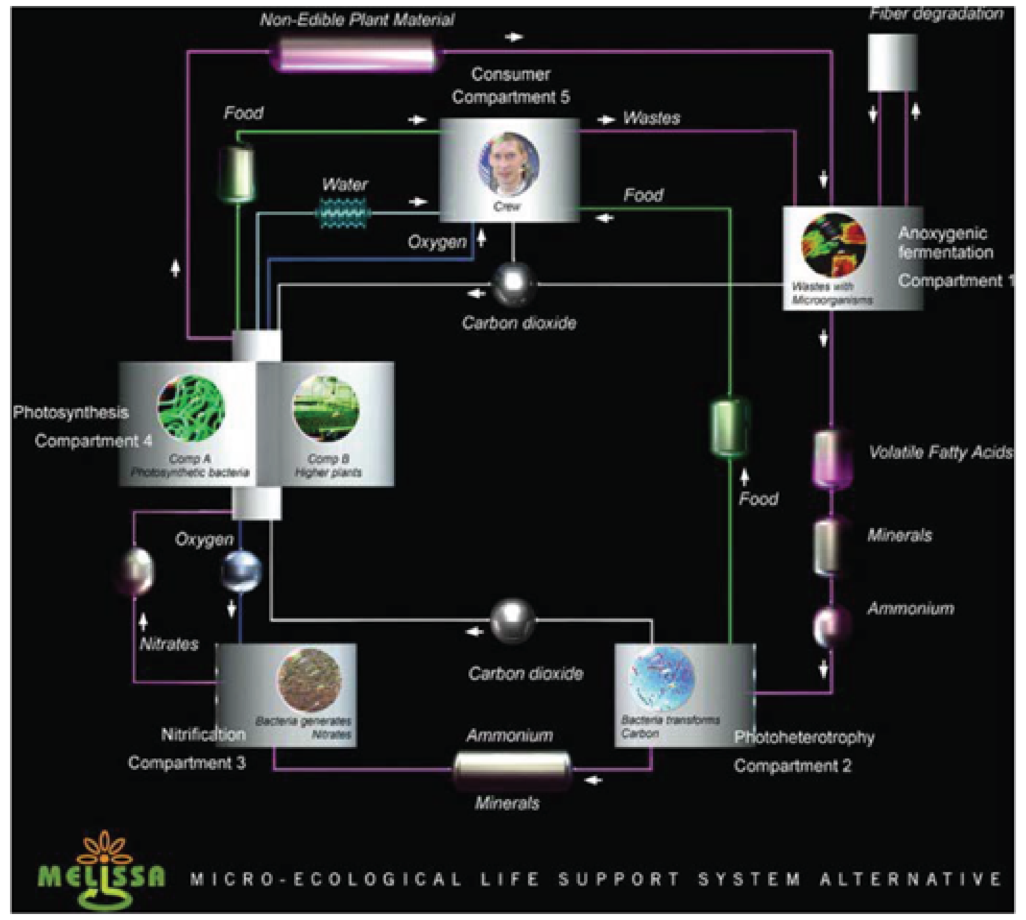
Components - Overview

Cables:
Base: 3 cables
Add-on: 2 cables

Flexible Pipes:
Base: 2 pipes
Add-on: 1 pipe







https://link.springer.com/chapter/10.1007/ 978-3-030-52859-1_3

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4 _ ENERGY AND MATERIALITY

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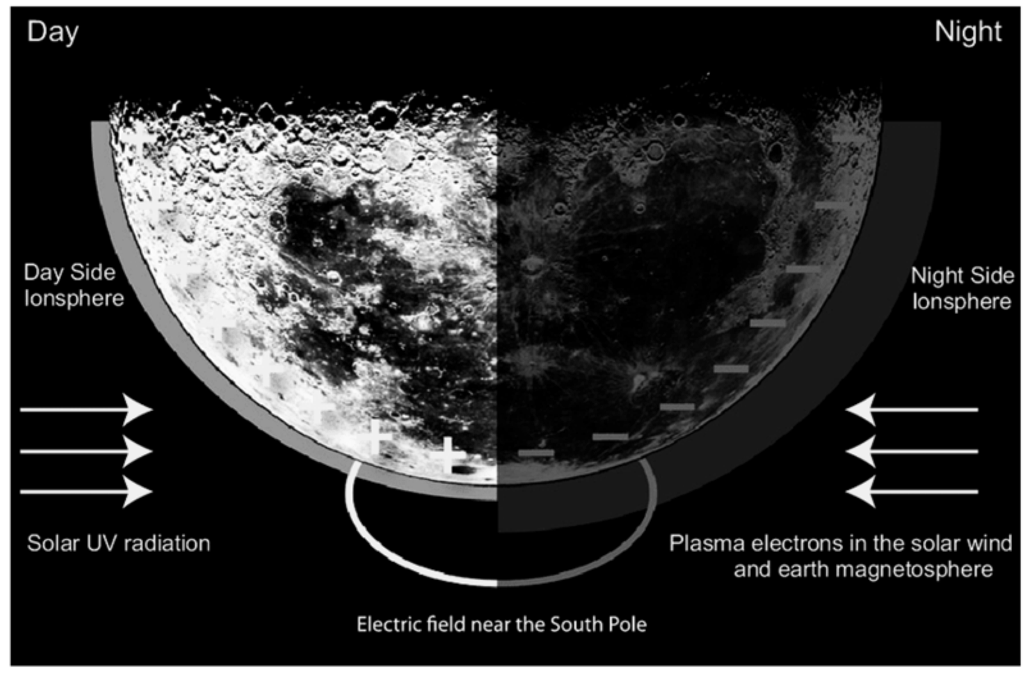
Radiation Protection

Exposure: Galactic cosmic radiation (GCR), Electromagnetic radiation (EM), Charged Particles (Protons, Electrons), Solar Particle Events (SPE) + Secondary Radiation (neutrons)

https://link.springer.com/content/pdf/10.1007/978-3-319-14541-9_179.pdf



https://www.researchgate.net/figure/Day-and-night-difference-on-the-Lunar-South-Polar-location-solar-UV-radiation-causes-the_fig2_230853777

Material Choice:

Radiation Protection of 3d printed regolith (Rhizome)? Geopolymer Binder Lunamer?
https://www.sciencedirect.com/science/article/pii/S0273117715004019?casa_token=7WhQc2vwIhwAAAAA:NRXUCd7Kc8sTs4IKwNj6Riw-WHTAOGvcNLF8M-QIrrLvIkbLl4B7iw5M1bdZYVbHET15xUZ1B2g

1) Recycled high-density polyethylene plastic (r-HDPE) reinforced with ilmenite mineral (Ilm)
Flexible “fabric”, not a structural material

https://pubs.rsc.org/en/content/articlehtml/2023/ra/d3ra03757f

2) Hydrogenated BNNT (nanotubes constructed of carbon, boron, nitrogen, hydrogen)
Can be structural
https://www.nasa.gov/general/radiation-shielding-materials-containing-hydrogen-boron-and-nitrogen-systematic-computational-and-experimental-study/

Wall Thickness
Habitat Position (surface or subsurface, which room where)
Window Number and Position (direct or no direct radiation exposure)

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Energy

https://www.sciencedirect.com/science/article/pii/S0094576521002289?casa_token=Ga-QD7l0HaoAAAAA:nEM-Sux46FxqeKvr2_Tp2508QrPT4Db4axNo1hEhVqsNK0BTzpwGjh_Bv9f-3a9bIRu3y22AlWw

Demand: depends mainly on its inventory and usage profile, along with the round trip efficiency of the applied energy storage system (ESS)

Generation:
Electricity: PV (efficiency, light exposure on site)
https://www.sciencedirect.com/science/article/pii/S030626192100266X?casa_token=0MxkHRTDgaQAAAAA:HL-tO-ni-lCin-_4osWvUwUlW1x0UjQ_Z-NP8-CBVq608W1HOF-McjSFoUSzC098FQs3lSAhGPQ#f0010

Heat: Internal heat gains?
Food: Melissa LSS and Greenhouse

Storage:
Lithium-Ion Batteries
Regenerative Fuel Cells
Lithium-Sulphur Batteries

-> Find out energy demand (KW) for core unit (x astronauts, y rooms)
-> Include growth of PV, batteries, greenhouse, LSS etc. in script

Considerations:

- total power demand of the base;
- daily power load management strategy;
- type of applied power source;
- type of solar array structure;
- type of energy storage or energy buffering system;
- the base location (selenographic latitude);
- solar illumination conditions

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5 _ PARAMETRIC INPUTS AND DESIGN

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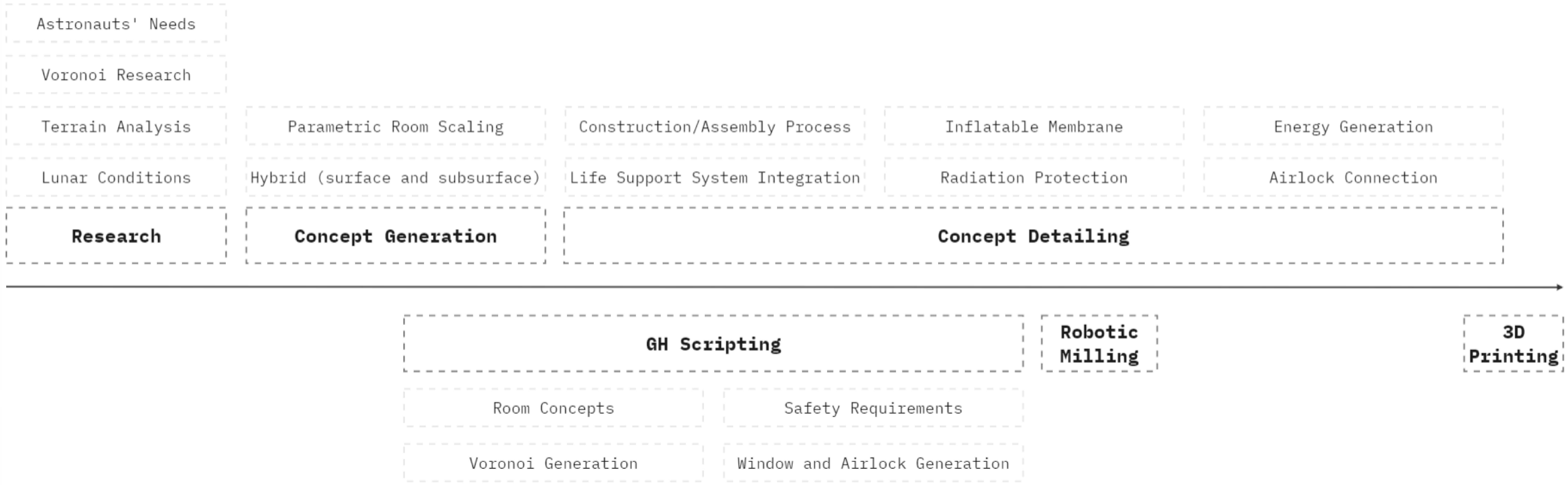
Timeline of the design process:



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INPUT FACTORS

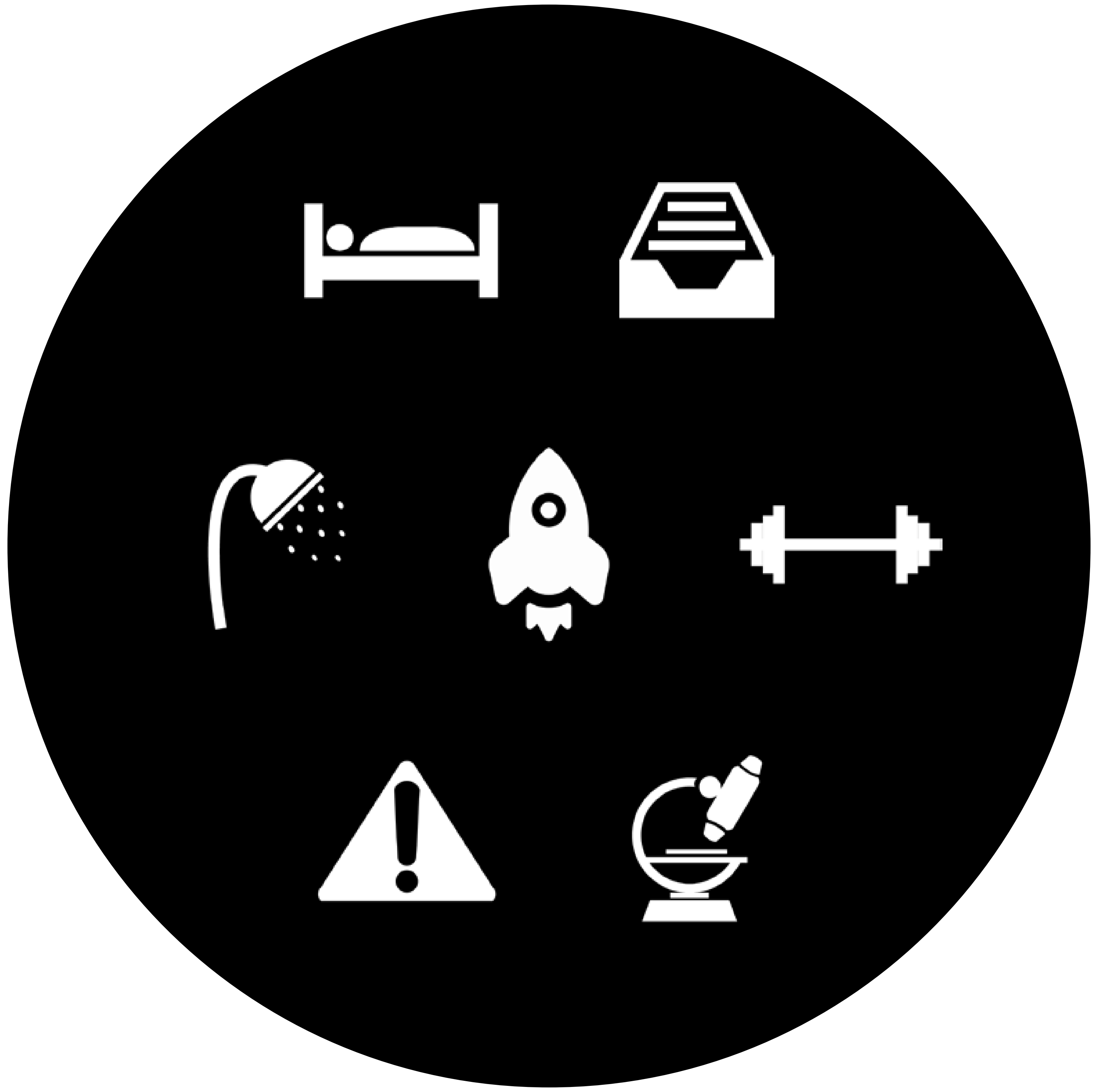
SIZE
Slider 0-100 metre cubed

TIME SPENT (SECURITY)
Wall Thickness 2h x 40cm
Toggle Underground

INTERNAL RISK
Risk Levels
Determine Distance from the Centre

ROOM CONNECTIONS

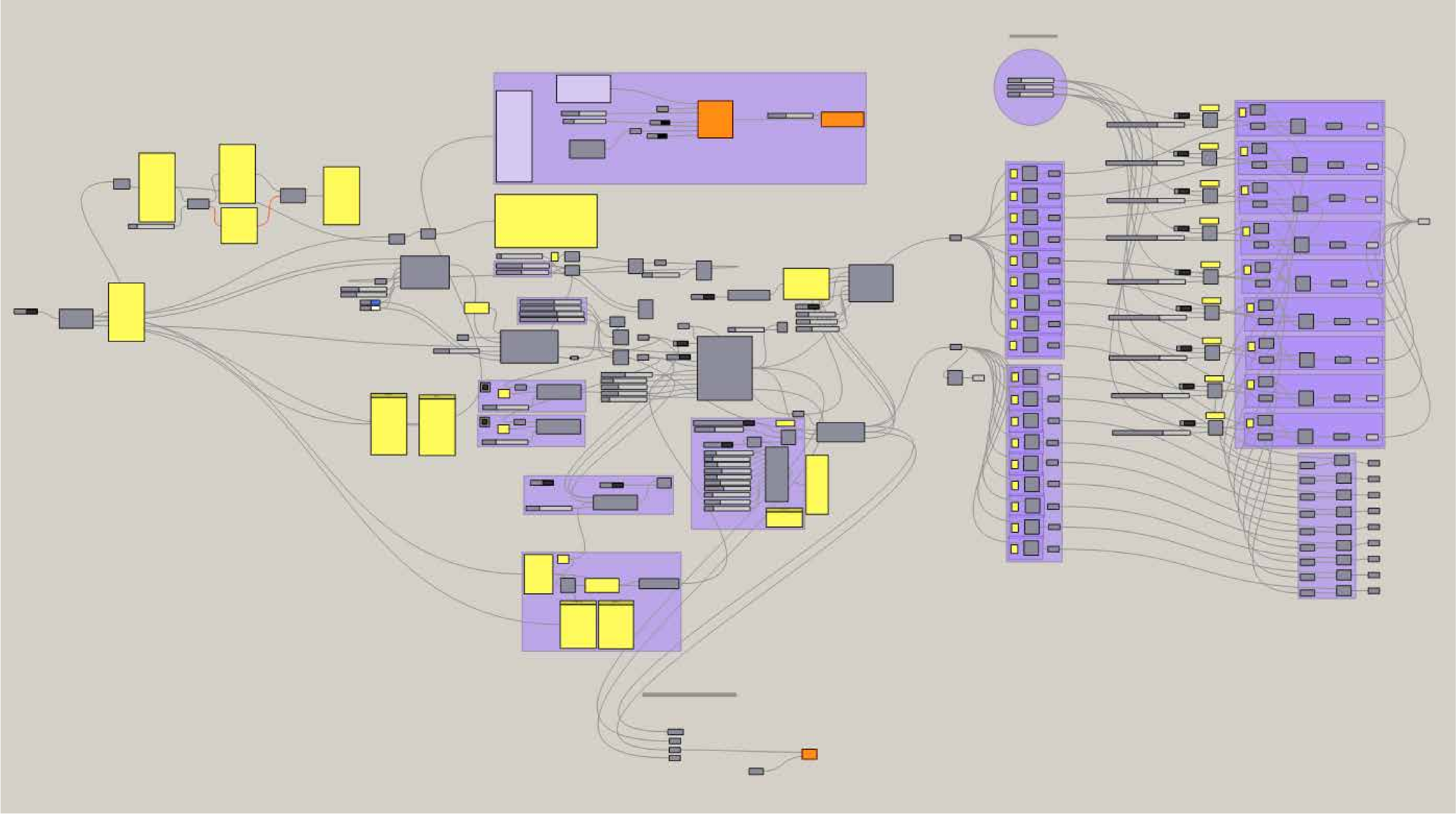
DOORS/OPENINGS
Based on Internal Risk Levels



Maximillian **Friedmann**
Lilian **Le**
Víctor **López Leftérov**
Antonia **Sattler**
Lowie **Swinkels**

GRASSHOPPER SCRIPT

Obtaining positions and sizes according to the use and risk level



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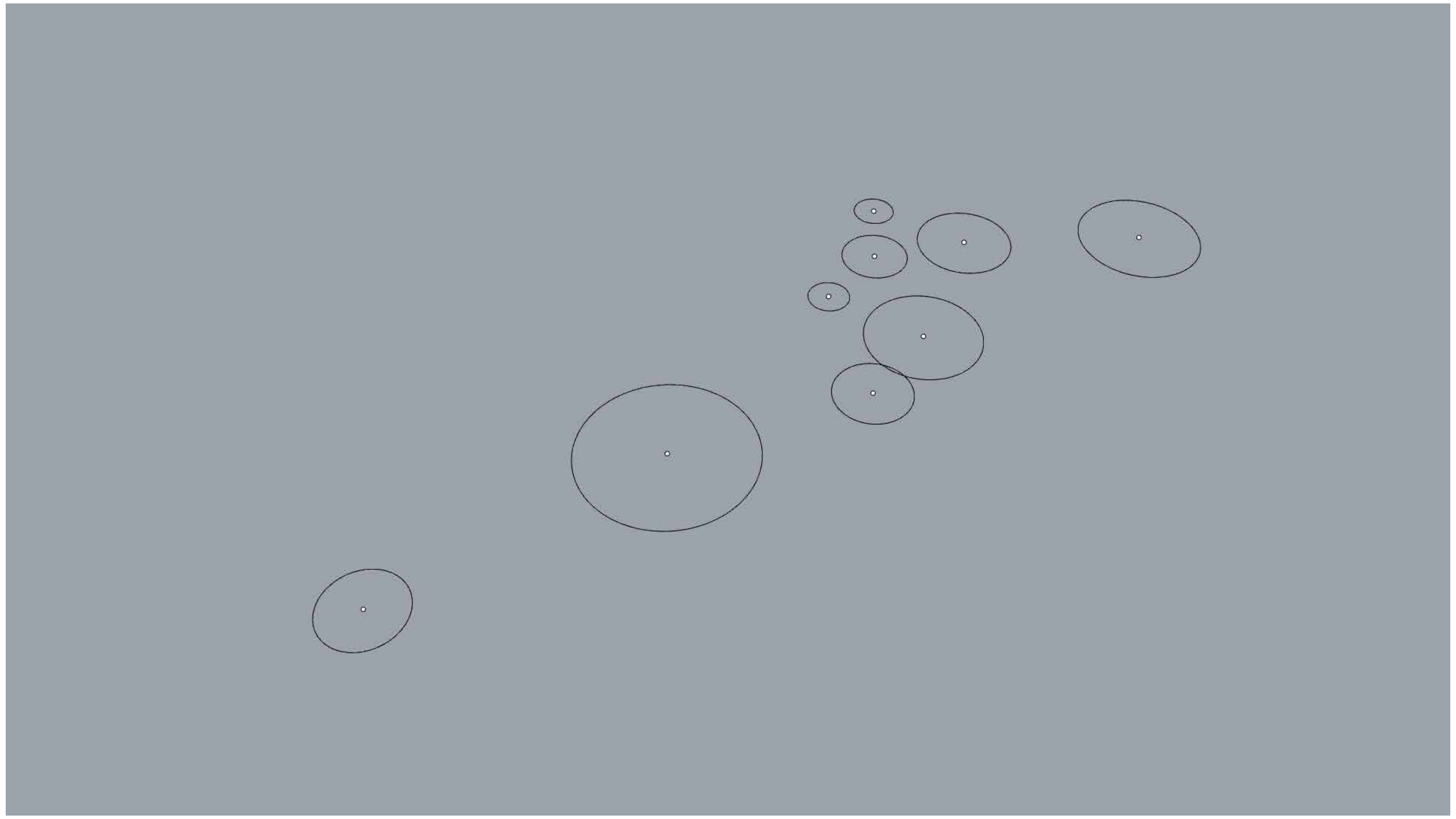
Lilian **Le**
Víctor **López Leftérov**
Antonia **Sattler**
Lowie **Swinkels**



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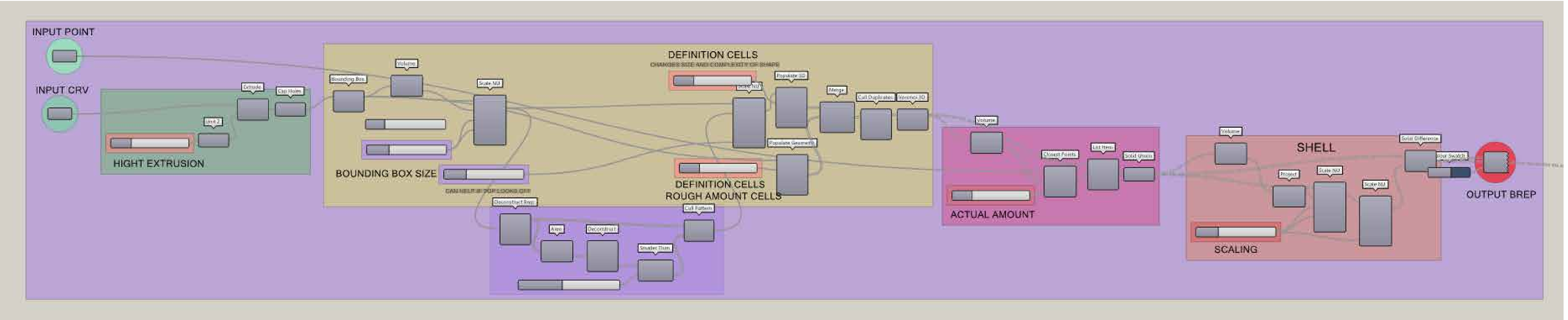
Antonia **Sattler**
Lowie **Swinkels**

Generation of Voronoi geometry of the rooms



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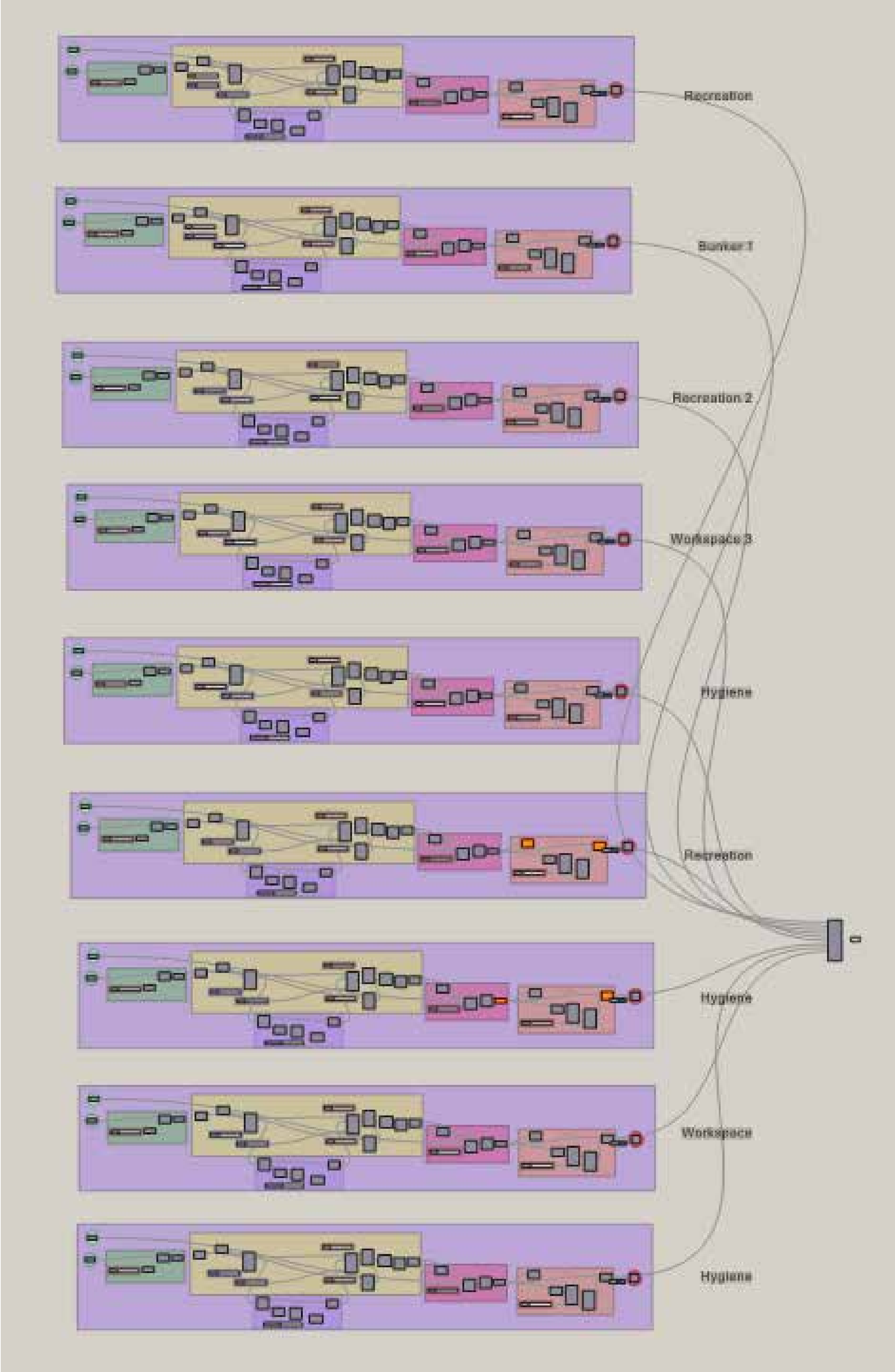

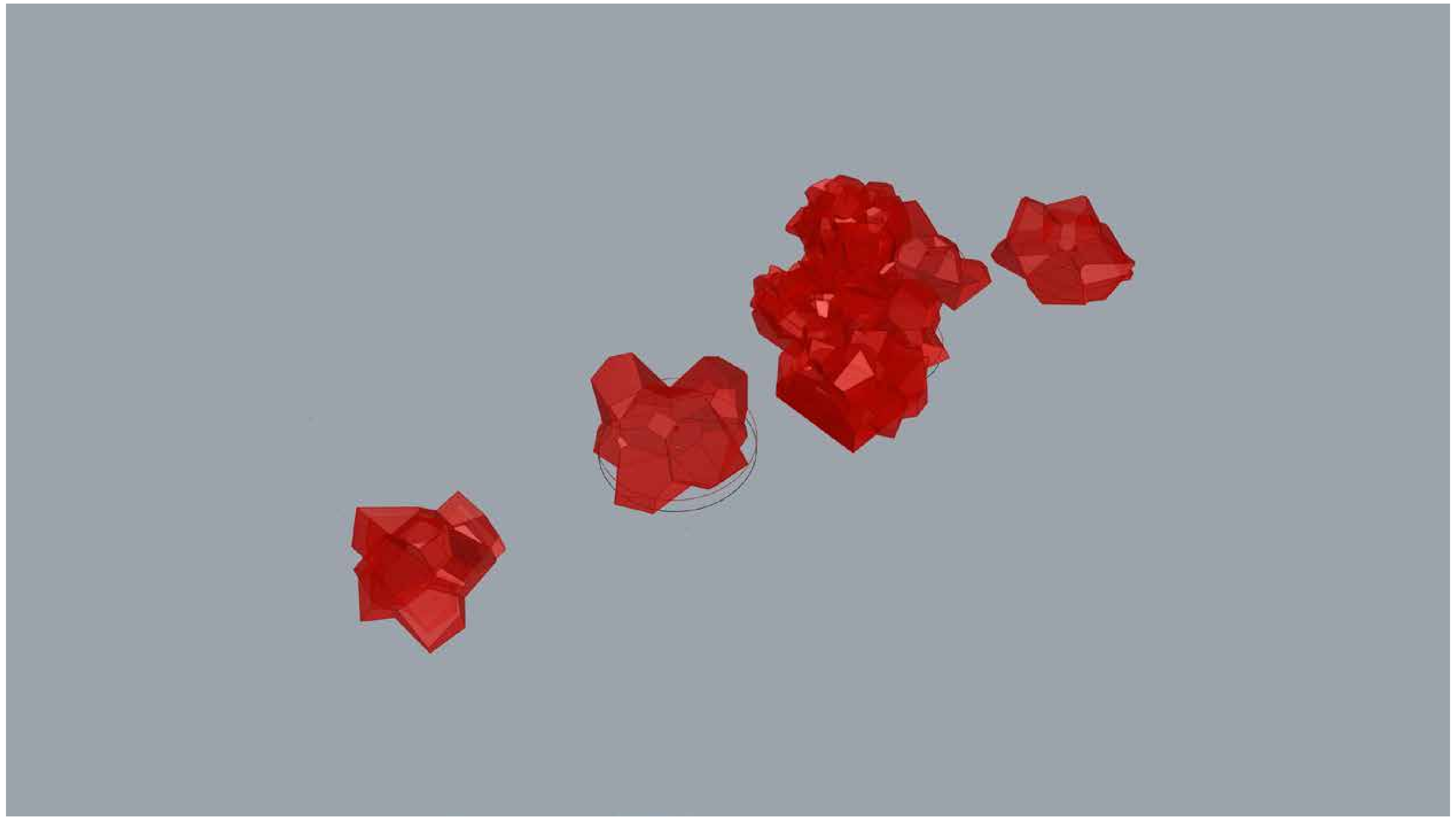

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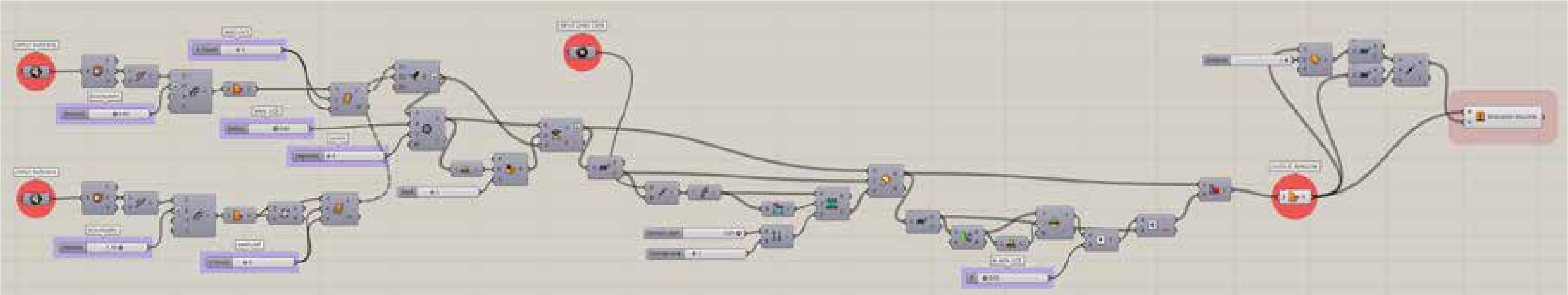
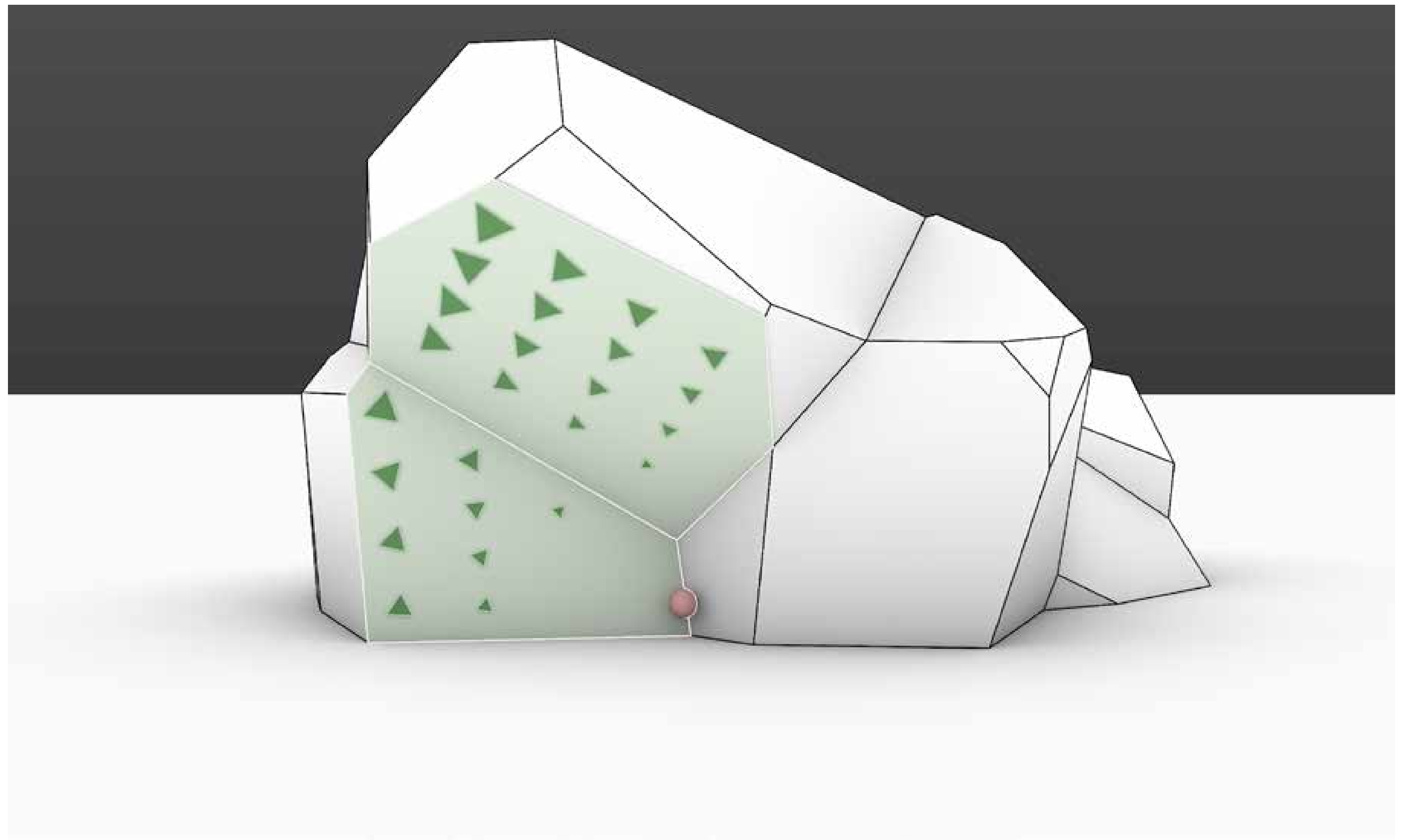
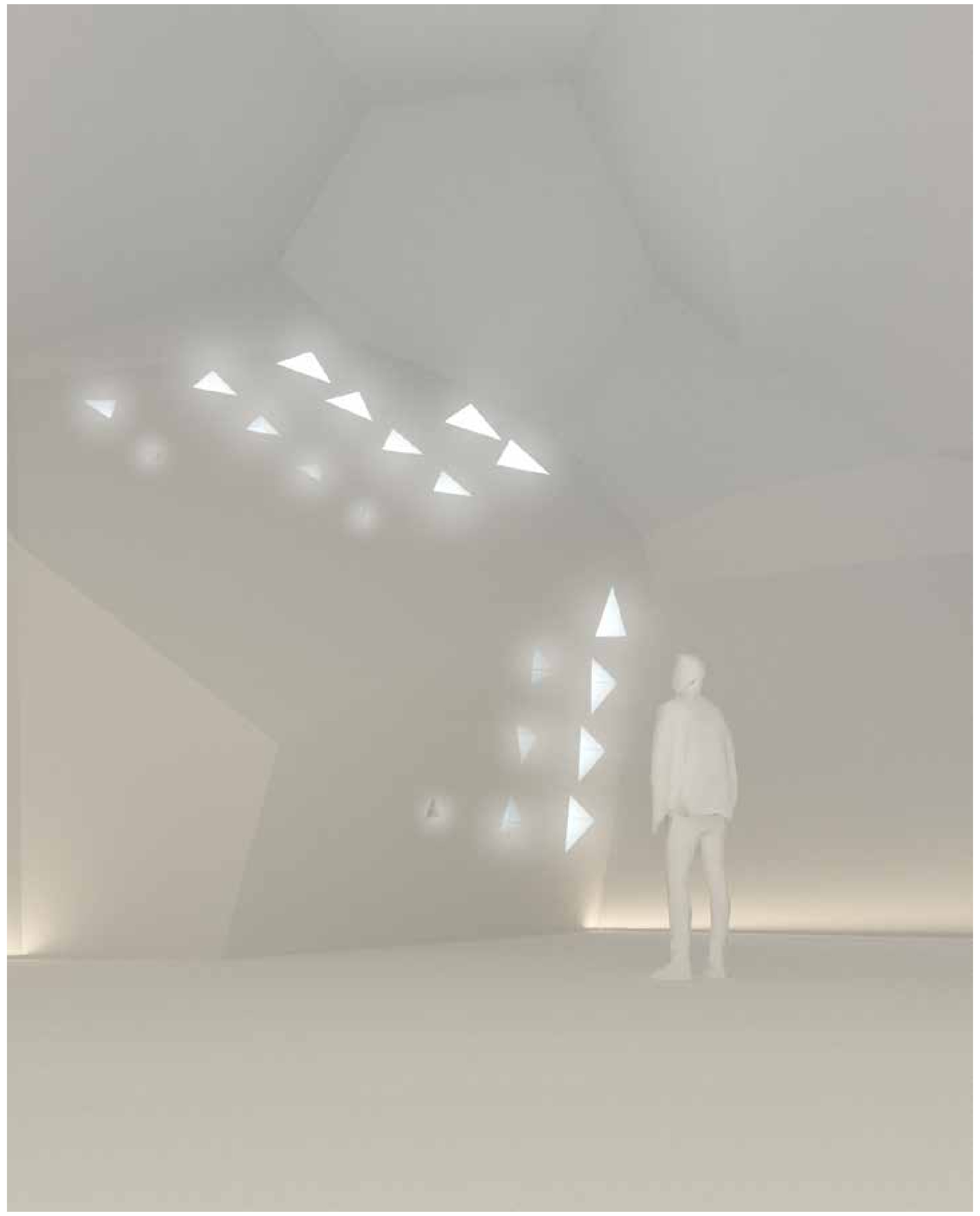
Generation of windows:







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Plan and section

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Antonia **Sattler**
Lowie **Swinkels**

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6_ PRODUCTION

Maximillian **Friedmann**
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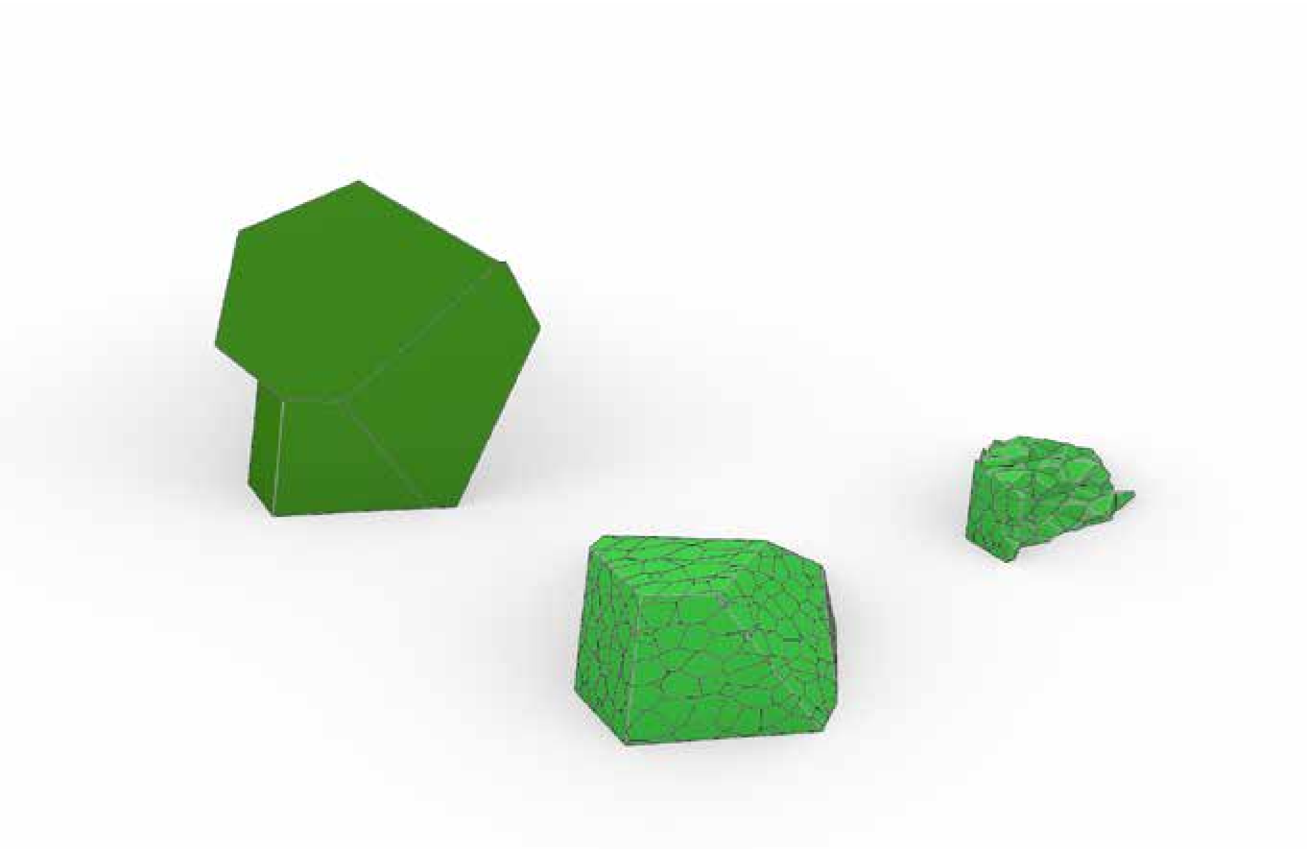
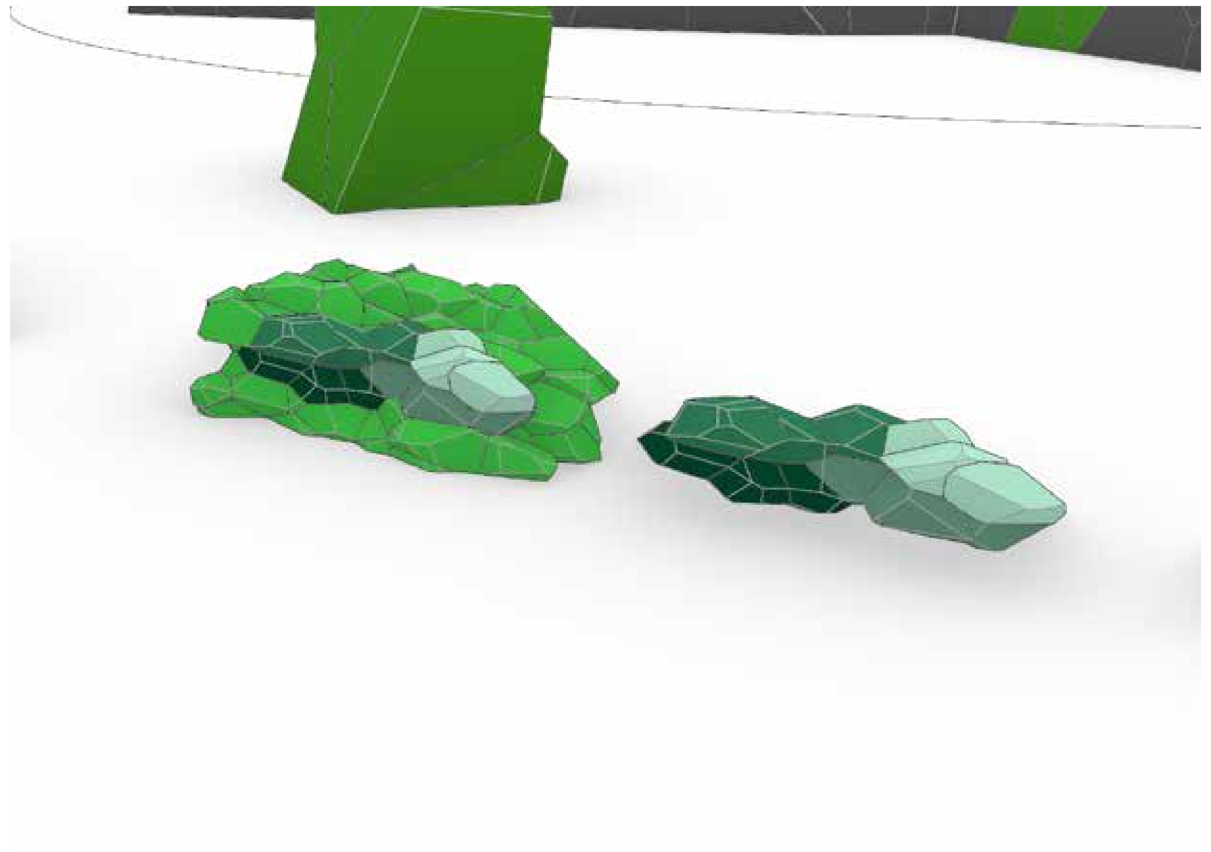
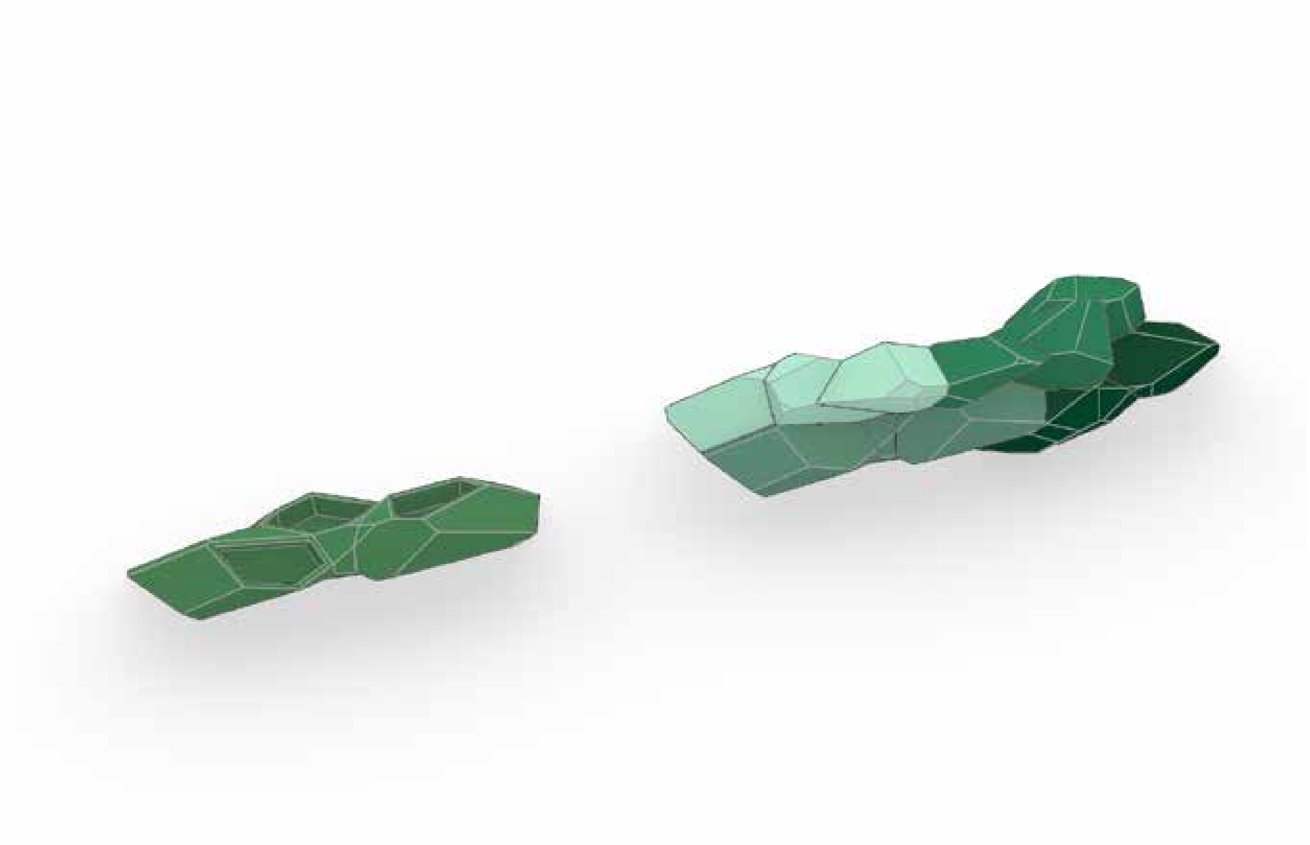
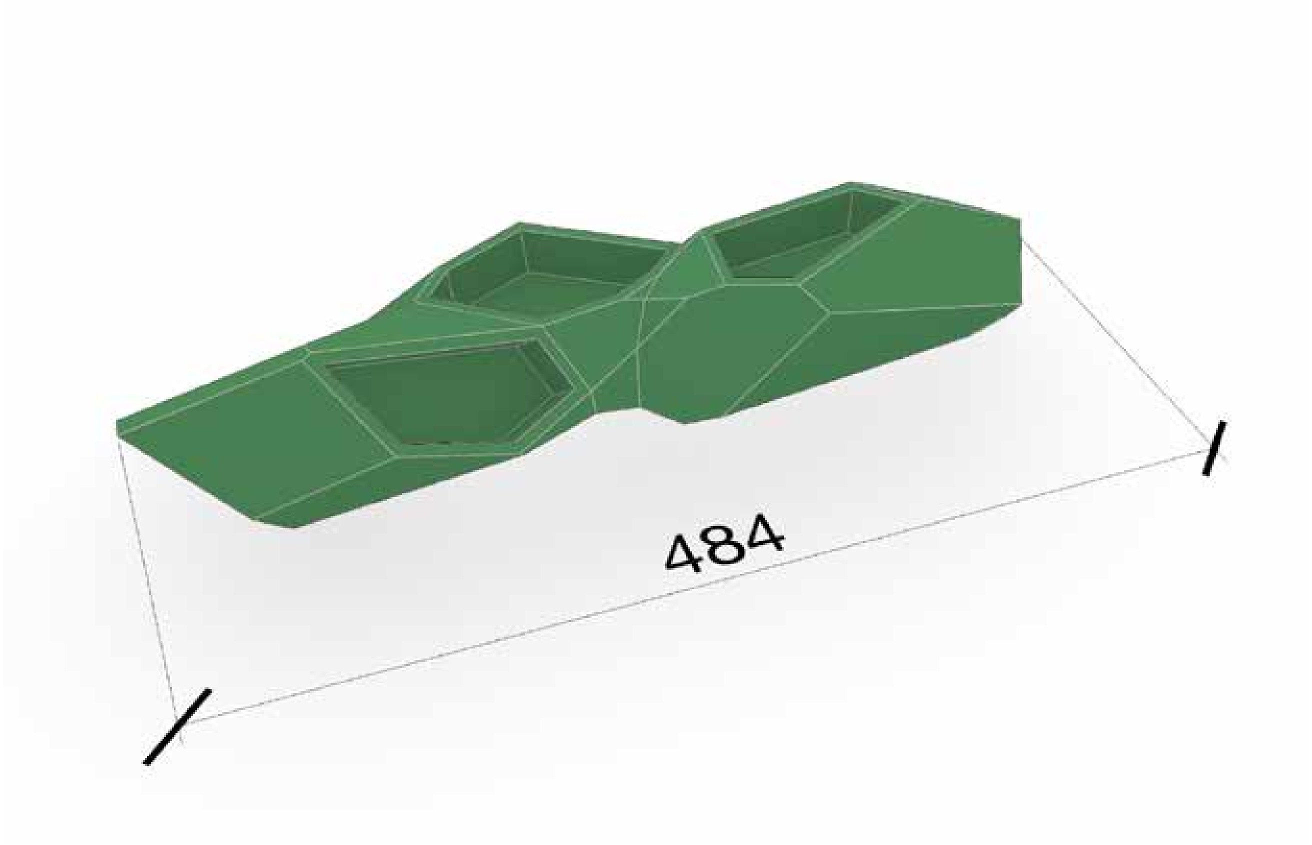
Víctor **López Leftérov**
Antonia **Sattler**
Lowie **Swinkels**

Fragment extraction









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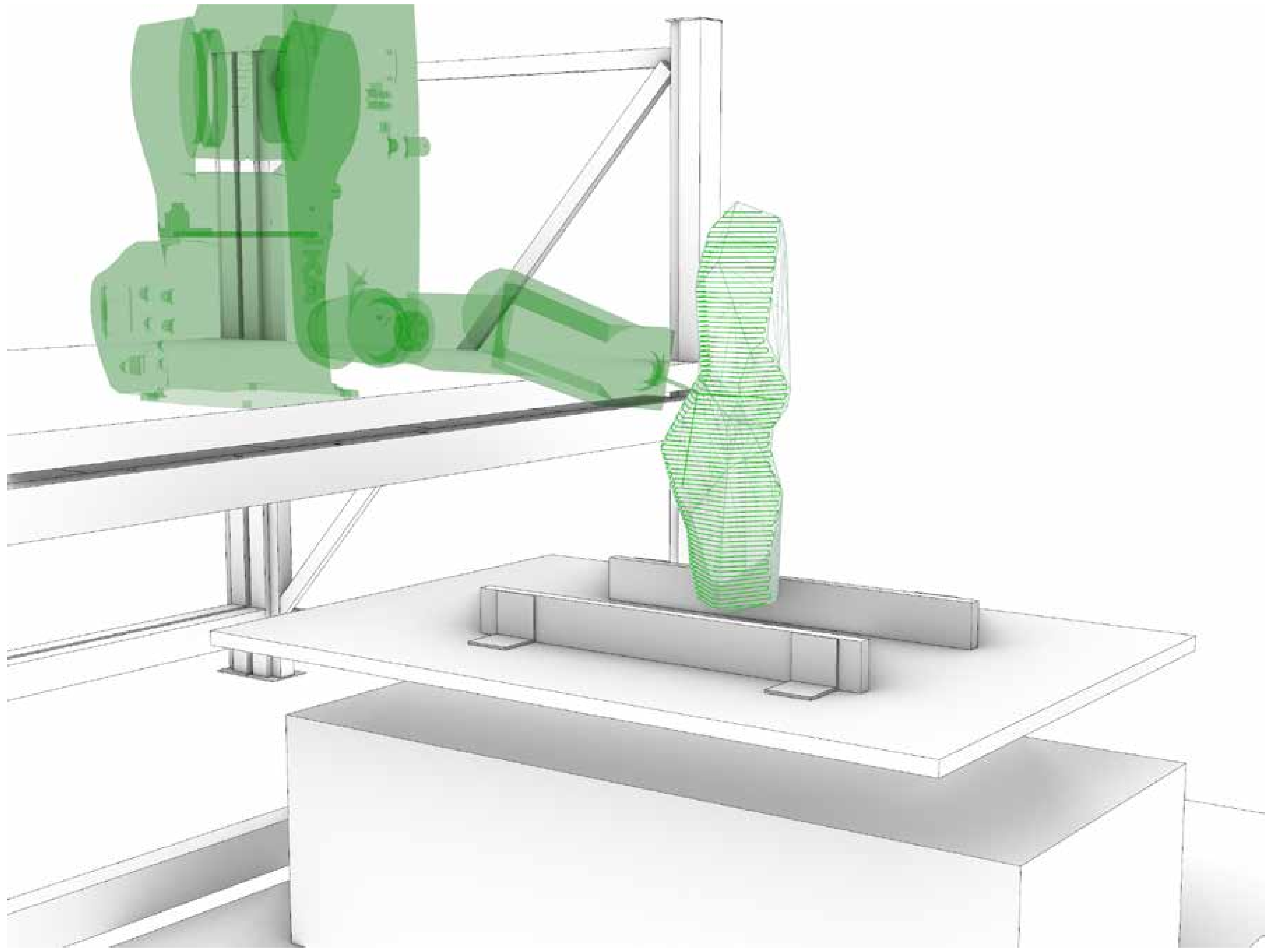
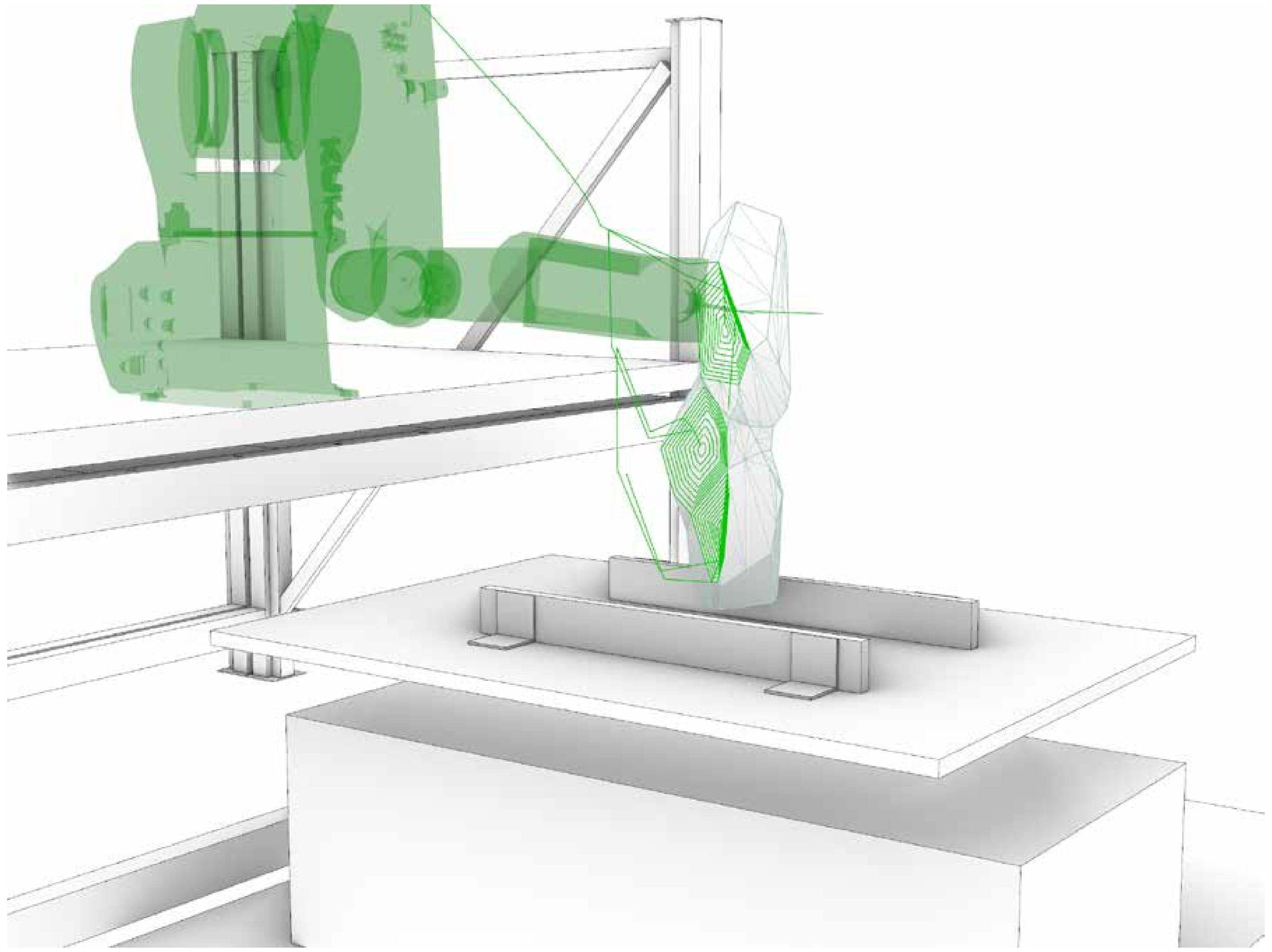
Fragment milling preparation





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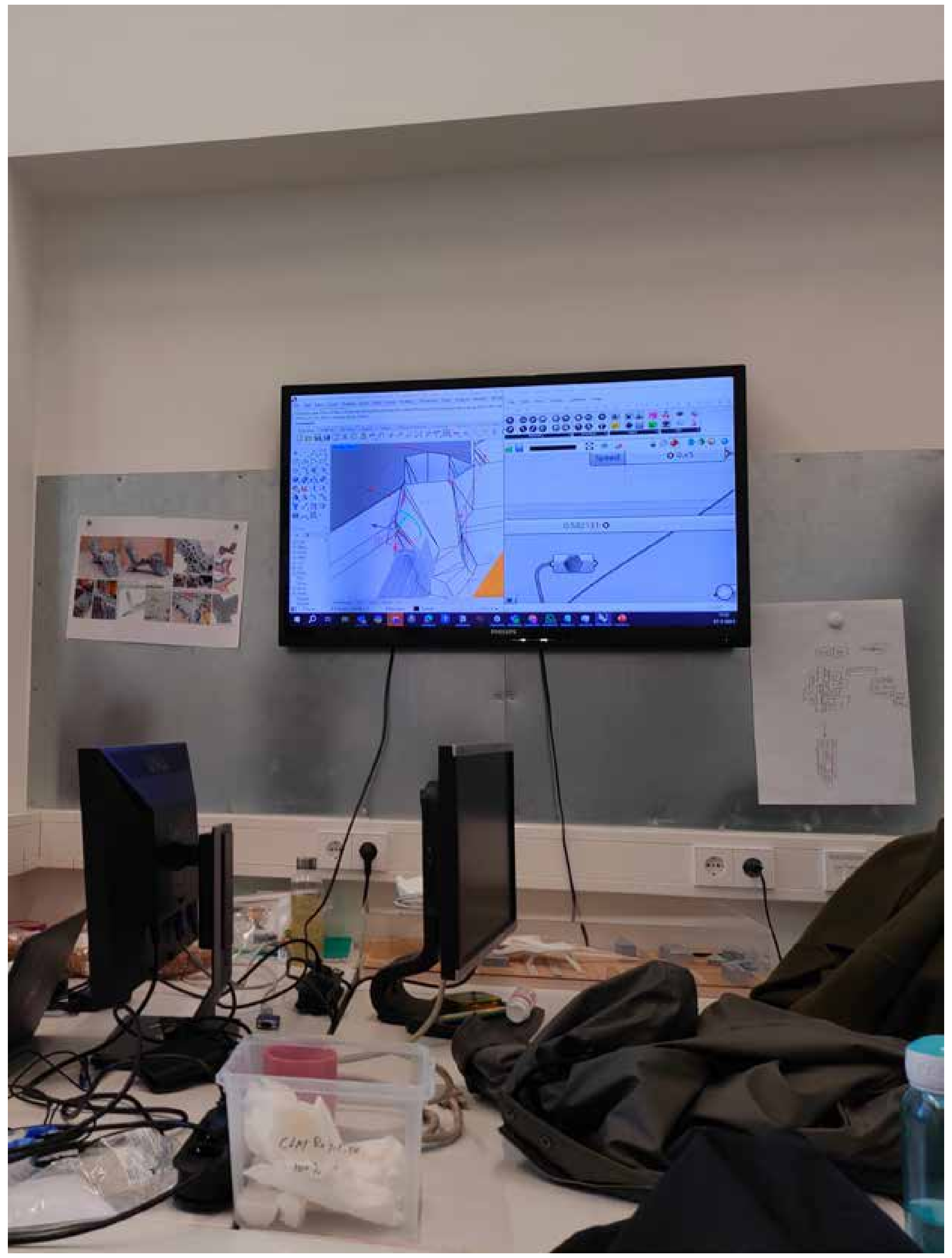
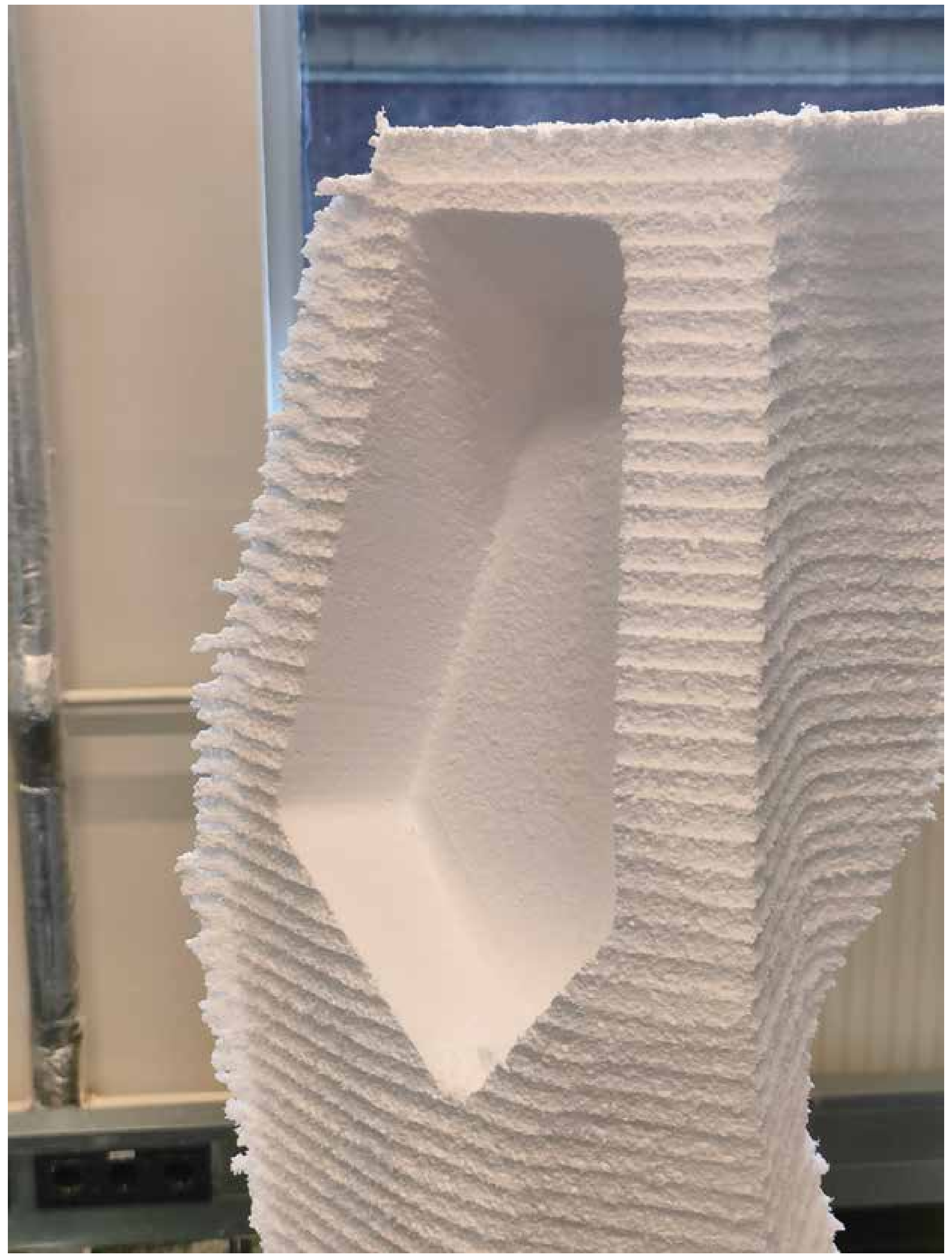
Fragment production in the RB Lab:





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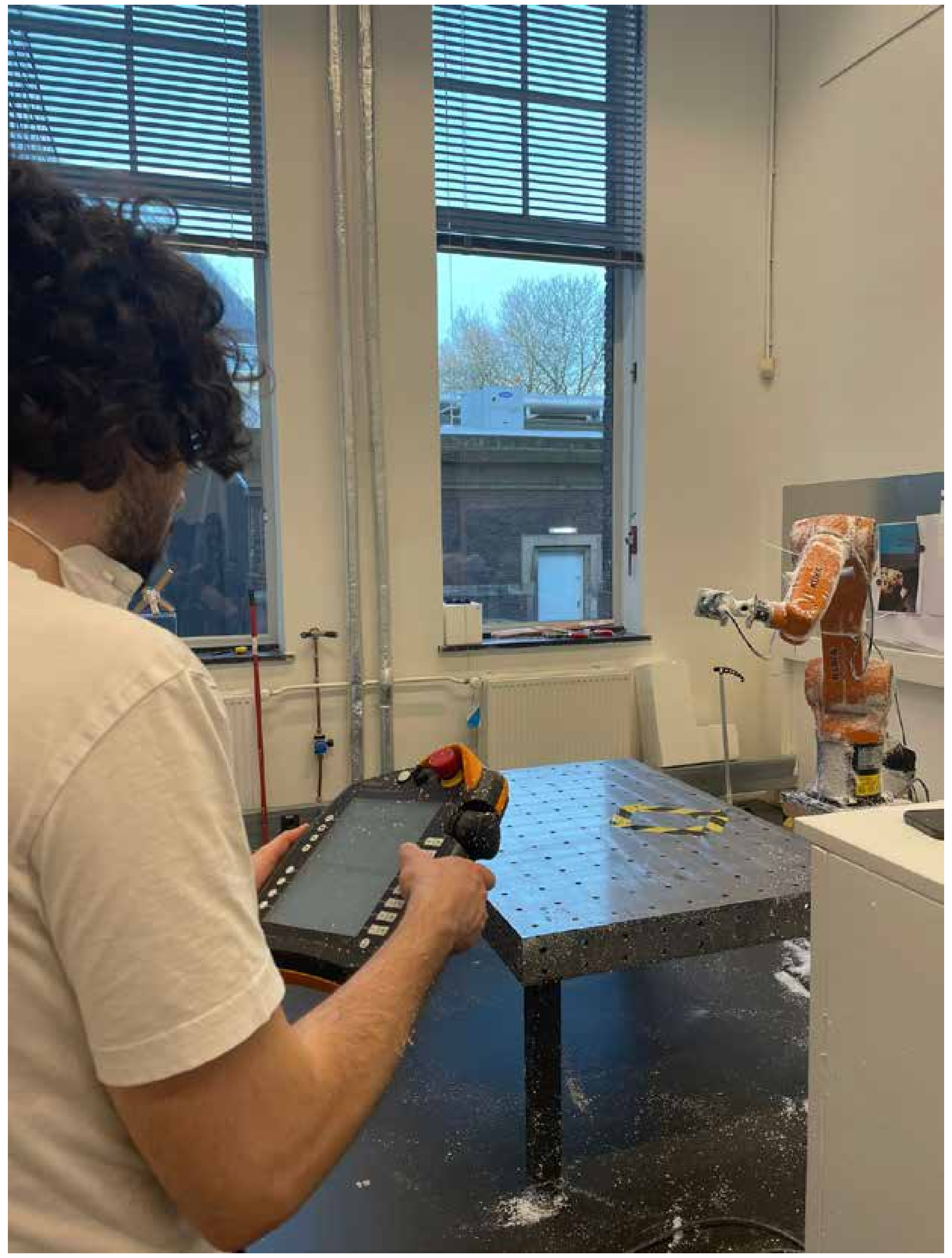

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Antonia **Sattler**
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7_ HUMAN-ROBOTIC INTERACTION

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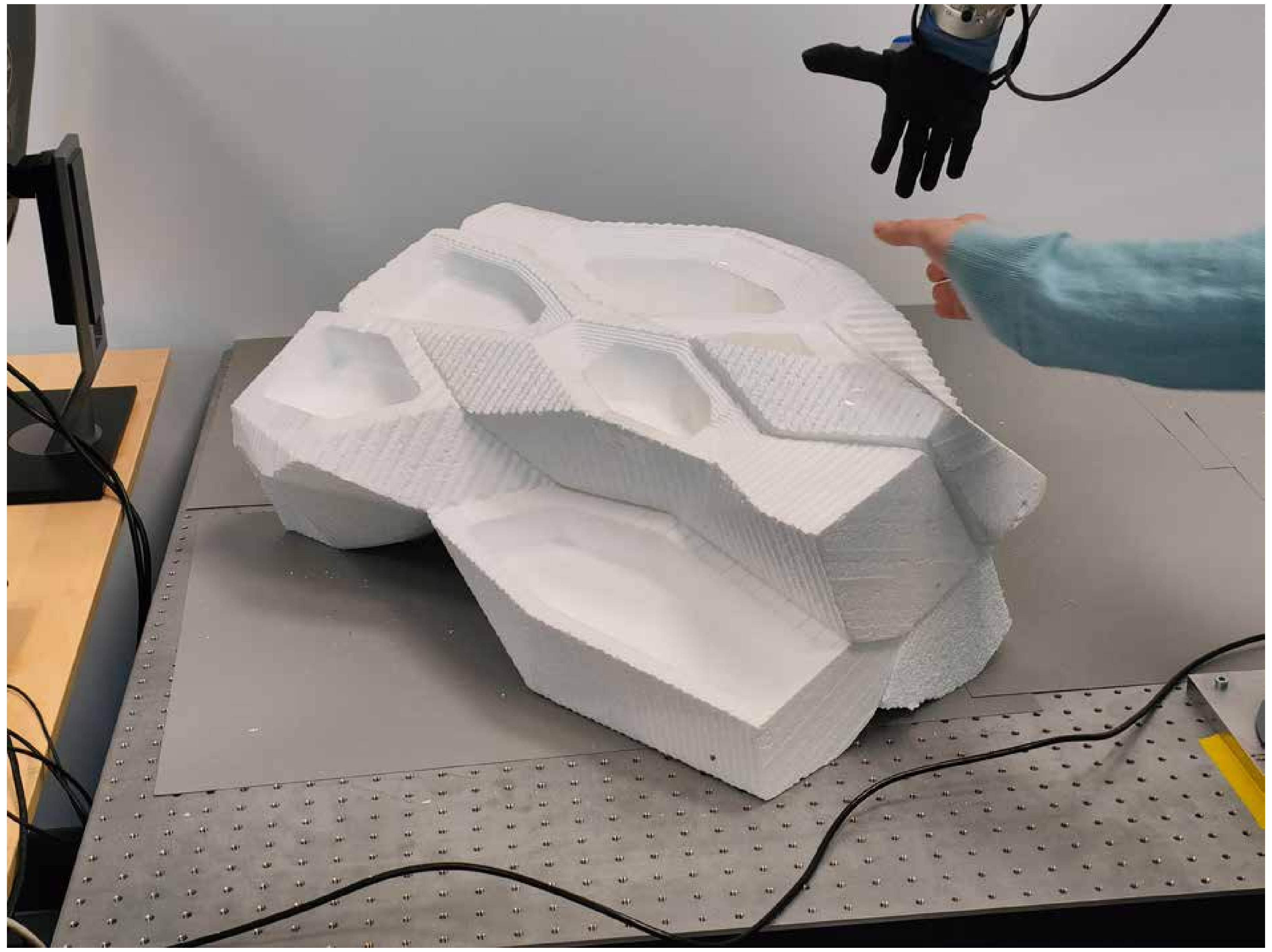
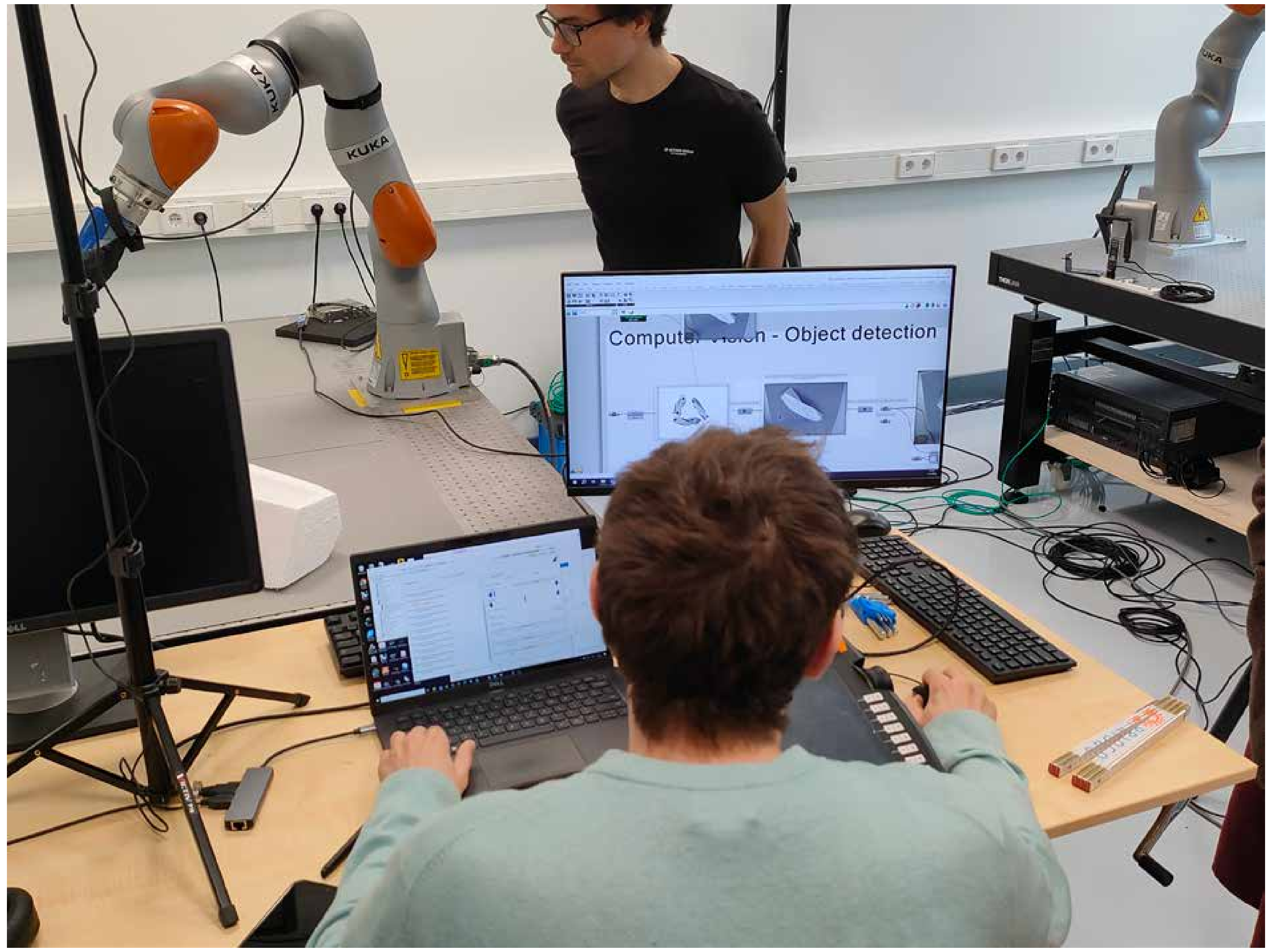
Antonia **Sattler**
Lowie **Swinkels**

HRI demonstration in the CoR Lab:





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8_ 3D PRINTING

Maximillian **Friedmann**
Lilian **Le**
Víctor **López Leftérov**
Antonia **Sattler**
Lowie **Swinkels**

3D-printing of a fragment of the shelter:

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Lilian **Le**
Víctor **López Leftérov**
Antonia **Sattler**
Lowie **Swinkels**


LUNASCAPE