

# Principles for a Practical Moon Base

Brent Sherwood

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69<sup>th</sup> IAC, Bremen



**Jet Propulsion Laboratory**  
California Institute of Technology

Small, habitable, ISRU lunar base could be constructed in four years of operations

13 cargo flights + 2 crew visits

LLOX from  $\text{FeTiO}_3$  for four flights/year

Most of the time, most of a Moon base must be robotic

Hierarchical supervisory control is required

Full autonomy is not



# Solar-powered, mare site, optimized for 28-day cadence



# Lander

- 30 mt down
- Cargo or crew
- LOX-hydrogen
- Reusable and surface-based
- LLO round-trip on single fill

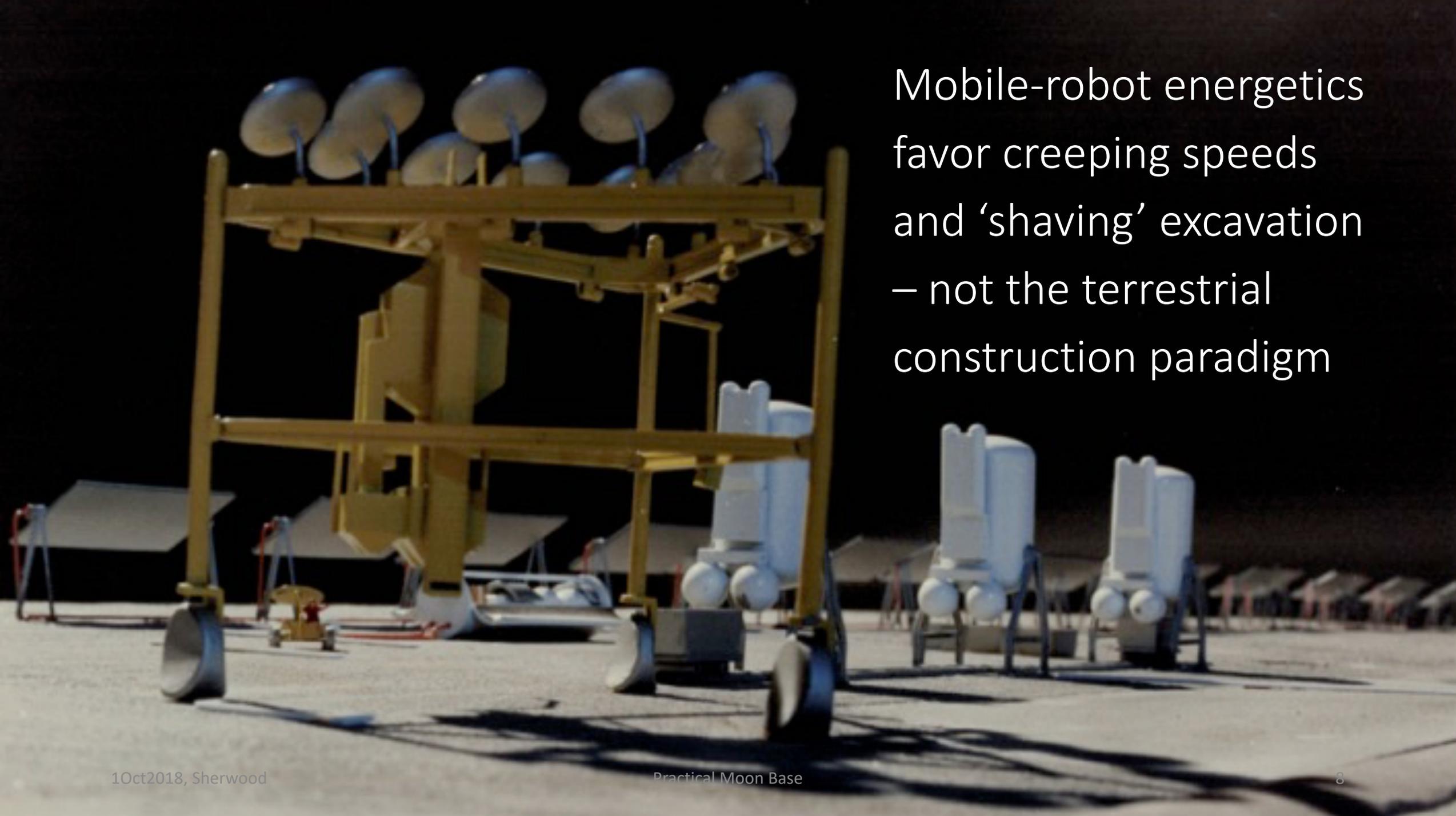


Elements must be designed to be robotically assembled and serviced



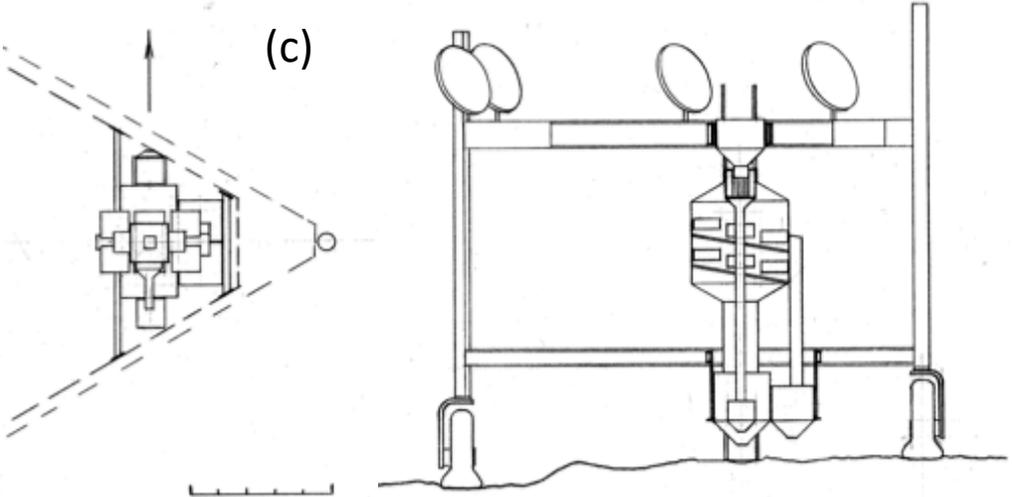
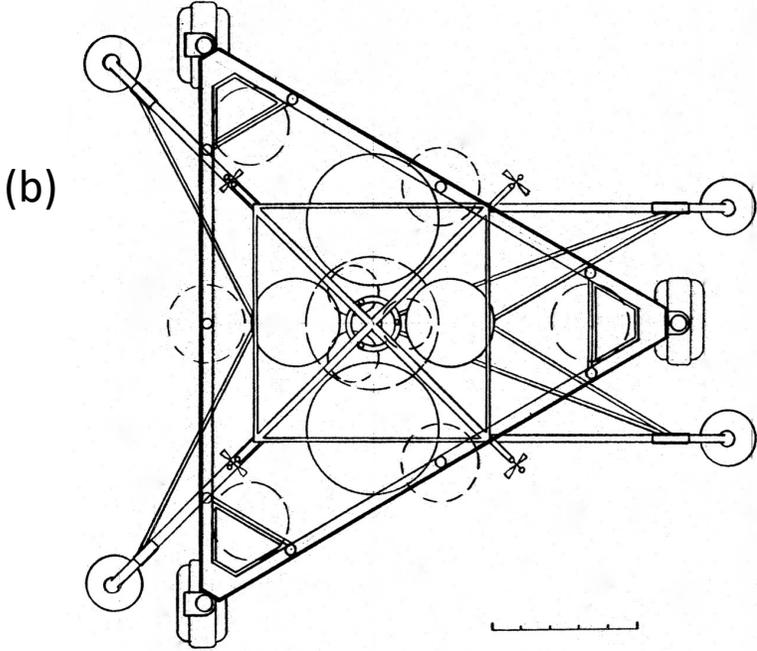
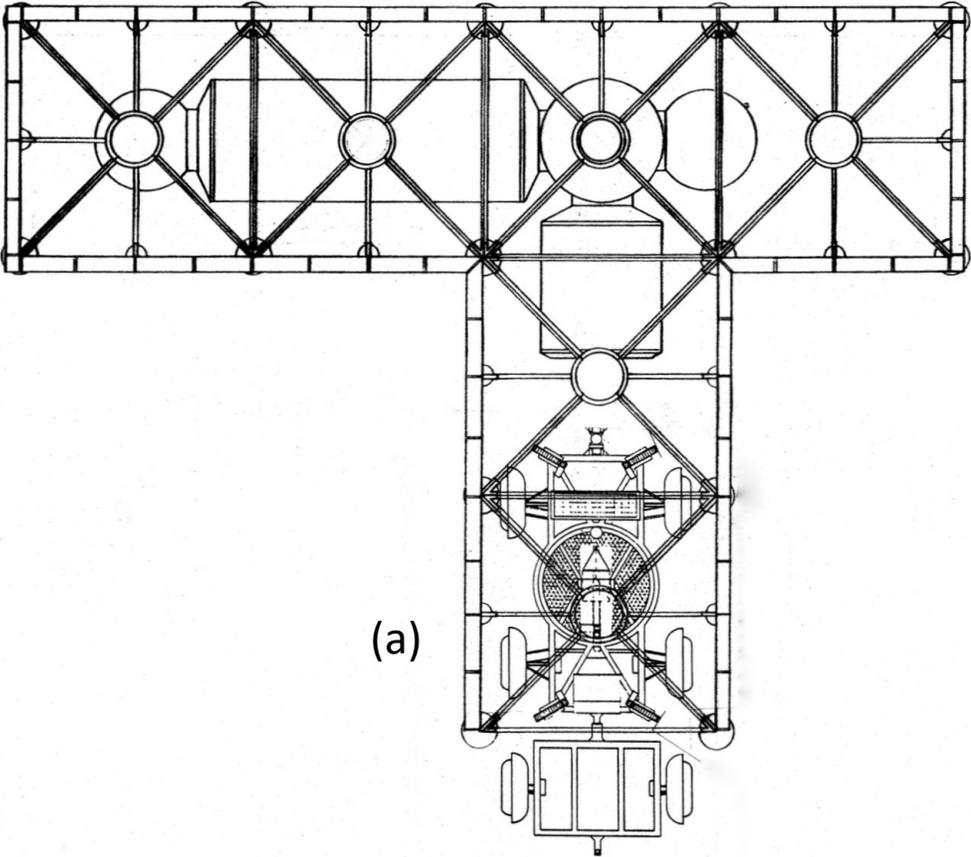
Minimum sufficient set of mobile robots is two each of three types (Rover, Truck, Straddler)



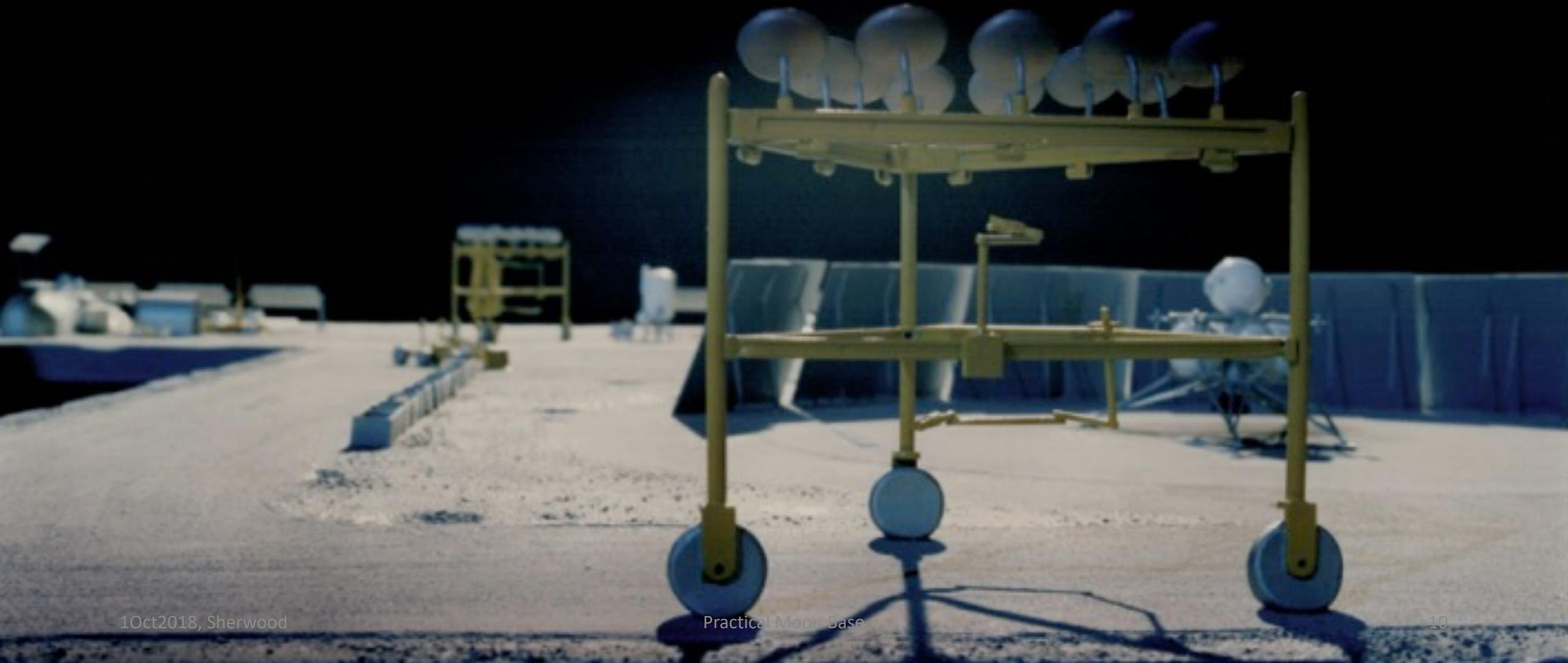


Mobile-robot energetics favor creeping speeds and 'shaving' excavation – not the terrestrial construction paradigm

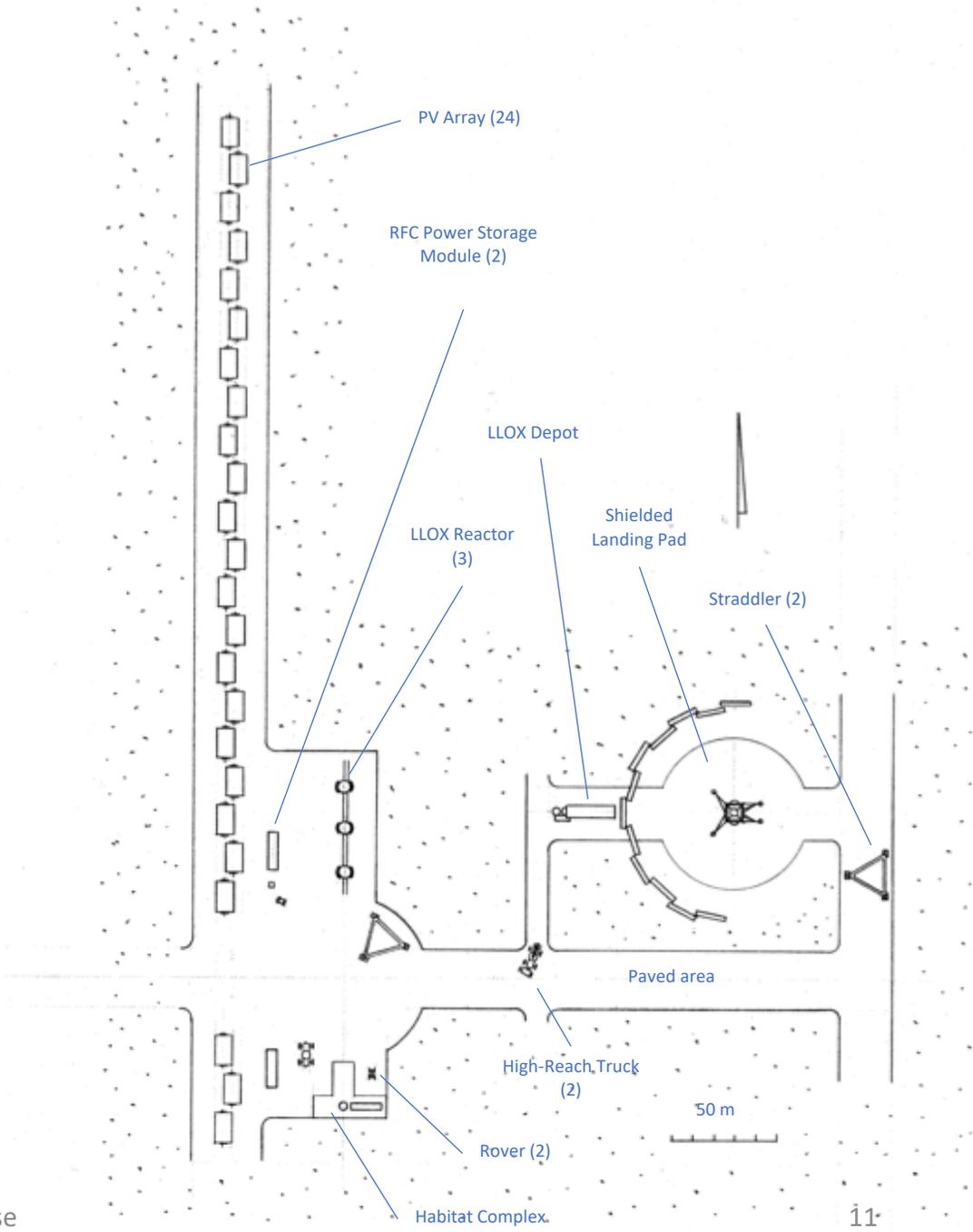
# All element designs must be highly integrated



Moving a crippled lander is the bounding requirement for cargo mobility on the surface



Paving routine traffic routes, to control dust and make a predictable environment for robot motion, is the driving requirement for construction timelines



# Maintenance scenario based on robot-replaceable units

- Component-level repair by crew in IVA workshop
- Spares comprise 15% of delivered manifest



# RLSO – Robotic Lunar Surface Operations study

Commissioned in 1989 by ARC (Sims-Mah)

- “Develop an ISRU lunar base concept, built and operated robotically before humans go”
- Bracketed the SEI 90-Day Study

Boeing Advanced Civil Space Systems

- G.R. Woodcock (lead), Sherwood (SE/configurator), P. Buddington (SE/ops analyst)
- RedZone Robotics (W.R. Whittaker, L. Bares) and MIT (D. Akin)
- Experienced Apollo-Skylab astronauts (Schmitt, Carr, Lousma)
- Operations reliability analysis (R. Folsom, R. Koch)

180-pp report, D615-11901, 2 Jan 1990

- Four papers in *Space 1990: Engineering, Construction, and Operations in Space*
- Sherwood called to brief lunar ISRU community at start of VSE, ~2005

# What has changed since 1989?

- Population grew by 31% from 5.24B to 7.63B
- Citizens are now extensively connected
- Apollo has become a half-century old solution



# What *else* has changed since 1989?

## Knowledge

- Lunar polar volatiles, including ice
- Non-Keplerian orbits (e.g., DRHO)
- Lessons from four planetary rovers

## Programmatic and technical context

- Widespread *terrestrial* use of A&R
- Demonstrated international collaboration on complex human space flight programs (ISS)
- Emergence of many 'commercial' providers and commitment of private capital
- New memes: Moon Village, SPD-1, lunar pivot

## Flight systems in development

- NASA: SLS, Orion, Gateway
- Commercial systems: CLPS landers, BFR, Blue Moon
- Multiple international: China, Japan, Korea, India, Europe

## Analysis and communications tools

- Performant desktop computers
- Spreadsheets, CAD, cinematic rendering
- Systems models

Lunar North Pole video from LRO data,  
[https://svs.gsfc.nasa.gov/vis/a000000/a004600/a004655/northpole\\_2160p30.mp4](https://svs.gsfc.nasa.gov/vis/a000000/a004600/a004655/northpole_2160p30.mp4)

