

Concept 3 "House on wheeled legs": a dome on 4 telescopic legs with tandem bogies

All calculations are conceptual, without FEM strength analysis.

Stage: concept / feasibility study. All figures were obtained with simplified formulas and serve to choose the layout and the class of components. This is not a detailed design calculation: the chassis, legs and joints must later be checked with FEM, and the components must be selected from catalogues together with the manufacturers' engineers.

The calculation is reproducible: `calc/calc.py` takes the masses and CoG from the FreeCAD model (`cad/mass_*.json`) and writes `calc/results.json` and figures 08-11 to `renders/`. References to the tyre and motor data sources are in `results.json` → `sources` and in section 12. Everything not confirmed by a catalogue is marked **"not verified"**.

1. Summary

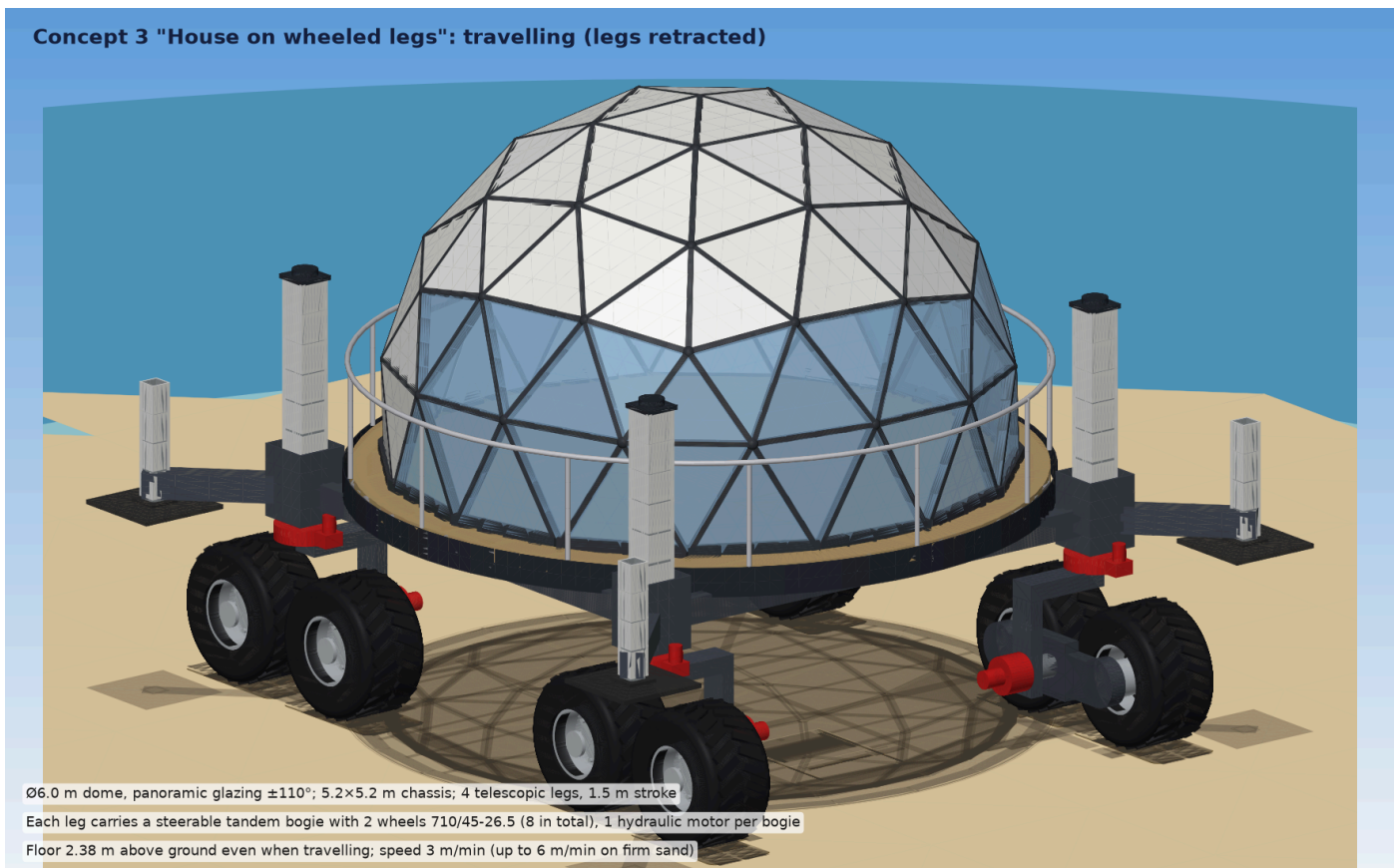
Recommended configuration. A geodesic dome (sphere Ø6.0 m, dome base Ø5.9 m (5/8 truncation)) with a panoramic glazing band of ±110°. It stands on a round Ø6.6 m platform, and the platform sits on a rigid welded square chassis of 5.2 × 5.2 m between leg centres. At the corners of the chassis are **4 vertical telescopic legs** with a Ø100/80 hydraulic cylinder and a **1.5 m** stroke. At the bottom of each leg, a **tandem oscillating bogie** (as on a forwarder) with two **710/45-26.5 Forest King F2** wheels in line (1.47 m wheelbase, 125 mm gap between the tyres) hangs from a worm **steering slewing drive. 8 wheels in total, 2 per leg.** Forwarder layout: wheels on outboard hubs, bogie case inboard, bogie pivot at the bogie centre.

Each bogie is driven by **1 hydraulic motor** (orbital, 100 cm³). The motor sits on the bogie pivot axis and drives through a planetary wheel gearbox with a spring-applied brake (*i* = 80), then through two chains in an oil-bath housing to both wheels.

When parked, the house is lowered onto **4 outriggers** with 900×900 pads: the wheels are unloaded and the hydraulic pressure is released.

Parameter	Value
Body	3V dome: sphere Ø6.0 m, dome base Ø5.9 m (5/8 truncation), platform Ø6.6 m; height above floor 3.56 m; 74 solid sandwich panels "0.7 steel + 100 XPS (Penoplex) + plywood" (42 m²) and a panoramic band of double-glazed units (23 m²); ring platform overhang with guardrail (≈0.3 m from dome to guardrail, not walkable; a full 0.8-1.0 m terrace on a Ø7.6-8.0 m platform is an option under study)
Chassis	welded square 5.2 × 5.2 m: 250×150×8 tube, diagonals and cross members 200×100; 520×520 leg socket nodes
Plan dimensions	≈8.3 × 7.1 m (bogies aligned with travel); with outriggers ≈8.1 × 8.1 m
Floor above ground	2.38 m when travelling (legs retracted), up to 3.88 m fully extended; parked-on-a-slope example: 3.05 m at the centre. The "floor ≥ 2.0 m" requirement is met in all poses, including when travelling
Overall height	5.94 m when travelling, 7.44 m with the legs extended
Mass	structure with interior ≈ 21.5 t , operating with 4 people ≈ 21.8 t (<i>W</i> = 214 kN); parked with snow ≈26.8 t
Leg	outer tube 300×300×10, inner 250×250×10 (S355), overlap ≥0.8 m; Ø100/80 cylinder, 1500 mm stroke , 89 bar nominal, 165 kN at 210 bar; 10 mm/s, full stroke in 150 s

Parameter	Value
Tyres	8 × 710/45-26.5 Nokian Forest King F2 24PR (Ø1345, 710 mm wide); 2.73 t per wheel nominal, 3.55 t design
Pressure on sand	≈ 170-190 kPa at a tyre pressure of 1.4-1.6 bar; with bogie tracks ≈30-60 kPa
Traction drive	4 × (100 cm ³ orbital motor → planetary gearbox i = 80, 22 kN·m, brake → 2 × 28B-2 chains); torque per bogie 15.8 kN·m design, up to 21 kN·m (220 bar pressure limit)
Speed	creep 0.5 m/min (positioning), working speed 3 m/min on sand, up to 6 m/min on firm ground
Steering	4 slewing drives (worm, self-locking), -100...+100°. Modes: Ackermann, crab up to 90°, turning in place
Hydraulic power unit	45 cm ³ LS pump (67 L/min) + 15 kW electric motor; peak hydraulic power ≈11.5 kW; 12-section proportional valve bank
Energy	≈0.9 kWh per 100 m on firm level ground; ≈5 kWh per 100 m on loose sand up a 10 % slope; raising the house by 1.5 m: 0.15 kWh
Stability	static tip-over angle 51° when travelling and 42° with the legs extended; 30 m/s wind when parked: K = 7.9...12 on wheels, 10.8 on outriggers
Actuators	12 hydraulic (4 legs, 4 steering, 4 traction) + 1 hydraulic power unit; + 1 electric stair drive
Access to the house	electrically driven scissor (pantograph) stair from a 0.8×1.0 m hatch: 12 treads 740×250, always horizontal; 70° angle; rise 2.0-3.9 m (in the parking example 3.30 m, riser 248 mm); deploys in ≈13 s (0.2 m/s); folded: a 0.48 m stack under the floor; 215 kg with drive, hatch and handrails



2. Input data and assumptions

- The body is from the same family as in concept 1: 3V dome (sphere Ø6.0 m, base Ø5.9 m, platform Ø6.6 m), 100 mm wall (100×50 frame, 100 mm Penoplex, sandwich).
- Unit masses as in concept 1: solid panel 18.2 kg/m², glazing unit 35 kg/m², floor 39 kg/m². Interior with a 15 kWh battery: 1500 kg. People: 4 × 80 kg. Welds, fasteners, galvanising and

paint: +6 % of the steel mass.

- Components with estimated masses (not verified):
- 710/45-26.5 wheel with rim and hub: 360 kg;
- gearmotor: 165 kg;
- slewing drive: 190 kg;
- cylinder: 135 kg;
- hydraulic power unit: 420 kg.
- Snow (parked): 1.5 kPa on the Ø6.6 m plan = 5.2 t. No driving with snow.
- Wind: $q = \frac{1}{2}\rho v^2$. Dome: $C_f = 0.6$ on a projected area of 17.5 m². Platform, legs and bogies: $C_f = 1.2$ –2.0. Lift on the dome: $C_L = 0.5$ on the plan area.
- Ground (beach) is defined by the cone index CI:
- 300 kPa: dry loose sand;
- 700 kPa: damp sand;
- 1500 kPa: wet firm sand of the tidal strip.

These are guide values: measure on site with a hand penetrometer. * The X axis is "forward", towards the sea. Beach slope in the parking pose is 10 % plus a +0.3 m hump under the rear left leg and a –0.15 m hollow under the front right one.

2.1 Mass (from the model + allowances)

Group	kg
Dome (frame, panels, glazing, base ring)	2802
Floor platform (frame, floor, cladding, handrail)	2573
Chassis 5.2 × 5.2 m	1876
Legs: sockets, telescopes, hydraulic cylinders, caps	3046
Steering: slewing drives and L-shaped struts	1280
Bogies: bogie cases, pivots, 8 wheels, 4 gearmotors	5420
Outriggers (brackets, posts, pads)	1609
Hydraulic power unit and piping	600
Scissor stair with electric drive, hatch, handrails	215
Welds, fasteners, galvanising + paint (+6 % of steel)	623
Interior and building services	1500
Total structure	21 545
People (4 × 80)	320
Operating mass	≈21.8 t

CoG when travelling is 2.10 m above ground, 2.93 m with the legs fully extended.

Why it is almost twice as heavy as concept 1 (11.6 t). * The running gear (legs, bogies, steering, outriggers, hydraulic power unit) weighs ≈13 t versus ≈2.8 t for the walking layout. * A forestry-class wheel assembly is heavy in itself: one complete 710/45-26.5 wheel is about 360 kg.

Ways to save 2–3 t: * an aluminium dome frame; * 600/50-22.5 tyres instead of 710 (–0.85 t; see section 5); * removable outriggers instead of permanent brackets (–1 t); * a lighter interior.

3. Choice of layout and body shape

3.1 Body: a dome rather than a rectangle

- **For a wheeled chassis with steering on every bogie, direction does not matter.** The house can move sideways (crab) and turn in place. A round symmetrical body looks the same from every side and has no "end face" pushing against the wind.
- **Wind:** a dome has $C_f \approx 0.6$, a rectangular module ≈ 1.2 – 1.3 . A high floor (≥ 2 m) increases the wind area, so the dome's advantage matters.
- **Look and "investor" image:** a rounded shape, a panoramic glazing band of $\pm 110^\circ$ (23 m^2) with a sea view, a ring platform overhang with guardrail (a full 0.8–1.0 m terrace is an option under study), an illuminated platform edge cladding, leg "towers" with LED caps.
- The body is the same dome as in concept 1: the same tooling, panel cutting and joints.
- An alternative on the same chassis is a 7×5 m elliptical capsule with rounded corners and a streamlined roof. It is more practical inside (straight walls for furniture), but 0.5–1 t heavier and has twice the wind area. Not recommended for now.

3.2 Wheels: tandem bogie (baseline) or one wide wheel per leg

Criterion	8 wheels: 4 tandem bogies	4 wheels: one per leg
Tyres	8 × 710/45-26.5 (or 600/50-22.5)	4 × 710/45-26.5
Load per wheel (nom./design)	2.73 / 3.55 t	4.73 / 6.15 t
Tyre pressure (per the Nokian table)	1.4–1.6 bar	3.5 bar
Mean pressure on sand	$\approx 170 \text{ kPa}$	$\approx 390 \text{ kPa}$
Traction on dry loose sand (Brixius, CI 300)	rolling resistance $\rho = 0.16$; net traction 27 % at 30 % slip → a 10 % slope is passable	$\rho = 0.25$; net traction $\approx 3 \%$ → practically does not move
Crossing obstacles	the bogie pivot rises by half the height of a bump; the rear wheel pushes the front one; $\pm 12^\circ$ oscillation	a $\varnothing 1.35$ m wheel confidently climbs a ≈ 0.3 – 0.4 m step; the impact goes entirely into the leg
Running gear mass	+2.9 t	—
Running gear cost (estimate, not verified)	≈ 1.6 – $1.8\times$	1×
Tracks for loose sand	fitted as standard (forwarder bogie tracks on the tandem) → 30–60 kPa	impossible

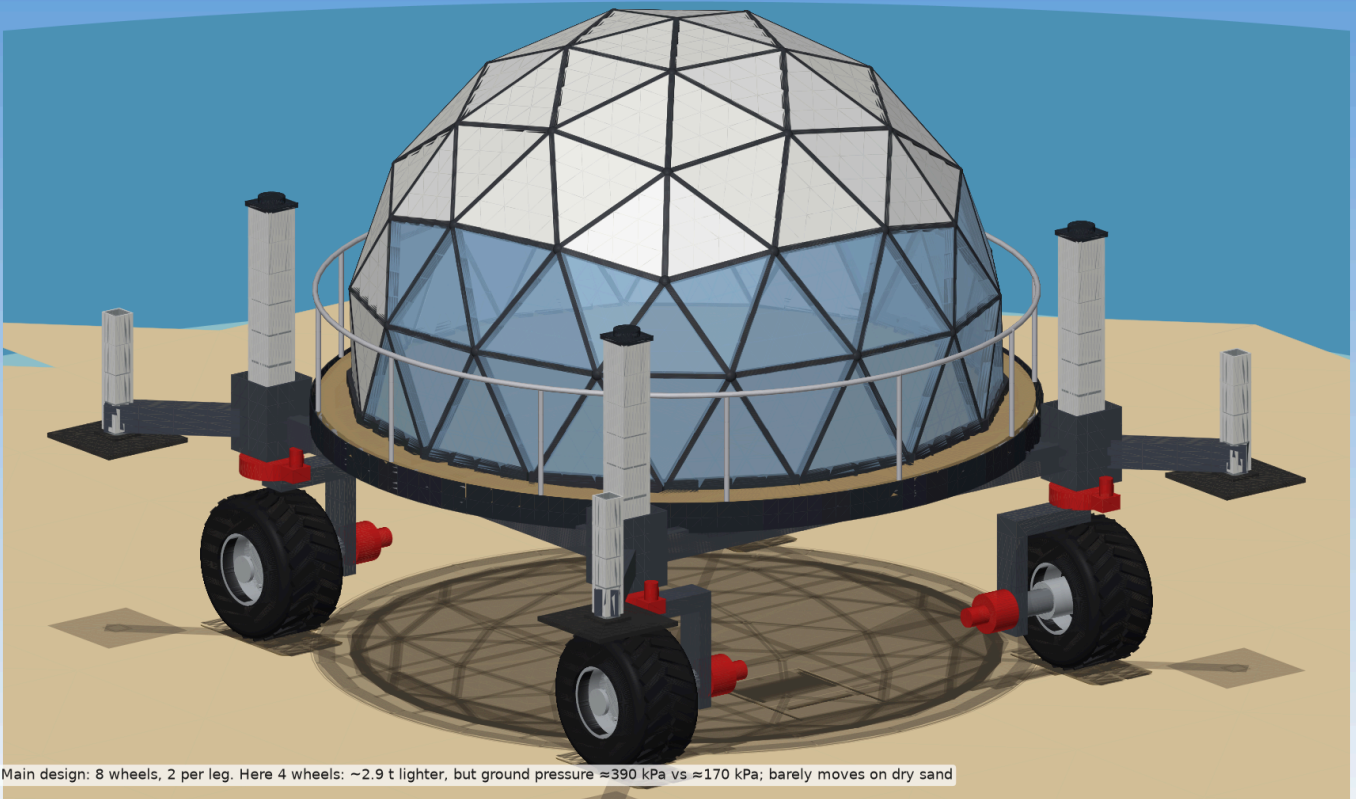
Conclusion: tandem bogie. It halves the pressure on sand and allows tracks to be fitted as standard. For soft ground this is decisive.

Bogie design (forwarder-style, as modelled):

- 2 × 710/45-26.5 tyres ($\varnothing 1345$, 710 mm wide, rounded shoulders, 25 mm chevron lugs) run **in line**: 1470 mm wheelbase, 125 mm gap between the tyres.
- The wheels are on **outboard** hubs. **Inboard** (towards the house centre) is a welded 160 mm bogie case with two 28B-2 chains in an oil bath. There is a 40 mm gap between tyre and case; no beam passes through the wheels.
- **The $\varnothing 220$ bogie pivot is at the bogie centre, at wheel-axle height.** Oscillation $\pm 12^\circ$.
- An L-shaped strut runs down from the slewing drive on the leg axis: a cantilever above the tyres, then a vertical member inboard of the case down to the pivot journal.
- The gear motor is coaxial with the pivot, on the inboard side of the strut.

- Ground contact: both tyres rest on the ground in every pose, including the slope with a hump and a hollow. The bogie pitch is solved so that both tyres touch; model tolerance ± 5 mm (the lug pitch).

For comparison only (NOT the main design): 1 $\times$ 710/45-26.5 wheel per leg instead of a tandem



3.3 Bogie drive: one motor per bogie, not per wheel

- **1 motor per bogie, as on a forwarder.** The motor with its gearbox is coaxial with the pivot axis, so oscillation does not interfere with the drive. Both wheels are linked by chains and always turn together: a mechanical "diff lock" inside the bogie. 4 motors, 4 brakes, 8 high-pressure hoses for traction. The chain housing is a familiar workshop assembly (as on mini loaders): a welded box, CNC-cut sprockets, an oil bath.
- **A motor on each wheel (8 pcs.)** is mechanically simpler: a walking beam without chains. But it means twice as many motors, brakes and hoses. A direct drive needs radial-piston motors, e.g. a Poclain MS18 of ≈ 2700 cm³ at 200 bar. Their minimum steady speed is ≈ 2 rpm, i.e. ≈ 8 m/min on a $\varnothing 1.35$ wheel. A creep speed of 0.5–3 m/min cannot be achieved without a gearbox: Black Bruin states plainly that a smooth speed below 1 rpm is difficult.
- **Conclusion:** a planetary wheel gearbox with an orbital motor. This is a standard combination: the Bonfiglioli 600 catalogue explicitly allows "hydraulic orbit motors". The motor runs at 10–120 rpm, where it is stable.

3.4 Steering: 4 slewing drives (the minimum sensible number)

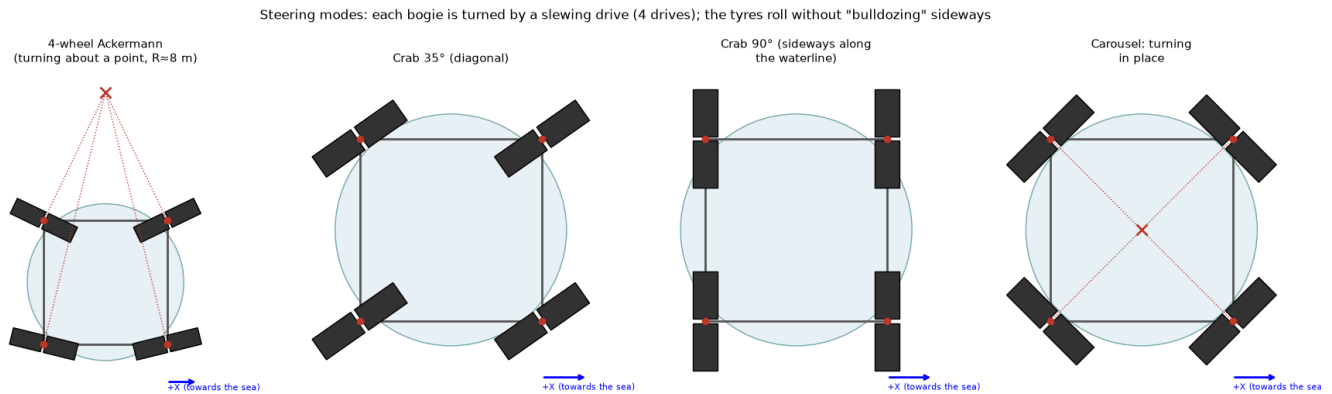
Option	Actuators	Pros	Cons
Skid steering	0	no actuators	8 wide tyres and 4 bogies 3.3 m long are dragged sideways: huge resisting moment, the sand is torn up, the legs are overloaded in bending. Unacceptable
Steering on the 2 front legs	2	fewer actuators	the rear tandems scrub when turning; no crab and no turning in place; cannot approach the waterline sideways

Option	Actuators	Pros	Cons
Steering on all 4 legs (slewing drive)	4	Ackermann, crab up to 90°, "carousel" in place; tyres roll without side slip	4 actuators and 4 encoders

The slewing drive is a self-locking worm drive with a hydraulic motor and an absolute encoder.

Requirements: * output torque $\geq 30 \text{ kN}\cdot\text{m}$: turning a bogie in place, lateral friction of 2 tyres on a 0.735 m lever arm, $\mu = 0.5$ ($\approx 26 \text{ kN}\cdot\text{m}$, 30 with margin); * $\approx 8 \text{ kN}\cdot\text{m}$ is enough when turning on the move; * tilting moment $\geq 60 \text{ kN}\cdot\text{m}$, axial load $\geq 120 \text{ kN}$.

This is the class of 17–21" worm slewing drives (not verified against a catalogue). **Operating rule:** turn the bogies while moving; turn in place only on wet or firm sand.



4. Legs: telescope, cylinder, buckling, lateral loads

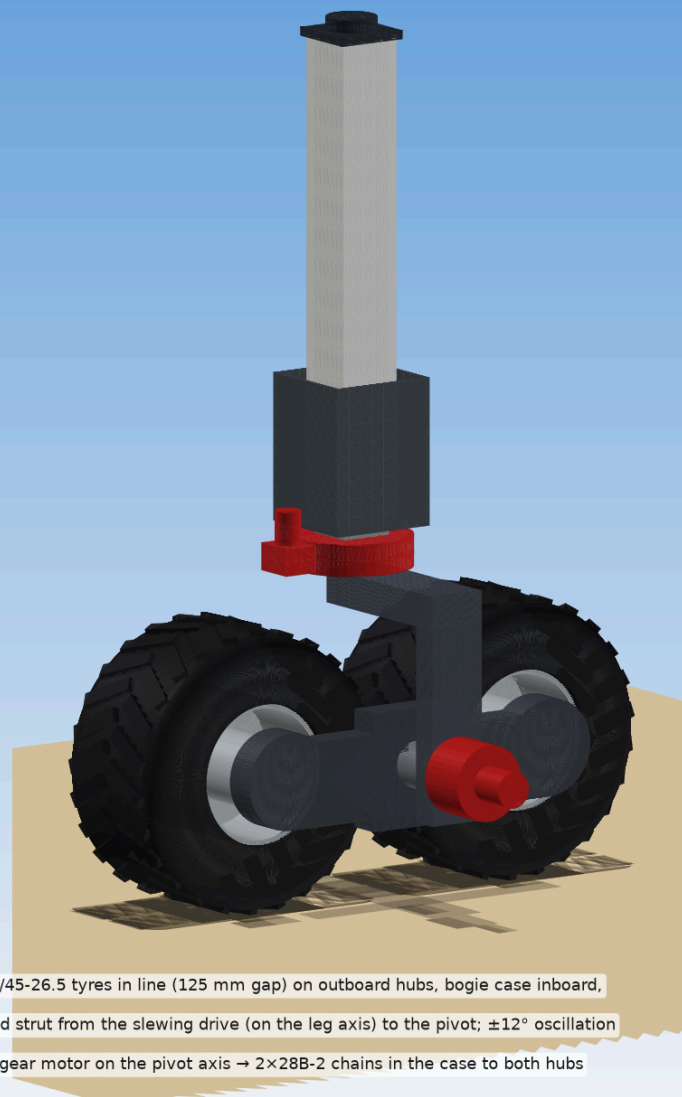
Design. * The 300×300×10 outer tube is welded into a 520×520×700 chassis socket node. On top is a cap with the cylinder trunnion. * The 250×250×10 inner tube slides on replaceable bronze or PA6-G polyamide wear pads: at the bottom of the outer tube and at the top of the inner one. * Inside is a Ø100/80 cylinder. It carries axial force only; bending is taken by the telescope. * Tube overlap is 2.3 m with the leg retracted and 0.8 m fully extended. * When parked: a locking pin through holes every 100 mm, and the pressure is released.

Check	Travelling (legs retracted)	Legs +1.5 m, full traction	Legs +1.5 m, traction limited to 50 %
Vertical load per leg ($k = 1.3$)	69.6 kN (85 kN with snow)	←	←
Horizontal force at the ground	42 kN ($\mu = 0.6$ when slipping)	42 kN	21 kN
Lever arm to the lower guide	1.73 m	3.23 m	3.23 m
Bending moment	72 kN·m	135 kN·m	67 kN·m
σ in the 250×250×10 inner tube ($W = 739 \text{ cm}^3$)	105 MPa ($K = 3.4$)	190 MPa ($K = 1.9$)	99 MPa ($K = 3.6$)
Reaction at the guides	31 kN	169 kN	84 kN
Deflection at the ground	4 mm	24 mm	12 mm
Leg stability as a column ($K_L = 2$)	$P_{cr} = 13\,600 \text{ kN}$	$P_{cr} = 4200 \text{ kN}$ (margin ≈ 50)	←

- **Buckling of the Ø80 rod** with an extended cylinder length of 3.9 m, pinned ends, counting the rod only (conservative): $P_{cr} = 274 \text{ kN}$. At 85 kN the margin is $K = 3.2$. A Ø70 rod gave only 1.9, so Ø80 was chosen.

- Cylinder pressure: 89 bar nominal, 109 bar with snow (if standing on the wheels). Relief valve 250 bar, force at 210 bar is 165 kN.
- **Conclusion.**
- The leg works with a margin in all cases except "full extension + slipping at the traction limit".
- In that case the controller limits the traction pressure to 50 % if the leg is extended by more than 1.0 m: "high stance: creep slowly and without jerks".
- The overall traction pressure limit is 220 bar.
- Design the guide pads for 170 kN (2 pads of 200×150: ≈3-6 MPa, acceptable for PA6-G and bronze).
- Wind on a leg (≈5 kN per leg at 30 m/s) and the downhill component on a 10 % slope (7 kN) are much smaller than the traction force.

Leg assembly: 300/250 telescope, Ø100/80 hydraulic cylinder, steering slewing drive, tandem bogie



5. Tyres and pressure on sand

Baseline tyre: 710/45-26.5 Nokian Forest King F2 SF 24PR 173A8 (forestry tyre, for forwarders). * Ø1345 mm, 710 mm wide, static radius 621 mm. * Per the Nokian table "Forestry service, 10 km/h": 160 kPa → 3350 kg, 200 kPa → 3750 kg, 240 kPa → 4250 kg. * Our load of 2.73 t (×1.15 = 3.14 t) fits at 160 kPa, the lowest point of the table. **So 1.6 bar is confirmed by the table.** * **1.4 bar** is an extrapolation below the table (**not confirmed**, to be agreed with Nokian; manufacturers usually allow more at creep speed). * Tube-type tyre: punctures on a beach are unlikely, but spare tubes are needed.

Mean ground pressure $p \approx p_{\text{tyre}} + p_{\text{carcass}}$ (≈ 30 kPa, empirical for low-pressure tyres):

Option	Tyre pressure	p on sand	Contact patch per wheel
8 × 710/45-26.5 (baseline)	1.4 (extrap.) ... 1.6 bar	≈170-190 kPa	≈0.16 m ² , length ≈0.28 m
8 × 600/50-22.5 F2 20PR (0.85 t lighter, cheaper; for firm wet sand)	≈2.1 bar (extrap.)	≈240 kPa	0.11 m ²
4 × 710/45-26.5 (1 wheel per leg)	3.6 bar	≈390 kPa	0.12 m ²
Bogies + tracks (option)	—	≈30-60 kPa (peaks under the wheels 1.5-2×)	≈1.5 m ² per bogie
Concept 1: Ø0.8 foot pad / Ø2 plate	—	73 / 36 kPa	—

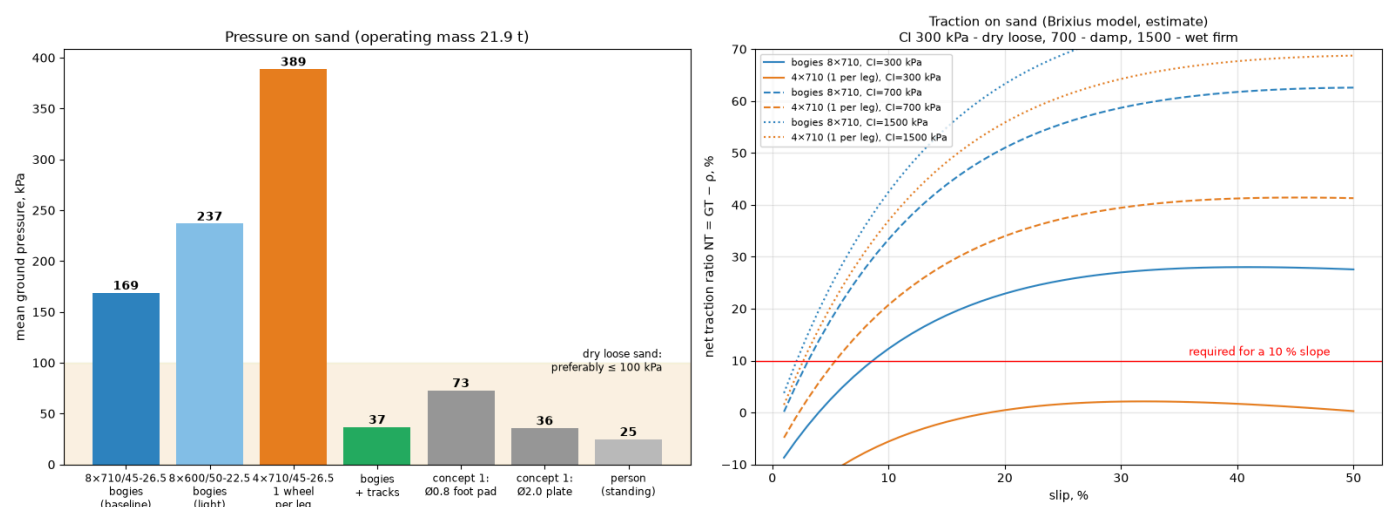
- Required tyre width.** To get ≤ 100 kPa on dry loose sand with a patch length of $\approx 0.3 \cdot D$, a width of ≈ 830 mm ($\varnothing 1.35$) or ≈ 740 mm ($\varnothing 1.5$) is needed. That is the 800/40-26.5...1050/50R32 class, which are already very large wheels. The realistic route for loose sand is **bogie tracks** (+0.5-0.65 t per bogie). They are fitted only for the season of work on dry sand.
- Traction (Brixius 1987, estimate; the model was developed for soils and gives a guide value for sand):**

Ground	8 × 710: ρ	8 × 710: net traction at 30 % slip	4 × 710: ρ	4 × 710: net traction
dry loose, CI 300	0.16	0.27	0.25	0.03
damp, CI 700	0.09	0.59	0.13	0.40
wet firm, CI 1500	0.06	0.73	0.08	0.65

- Required traction** on a 10 % slope with $f = 0.25$ (the specified "bad" sand): $F = W \cdot (f \cdot \cos \alpha + \sin \alpha) + \text{wind} = 76 \text{ kN}$ (19 kN per bogie), the required $\mu \approx 0.36$. Per Brixius at CI 300 this is at the limit: with 20-30 % slip the traction is sufficient, but the wheels will dig into the sand.

Recommendations: * on dry sand drive on slopes of $\leq 5-7 \%$; * reduce the tyre pressure to 1.2-1.4 bar: inflation by the house compressor, optionally a 4-circuit central tyre inflation system (CTIS); * fit tracks; * have a **5-8 t hydraulic winch with a screw anchor** for self-recovery (powered by the same hydraulic power unit).

On the wet firm tidal strip the house drives easily: $\rho \approx 0.06$.



6. Traction drive

Quantity	Value
Dynamic radius	0.64 m (Nokian: 0.650 m at 8 t / 600 kPa)
Traction per bogie, design (10 % slope, $f = 0.25$, unevenness 1.3)	24.7 kN → torque 15.8 kN·m
Adhesion limit ($\mu = 0.6$)	26.7 kN·m → limited by 220 bar pressure: 21 kN·m , 33 kN per bogie
Gearbox	planetary wheel drive, $i = 80$, stall 22 kN·m, built-in spring-applied multi-disc brake with hydraulic release. Bonfiglioli 607W class (600 series: 3–85 kN·m, $i = 4.3$ –153, accepts orbital motors)
Motor	orbital (gerotor) 100 cm³ , Danfoss OMS 100 / Eaton 6000 class (not verified). Torque 224 N·m, $\Delta p \approx 166$ bar design
Chains	2 × 28B-2 (one per wheel), ≈ 310 mm sprockets, tensioners, oil bath; ≤ 86 kN per chain when slipping (breaking-load margin ~ 4 , check per ISO 606)

Speed	Wheel, rpm	Motor, rpm	Flow for 4 motors
0.5 m/min: positioning, "docking"	0.12	10	4.3 L/min
3 m/min: working speed on sand	0.75	60	26 L/min
6 m/min: on firm ground, no gradient	1.49	119	52 L/min

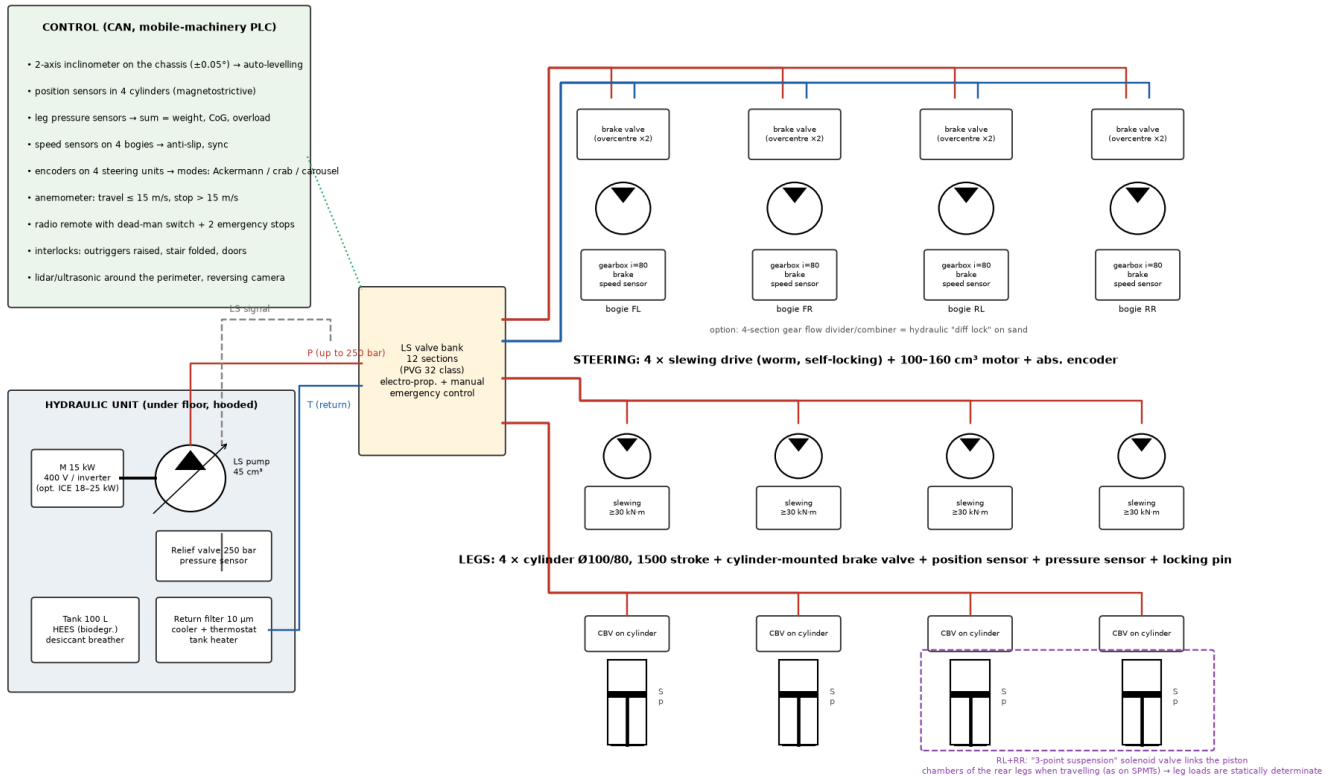
Mechanical power at 3 m/min in the heaviest case is 3.8 kW; hydraulic power for traction is 7.8 kW.

Direct drive (alternative). * For a wheel torque of 7.9 kN·m with 8 motors, a Poclain MS18 (up to 2812 cm³, 17.9 kN·m) or an MS11 of 1687 cm³ (at the limit) would fit. * But 2 rpm (≈ 8 m/min) is the lower limit of steady speed for radial-piston motors. With Black Bruin's slow-speed option it is 0.5 rpm, i.e. 2 m/min. * A direct drive does not suit our range of 0.5–3 m/min, so a gearbox was chosen.

7. Hydraulic circuit and control

Hydraulic schematic (simplified): one LS power unit, 12 proportional sections, 4 bogies / 4 steering / 4 legs

DRIVE: 4 x (100 cm³ motor → planetary gearbox i=80 with spring brake → 2 chains → 2 wheels)



- **Hydraulic power unit under the floor:** a 15 kW electric motor (400 V, soft starter or inverter) + a 45 cm³ variable LS pump (Rexroth A10VO45 DFR class, 67 L/min at 1500 rpm).
- 100 L tank, 10 μ m return filter, oil cooler, tank heater, desiccant breather (sea air).
- HEES oil (biodegradable synthetic ester): we operate on a beach, so a leak must not become an environmental problem.
- Peak flow 47 L/min (traction at 3 m/min + half of the steering + half of the legs), peak power 11.5 kW.
- Option: an 18-25 kW diesel on the pump, or a generator.
- **Valve bank:** sectional proportional LS, 12 sections (Danfoss PVG 32 class): 4 traction, 4 steering, 4 legs. Electro-proportional control via CAN plus manual emergency control.
- **Traction:**
 - a dual overcentre (brake) valve on each motor: holding on descents and on hose failure;
 - the gearbox brake is normally closed and is released by the traction pressure;
 - a speed sensor on each bogie → electronic anti-slip (equalising the speeds of the 4 bogies);
 - option: a 4-section gear flow divider/combiner as a "hydraulic diff lock" on loose sand.
- **Legs:**
 - on each cylinder, mounted directly on the body: a counterbalance valve (hose-burst protection), a magnetostrictive position sensor, a pressure sensor, a mechanical locking pin;
- **3-point suspension, as on SPMTs.** When travelling, a solenoid valve links the piston chambers of the rear legs (RL + RR). The support becomes statically determinate: 3 "points". The leg loads do not depend on unevenness, and there is no "diagonal" hanging;
- levelling: a 2-axis inclinometer ($\pm 0.05^\circ$) on the chassis. The controller keeps the floor level within $\pm 1^\circ$ when travelling and $\pm 0.3^\circ$ when parked, and computes the weight and CoG from the sum of the leg pressures.
- **Steering:** slewing-drive hydraulic motor + absolute encoder. Modes: Ackermann, crab, carousel, "parking" (bogies across the diagonals, freeing space under the outriggers).
- **Safety:**

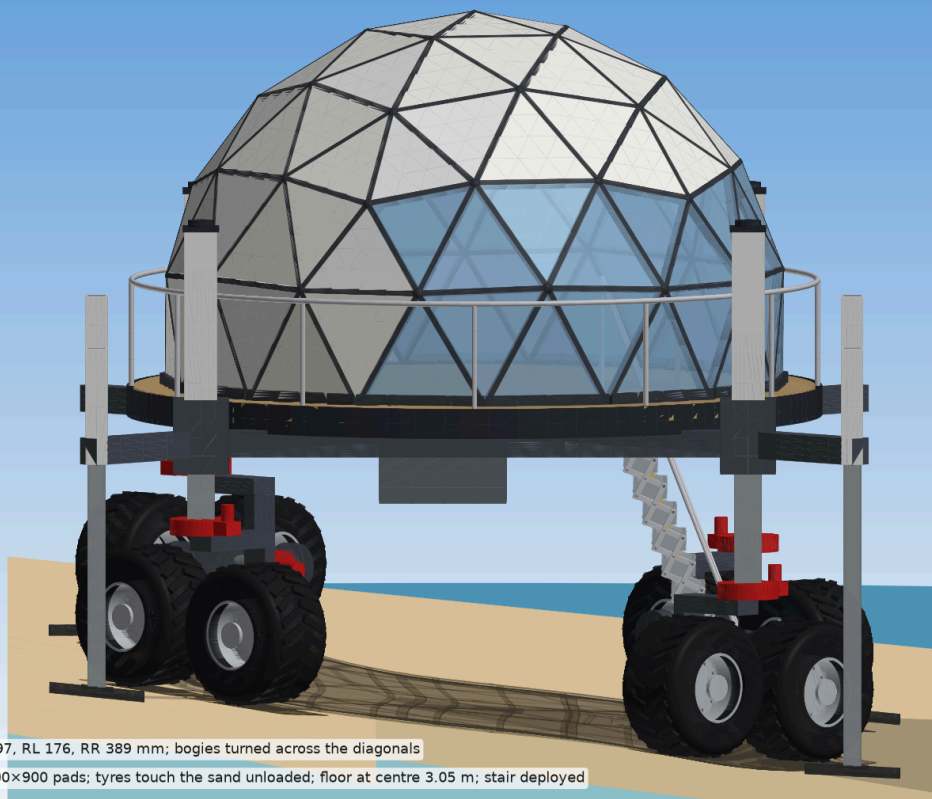
- radio remote with a dead-man button and 2 emergency stops;
- anemometer: travel ≤ 15 m/s;
- interlocks: outriggers raised, stair folded (limit switch + latch), doors closed;
- lidar or ultrasonic sensors around the perimeter.

On power loss the brakes close and the cylinder valves hold the legs. * **Energy:** * on firm level sand: 0.9 kWh per 100 m; * on loose sand up a 10 % slope: 5 kWh per 100 m; * raising the house by 1.5 m: 0.15 kWh.

The house's 15 kWh domestic battery (15–20 kVA inverter) is enough for ~1 km on firm sand or ~250 m on heavy sand. This fits with the house's off-grid power system (solar panels).

8. Parking on outriggers, levelling, floor height

Parked on the beach: 10 % slope towards the sea, a hump and a hollow - floor levelled



- **Can it stand on the outriggers with the wheels unloaded? Yes, and this is the recommended mode for long-term parking.**
- Each corner has a 250×220×10 bracket reaching 1.4 m out along the diagonal. It carries a manual 200/160 telescopic post with pin holes, a screw for fine adjustment and a 900×900 pad on a swivel (it settles onto the slope).
- Sequence: the bogies are turned across the diagonals → the posts are lowered to the sand and tightened with the screw → the legs retract until the wheel load is ≈ 0 (the tyres touch the sand unloaded, as shown in the model) → the pressure is released, the leg pins are inserted.
- The tyres do not stand loaded for months on salty sand, and the hydraulics are unpressurised. The support square grows from 5.2 to 7.2 m.
- Pressure under a pad is 85 kPa, 105 kPa with snow. For storm-exposed sites: screw anchors with guy lines to the brackets (surf scour of the sand!).
- Option: hydraulic outriggers (+4 cylinders), push-button.
- **Levelling on a slope.** Example in the model: 10 % slope, +0.3 m hump, −0.15 m hollow. Leg extension: FL 909, FR 997, RL 176, RR 389 mm. The floor is level, 3.05 m above the sand at the centre and ≈ 2.5 m above the highest ground point under the house. A 1.5 m stroke on a 5.2 m

base can in theory take up a slope of up to 29 %. In practice the limit is traction (section 5): $\approx 10\text{--}15\%$.

- **Floor ≥ 2.0 m: requirement met:**
- 2.38 m when travelling (legs retracted);
- 2.4–3.9 m when parked.

It can also travel with the legs extended: there is no overturning even at 3.9 m (section 9). But with an extension of more than 1.0 m the traction is limited to 50 % because of leg bending.

Recommended travel floor height: 2.4–2.9 m (extension 0–0.5 m).

The stability minimum is lower than what the structure allows. The stricter limit is leg bending when slipping.

Leg designations: FL – front left, FR – front right, RL – rear left, RR – rear right.

8.1 Access to the house: electrically driven scissor stair

It replaced the folding two-flight stair.

Kinematics. Two side "lazy tongs" (pantographs) of 12 cells each, Al 6082-T6 links of 50×10 mm, 382 mm between pivots; stainless $\varnothing 20$ pins in PTFE bushings. Top pivots: A is fixed, B is a slider in a guide inclined at 20° . The pantograph opens perpendicular to the line AB, so the stack axis is inclined 20° from vertical and **the stair angle is 70°** (a steep ladder-type stair, like loft scissor stairs, but with handrails). The pairs of pivots at each cell boundary are always parallel to AB. A tread (Al grating 740×250 , 30 mm) is attached to such a pair: one pivot in a bushing, the other in a slot in the side plate. This is the parallel linkage: **the treads stay horizontal at any extension**, and nothing needs to be adjusted.

Parameter	Value
Rise (from floor to ground)	2.0–3.9 m ($\alpha = 25\text{--}55^\circ$); in the park_slope pose 3.30 m , $\alpha = 43.6^\circ$
Treads	a fixed top tread in the hatch well (-225 mm) + 12 moving ones; riser 248 mm in the parking example (≈ 170 mm at 2.4 m)
Folded	$\alpha = 6^\circ$, a stack of 479 mm along the axis; its bottom is 0.83 m below the floor, ≈ 1.55 m above the ground when travelling (0.3 m below the chassis frame)
Mass	215 kg in total: moving part 95 kg, top frame 38, drive with drum 40, hatch 28, handrails 22

Drive. A 48 V, 400 W gearmotor (BLDC/servo, planetary $i \approx 80$, spring-applied brake, encoder) under the floor behind the hatch. It turns a $\varnothing 120$ drum with two 25 mm Dyneema straps running to the bottom support. Going down, the stack opens **under its own weight with speed control** (the motor in braking mode); going up, by winding the straps.

- Mass referred to the support ≈ 58 kg, strap force with friction ≈ 0.85 kN, drum torque ≈ 51 N·m, 32 rpm.
- Support travel 2.7 m at **0.2 m/s: deployment ≈ 13 s**, power ≈ 170 W (motor margin $\approx 2.3\times$).
- Soft start and stop by encoder: the last 0.3 m at 0.05 m/s.

A screw or linear actuator on slider B is not suitable: in the folded position ($\alpha = 6^\circ$) the scissors put a force of ≈ 50 kN on B. The drum with straps pulls on the lower end, and the force is constant over the whole travel. A screw variant is possible only if the screw pulls a cable to the bottom support through a block and tackle.

Handrails. Telescopic, stainless, 3 sections $\varnothing 42/36/30$, on both sides inside the hatch opening (opening widened to 1000 mm).

- Top: posts on the well walls, 1 m above the floor.

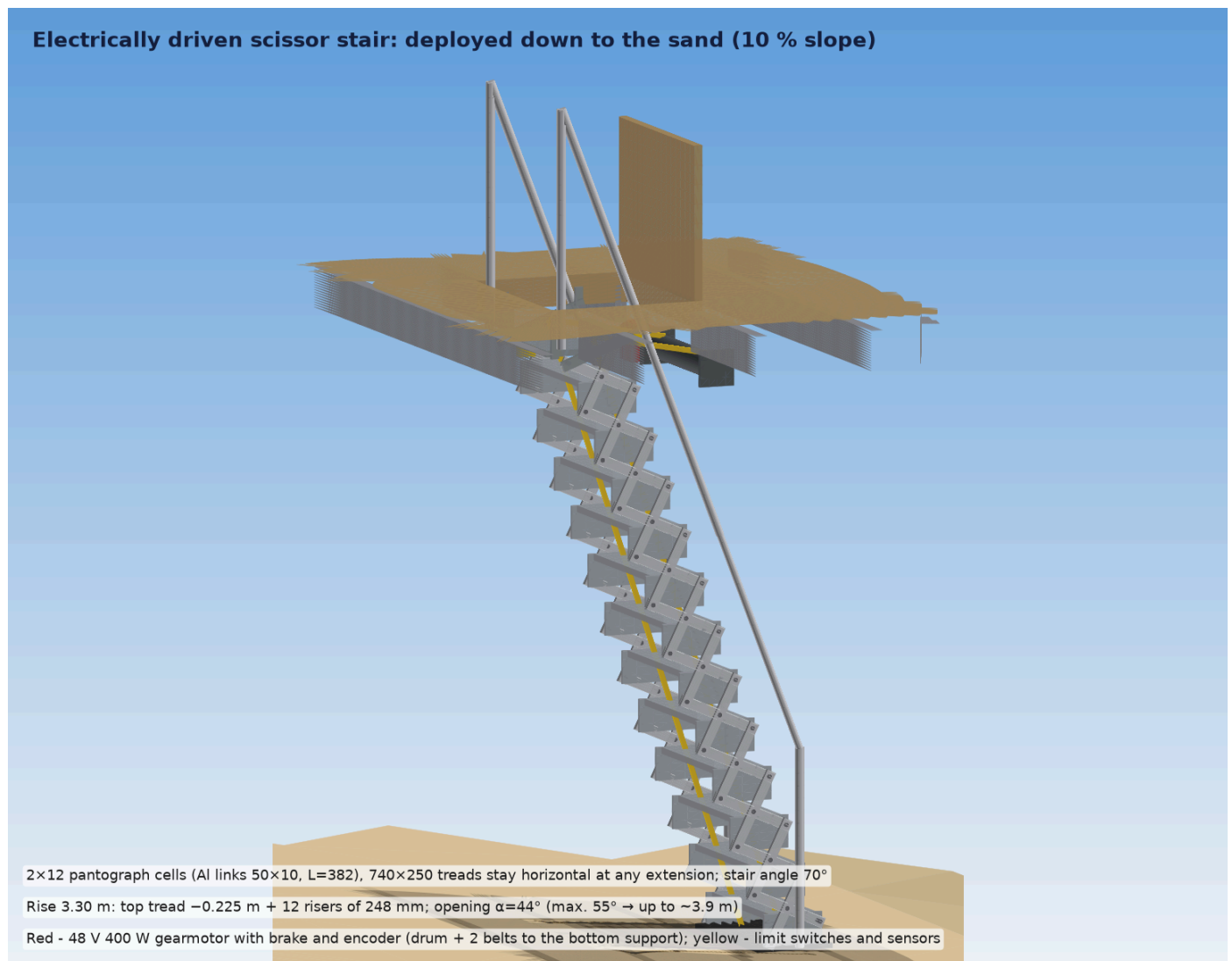
- Bottom: folding posts on the bottom support.
- The folded handrail (1.18 m) lies along the stack under the chassis; the top posts retract to 560 mm and fold into the well under the hatch cover.

Bottom support. A 400×820 frame on a pivot with a rubber sole and a contact sensor. It settles onto a slope or a hump, and the scissors take up the difference by themselves.

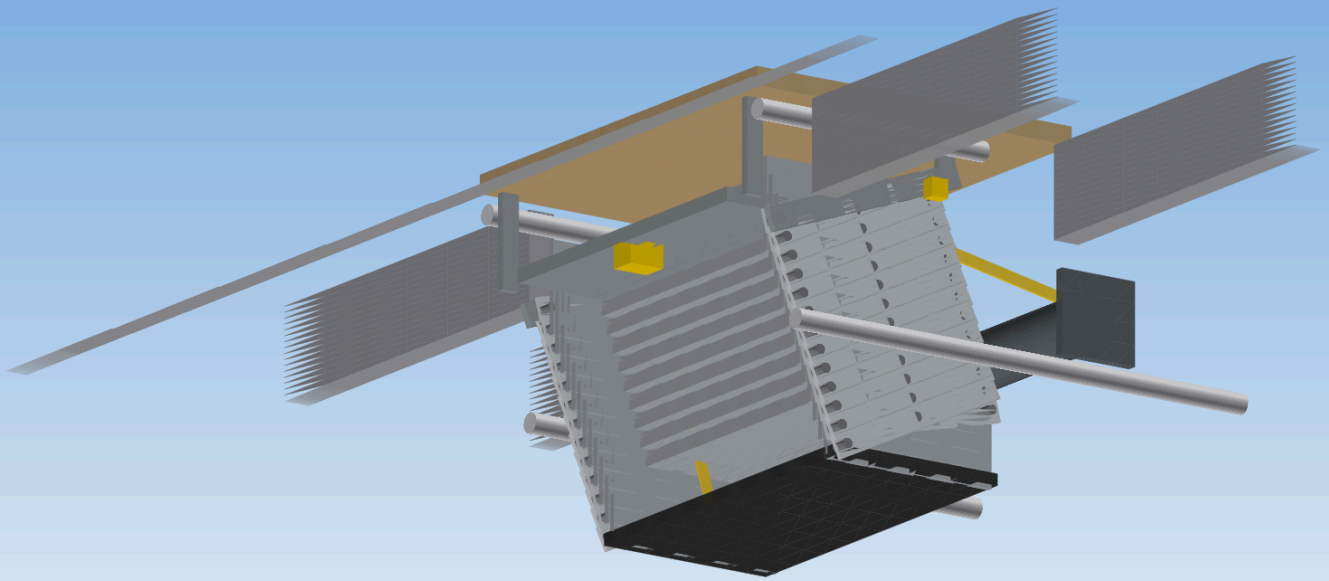
Limit switches and interlocks (drive PLC):

- **"folded" (inductive) + a mechanical latch with a sensor:** without both signals, traction, steering and leg extension are disabled;
- "max. opening" ($\alpha = 55^\circ$) and a software limit by encoder;
- support contact sensor: stops the deployment, then the straps are tensioned to a minimum;
- strap slack sensor: tracking mode, so when the legs are levelled the stair stays on the ground and the drive takes in or pays out the strap;
- deployment is allowed only when parked: speed 0, brakes closed, steering in "parking", doors closed, wind < 20 m/s;
- a hold-to-run button at the hatch and on the remote; on release: stop and brake;
- on power loss the brake holds the stair. In an emergency: a manual crank on the drum shaft.

A vertical platform lift at a leg (300 kg, 1.1×1.4 m) remains an option for guests with reduced mobility.



Scissor stair folded under the floor (travelling): view from below



Stack of 12 cells at $\alpha=6^\circ$ - 479 mm along the axis; bottom 0.83 m below the floor (≈ 1.55 m above ground when travelling)

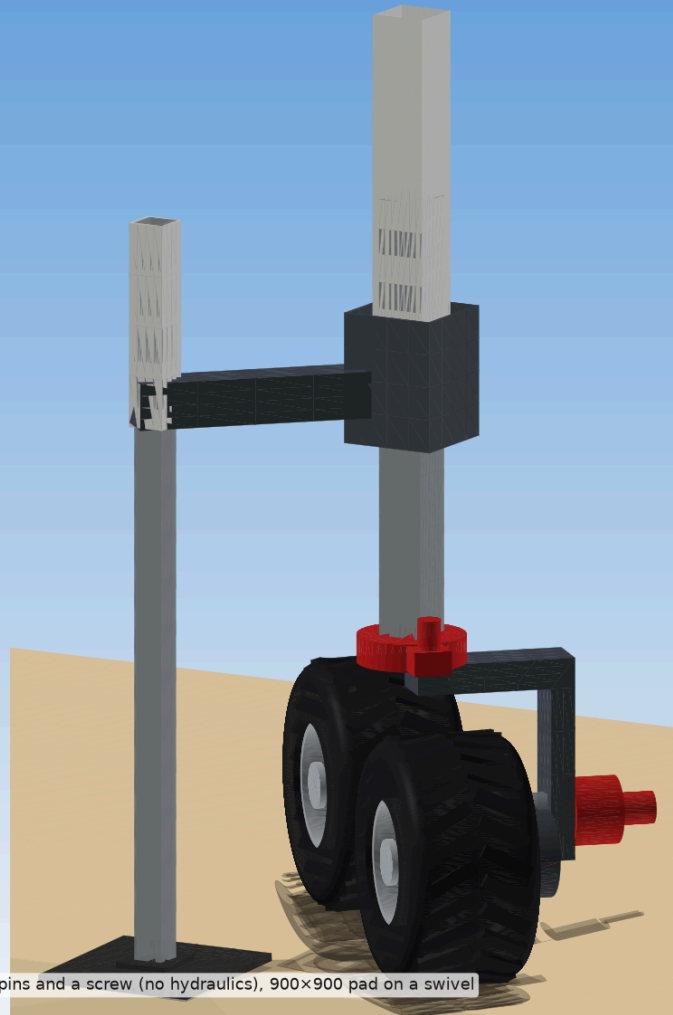
Hatch cover closed, handrail posts lowered into the well; the "folded" limit switch + a mechanical latch enable travel

Parked on a slope: view from the sea



Legs at different lengths, body levelled (inclinometer), outriggers on pads, wheels unloaded

Parked: outrigger on its pad, both bogie tyres resting on the ground unloaded

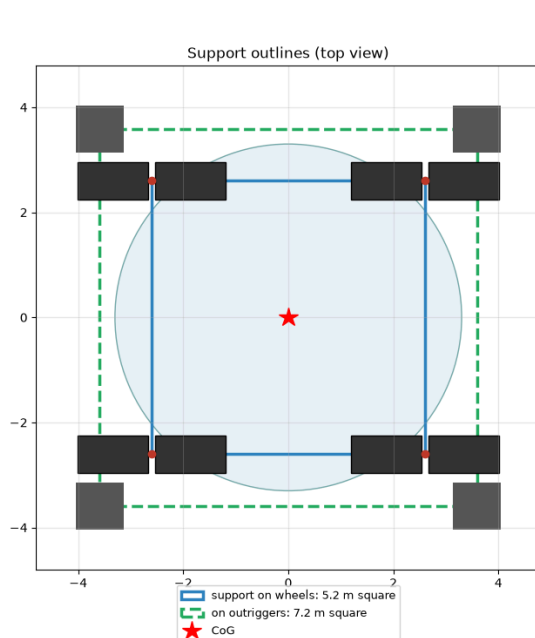


Outrigger - manual telescopic post with pins and a screw (no hydraulics), 900×900 pad on a swivel

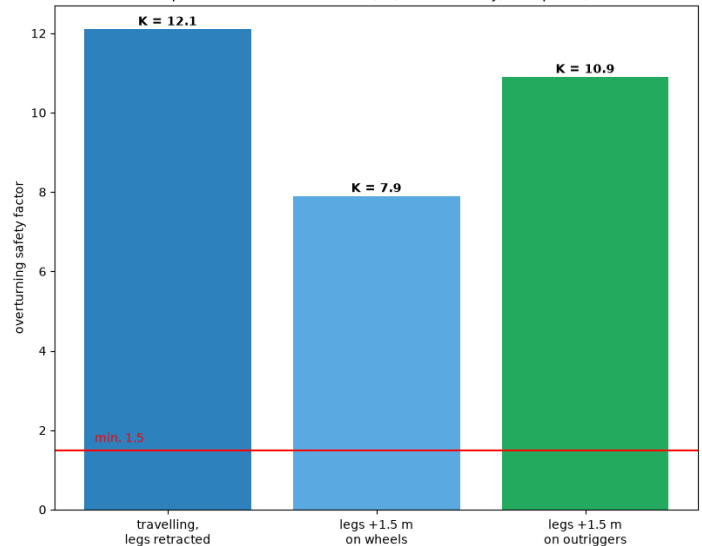
9. Stability and wind

Case	CoG height	C _f ·A / lever arm	Wind 30 m/s: F / M	Margin K
Travelling, legs retracted, on wheels (5.2 m support square)	2.10 m	34.2 m ² / 2.3 m	18.9 kN / 43 kN·m	12.1
Legs +1.5 m, on wheels	2.93 m	37.8 m ² / 3.2 m	20.8 kN / 67 kN·m	7.9
Legs +1.5 m, on outriggers (7.2 m square)	2.93 m	←	←	10.8

- Lift on the dome is included ($C_L = 0.5$, 9.4 kN at 30 m/s).
- Sliding on the outriggers: $\mu = 0.4$, margin 3.9; plus brakes and anchors.
- **Static tip-over angle:** 51° when travelling, 42° with the legs extended.
- **Travelling on a 10 % slope without levelling** (inclinometer failure), wind 15 m/s: $K = 47$ (retracted) and 29 (extended). In terms of overturning it could travel even in winds >50 m/s. **The operational travel limit of 15 m/s** is set by controllability, people nearby and levelling accuracy.
- The heavy, low chassis (13 t of running gear below the floor) makes the house very stable. The high floor (2.4–3.9 m) does not use up the margin.
- When travelling, the CoG lies inside the 5.2 m square with a margin of ≥ 2.6 m. If one bogie is lifted onto an obstacle, a triangle with a 1.8 m margin remains. So in an emergency a leg can be raised to "step over" a log or a hole.



30 m/s wind when parked (with lift on the dome, $CL=0.5$)
by overturning, travel is acceptable up to 67.5 m/s (retracted) and 56.0 m/s (extended);
operational travel limit 15 m/s (controllability, occupants)



10. Corrosion protection (beach, salt, surf)

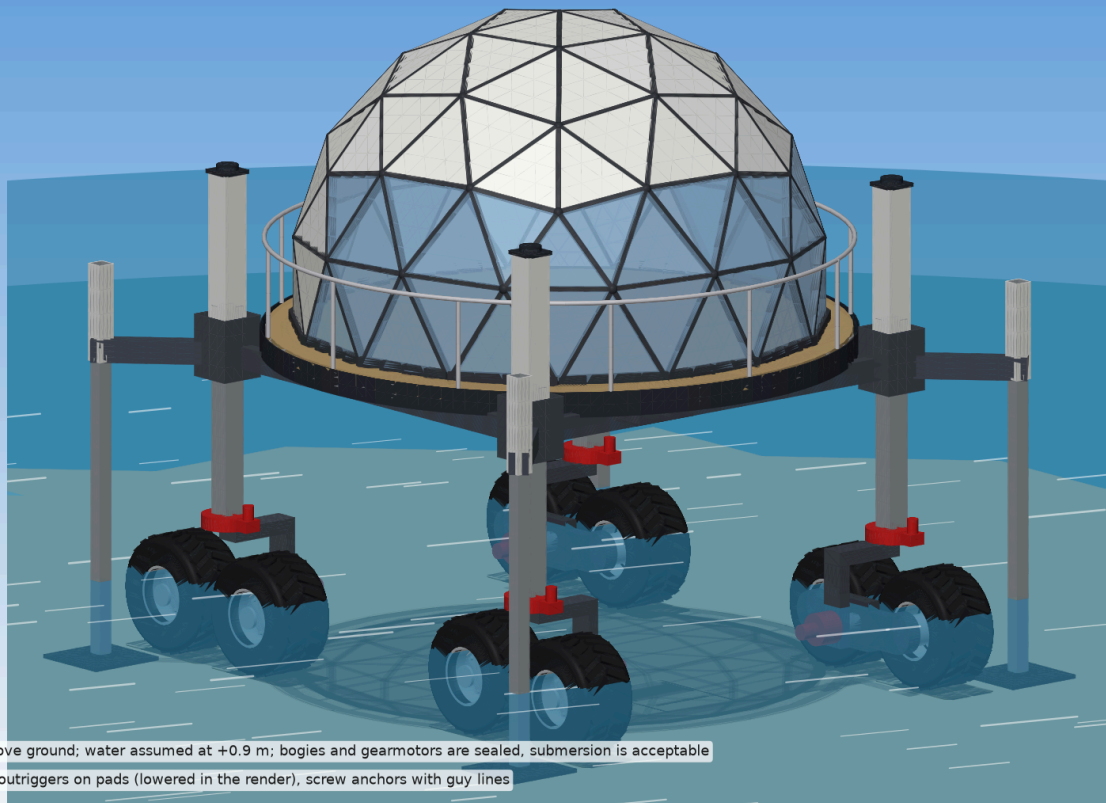
- **Steel:**
 - hot-dip galvanising of all welded assemblies: chassis, legs, brackets, bogies (GOST 9.307 / ISO 1461), 85–100 μm ;
 - on top, a duplex coating per ISO 12944 C5 / CX: epoxy primer + epoxy mastic + polyurethane, $\geq 240 \mu\text{m}$;
 - design the assemblies for galvanising: vent and drain holes, no closed cavities;
 - inner cavities of the leg tubes: zinc plus a preservative.
- **Cylinder rods:** chrome over nickel ($\text{Ni} + \text{Cr} \geq 50 \mu\text{m}$) or ceramic / laser-clad stainless steel. Bellows boots on the rods. The cylinders inside the leg tubes are protected from spray.
- **Sliding pads:** bronze or PA6-G. Not steel on steel (otherwise fretting corrosion).
- **Bogies and gearboxes.**
 - The chain housing and gearbox are sealed: double lip seals, "duo-cone" face seals on the hubs.
 - Breathers are routed up along the leg (submersion is acceptable).
 - Sacrificial zinc anodes on the housings.
 - Hubs and rims are galvanised.
- **Hydraulics:**
 - Zn-Ni coated fittings, A4 stainless clamps and fasteners;
 - hoses in protective spiral wrap, IP69K connectors;
 - the valve bank in an enclosure under the floor.
- **Electrics:** IP67, cables in corrugated conduit, sensors in stainless housings.
- **Maintenance schedule:**
 - after working in the surf: fresh-water wash of the running gear (pump from the house tank);
 - coating inspection once a season;
 - hub lubrication;
 - oil analysis (water content).

11. Comparison with concept 1 (scheme B: walking "excavator" with a plate)

Criterion	Concept 1, scheme B (dome + 4 legs + plate)	Concept 3 (wheeled legs, 8 × 710 on bogies)
Operating mass	11.6 t	21.8 t
Speed	0.92 m/min	3 m/min (0.5–6)
Actuators	6 electromechanical (4 lifts + shuttle + slewing ring)	12 hydraulic (4 legs + 4 steering + 4 traction) + hydraulic power unit + electric stair drive
Ground pressure	73–113 kPa (foot pad), 36 kPa (plate)	170–190 kPa (tyres), 30–60 kPa (tracks), 85 kPa on outriggers
Floor height	2.76 m (almost fixed, 0.3 m stroke)	2.38–3.88 m (1.5 m leg stroke)
Levelling	±0.3 m	up to 1.5 m (slope up to ~29 % in theory)
Slope while moving	≤5 %	≤10 % on damp sand, ≤5–7 % on dry sand (more with tracks or a winch)
Turning	in place on the slewing ring	Ackermann / crab 90° / carousel
Smoothness	stepping, jolts, a pause every 39 s	continuous motion
Noise	quiet (electric)	hydraulic power unit ~70–75 dB(A) when moving (only while moving)
Sand, surf	the foot pads sink, the plate acts as an "anchor" in the sand	designed for sand; the running gear is sealed, submersion is acceptable
Workshop complexity	screw jacks, frame, slewing ring: simple	bogie chain housings, slewing assemblies, hydraulic circuit: medium; the main components are bought in (tyres, gearboxes, motors, slewing drives, cylinders, PVG)
Running gear cost (very rough, not verified)	1×	≈2–3× (8 forestry tyres, 4 wheel gearboxes, 4 slewing drives, PVG, hydraulic power unit)
Effect on the public	"walking castle": a wow effect	"lunar-rover villa": futuristic, clear to an investor, really drives on the beach

Bottom line: for a beach, concept 3 is more practical. It is 3 times faster, levels itself on a slope, lifts the house above the tide and does not sink the way the foot pads do. The price is almost double the mass, plus hydraulics.

Legs fully extended (+1.5 m): the house above the tide and waves



12. FreeCAD model and files

- `cad/wheeled_house.py`: parametric FreeCAD 1.0 model.
- Run: `freecadcmd wheeled_house.py POSE=travel | park_slope | extended [WHEELS_PER_LEG=1] [TIRE_SIZE=600] [KEY=VALUE...]`.
- The parameters are written to the "Parameters" spreadsheet inside the .FCStd together with the mass, CoG, floor height and leg extensions.
- All objects are labelled in Russian; each has a `Massa_kg` property.
- The ground (beach) is a separate object `Грунт_пляж...` (beach ground), not included in the mass.
- Poses (each one .FCStd + .step):
- `travel`: travelling, legs retracted, floor +2.38 m;
- `park_slope`: parked on a 10 % slope with a hump and a hollow, legs at different lengths, outriggers on pads, both tyres of every bogie touching the ground unloaded, scissor stair deployed to the ground;
- `extended`: legs extended by 1.5 m, floor +3.88 m, outriggers lowered;
- `travel_1wheel`: comparison variant with one wheel per leg;
- `travel_600`: bogies with 600/50-22.5 tyres.
- Check: all 5 .FCStd files open, all objects are non-empty. All .step files load (`isValid = True`, ≈ 1190 bodies; ≈ 910 for the one-wheel variant). Every tread lug is a separate body.
- Wheel check (script over the .FCStd files): in the main poses 8 tyres, 2 per bogie; 125 mm gap between the tyres; ground contact -3 to $+5$ mm in every pose, including the slope; no intersections of tyres with the case, strut, pivot, outriggers or stair.
- `cad/render_mpl.py`: renders 01-07 and 12-13 (scissor stair). Presentation rendering from STL (`cad/mesh_*`): matplotlib, shadows, sky, sand, water. FreeCAD's GUI renderer gives blank frames on the server.
- `calc/calc.py` → `calc/results.json`, figures 08-11.

The model is conceptual: bodies intersect at the joints; welds, fasteners, hoses, seals and chains are not modelled. The cylinder is shown inside the leg tube.

Data sources (checked online on 10.10.2026): * Nokian Forest King F2 600/50-22.5: https://www.nokiantyres.com/static/studio/pub/PIH/certificates/heavy/if-3411-f2/tire-certificate_600-50-22-5-20-159a8-167a2-nokian-tyres-forest-king-f2-sf-tt_en_SI.pdf * Nokian Forest King F2 710/45-26.5 24PR: https://ditopony.pl/certyfikaty/nokian/nokian%20forest%20king%20F2%20710_45-26.5%2024PR%20173A8.pdf * Alliance 328 600/50-22.5 (5150 kg @ 2.6 bar, 40 km/h): <https://liamevanstyres-catalogue.co.uk/products/product/600-50-22-5-16-pr-alliance-328-165a8-161b--fr-153a8-149b--dw--i-3-tl-120-3047> * Poclain MS11 / MS18: <https://poclain.com/products/hydraulic-motors/ms-multipurpose/ms11-mse11-motor-max-1687cc-50-kw>, <https://poclain.com/products/hydraulic-motors/ms-multipurpose/ms18-mse18-motor-max-2812cc-70-kw> * Black Bruin, minimum speed (2 / 0.5 rpm, "below 1 rpm is difficult"): <https://www.blackbruin.com/media/x-series-product-manual-black-bruin.pdf> * Bonfiglioli 600W, wheel drives 3-85 kN·m, $i = 4.3-153$, orbital motors: https://www.bonfiglioli.com/usa/en/product/600-series_travel-drives_wheel-drives * NAF, forwarder bogie axles (wheelbase 1300-1890 mm, a guide to the bogie class): https://www.nafaxles.com/wp-content/uploads/2026/07/Portal_Bogie_Axles_2026.pdf

Not verified against a catalogue: the 100 cm³ orbital motor, the ≥ 30 kN·m slewing drive, the 28B-2 chains, the mass of the wheels and assemblies, tyre load below 160 kPa, cost.

13. Open questions for you

1. **Ground and route.** What kind of beach: dry loose, damp or firm? What slopes and travel distances (tens of metres per season or regularly)? This determines whether tracks and a winch are needed.
 2. **Is a mass of 21.8 t** acceptable? Or do we lighten it (aluminium dome, 600 tyres, removable outriggers) and accept worse off-road ability?
 3. **710/45-26.5 tyres (baseline) or 600/50-22.5** (cheaper and lighter, but ≈ 240 kPa on sand)? Is a set of bogie tracks needed?
 4. **Drive:** one motor per bogie with an in-house chain housing (recommended), or 8 wheel gearmotors on a simple walking beam (more bought-in, less in-house)?
 5. **Energy:** only from the house battery and solar (quiet, ~ 1 km of travel on firm sand), or do we fit a diesel on the hydraulic power unit (unlimited, noisy)?
 6. **Outriggers when parked:** manual posts (recommended, cheap, failure-free) or hydraulic (+4 cylinders, push-button)?
 7. **Access:** is the 70° electrically driven scissor stair (in the model) sufficient, or is a shallower one needed ($\leq 45^\circ$, then the stack is longer and does not fit under the floor) and/or a lift for people with reduced mobility?
 8. **Appearance:** a dome (as now) or an elliptical capsule with a rounded roof (better for furniture, heavier and with more wind area)?
 9. **Surf:** does the house go into the water (running gear regularly submerged)? This affects the seals, anodes and bio-oil.
 10. **Legal status and transport:** an 8.1 m plan does not fit on a lowboy trailer without dismantling. Is transport dismantling needed (removable outrigger brackets, legs)? Registration as a self-propelled machine or as a non-permanent structure?
 11. **Climate:** winter, snow, ice in the surf (hydraulics: winter oil, heating; tyres: frost resistance of the tubes).
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14. Caveats

- All calculations are conceptual: simplified schemes, no FEM, no dynamics and no fatigue. The Brixius traction model was developed for soils and gives only a guide value for sand. Traction must be verified by a test run of a loaded bogie on the specific beach.

- Component classes (Bonfiglioli 607W, Danfoss OMS, Rexroth A10VO, Danfoss PVG 32, Nokian F2) are given as a guide. Selection must be done with the manufacturers' engineers: tyre load at <160 kPa at creep speed, radial loads on the gearbox from the chain, service life.
- Main risks of the concept:
 - (1) the mass and the resulting ability to cross dry sand;
 - (2) leg bending at full height while slipping, solved by a software traction limit;
 - (3) corrosion of the running gear and salt in the seals.
- The scissor stair is a kinematic model. The 50×10 link sections, Ø20 pins and treads have not been checked by FEM; a check for 150 kg per tread and for the lateral stiffness of the stack in wind is needed. A 70° angle makes it a ladder-type stair (standards as for loft and ship stairs: EN 14975, ISO 14122-3), not a flight of stairs. It must be used facing the treads, holding both handrails. Sand in the 76 pivots: PTFE bushings, scrapers, fresh-water flushing.