

Concept 2: walking house module in the spirit of the OSU ASV-84 (pantograph legs)

All calculations are conceptual, without FEM strength analysis.

Revision v2 (10.10.2026): - the body was redesigned as a "capsule": rounded plan, vaulted roof, panoramic glazing, fairings; - a deployable, electrically driven scissor stair was added; - mass and loads were recalculated.

What changed compared with the rectangular v1 body is described in section 1A. The v1 files are kept unchanged.

Stage: concept. All figures are estimates based on simplified formulas. They serve to choose the layout and the class of actuators. This is not a detailed design calculation: the frame, legs, guides and joints must later be checked with FEM.

The calculation is reproduced by the script `calc/calc_asv.py`. The script takes the masses and CoG from the model (`cad/mass_*.json`) and writes the figures to `renders/`. - For v2 run: `ASV_VARIANT=v2 python3 calc_asv.py`; results go to `calc/results_asv_v2.json`. - For v1: `calc/results_asv.json`.

The prototype is the OSU Adaptive Suspension Vehicle (1980s): 6 legs, each a planar pantograph, tripod and wave gaits, 3 hydraulic actuators per leg. We take its key idea, the **pantograph**. It decouples the axes: one linear actuator moves the foot only vertically, the other only horizontally. Hydraulics are replaced by electric actuators, and we keep 2 actuators per leg.

1. Summary

Parameter	Value
Body (v2)	capsule $7.9 \times 4.0 \times 3.1$ m: plan is a rounded rectangle R1500, vaulted roof (nose and stern taper 1.6 m, sides 0.42 m)
Area and volume	net floor area 27.1 m^2 (26.7 m^2 at a height ≥ 1.9 m), volume $\approx 72 \text{ m}^3$
Body structure	frame of roll-bent tubes (arches, ribs, rings); 100 mm sandwich: kerf-cut Penoplex on gentle curves, PIR/PU foam on tight ones
Levels	floor +1.16 m, overall height 4.0 m; clearance under the skirt 0.84 m, under the stair cassette 0.54 m
Legs	6 pantograph legs , 3 per side ($x = -2.9 / 0 / +2.9$ m), foot track 4.5 m
Actuators	12: 2 per leg . Lift: trapezoidal screw, self-locking. Step: ball screw with brake
Gait	tripod (always 3 feet on the ground). On uneven ground: wave gait (5 feet)
Mass	walking 11.7 t ($W = 115 \text{ kN}$); parked with snow 16.2 t (v1: 10.3 and 14.9 t)
Speed	0.95 m/min (76 s cycle = 2 steps of 600 mm); 0.86 m/min with the selected LW63-RV1 actuators and VFDs
Stability margin on a tripod	≥ 0.92 m nominal; ≥ 0.72 m including a 3° slope and occupants moving
Leg load	worst single-leg reaction 63 kN (v1: 55 kN)

Parameter	Value
Lift actuator (pantograph $\lambda = 1.5$)	$0.5 \times 63 \times 1.2 = 38$ kN, 700 mm stroke. LW63-RV1 (45 kN) passes; RV2 (33 kN) no longer does
Step actuator	5.9 kN, 400 mm stroke
Foot pad	Ø800 mm, ground pressure 76 / 125 kPa (nominal / worst case)
Turning	by differential stepping with "floating" feet ± 75 mm: $\approx 1.5^\circ$ per half-step, $R \geq 23$ m



Important note on Lishuan. I could not find a linear actuator manufacturer by that name (searches in English, Chinese and Russian, B2B platforms): - "Lishuan Technology" (砺算) is a GPU maker; - the closest-sounding name is **Shenzhen Lichuan (立川)**. They make servo motors, drives and small "ball-screw motors" of 20–57 mm; there are no heavy electric cylinders in their catalogue (<https://en.xlichuan.com/product-xq/23.html>).

Therefore the actuators below are selected from **a verified catalogue of a Chinese manufacturer of the same class, Wuxi Shenli (无锡神力), LW series**. That catalogue has both trapezoidal (self-locking) and ball-screw versions: <http://www.slddtg.com/productshow.asp?bid=160<=1151>. A specification for a request to any supplier has also been prepared (section 6). **If you have a link to Lishuan or their catalogue, send it and I will substitute their models.**

1A. Body v2: the "capsule" (presentation design)

Goal. A plain rectangular box is boring for investors. The image should be a "capsule / Airstream / yacht", but it has to be built in our own workshop from the same materials. The floor area and legs stay the same: 6 pantographs, $x = 0 / \pm 2.9$ m, 4.5 m track, kinematics as in v1.

Concept v2: capsule body

Rounded plan R1500, vaulted roof, panoramic nose glazing, canopy, actuator fairings



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Shape and model parameters

The body shape is defined by horizontal "slices". At height z the plan is a rounded rectangle (or superellipse) with semi-axes $A = dx(z)$, $B = dy(z)$. Roof taper profile:

$$d(t) = RH \cdot (1 - (1 - t^n)^{1/n}), \quad t = (z - (ZTOP - RV)) / RV, \quad n = ROOF_N$$

The curve is smooth, with a horizontal tangent at the ridge. So the roof "flows" into the walls without a crease.

asv_castle_v2.py parameter	Default	Meaning
PLAN	rrect	rrect: rectangle with rounded corners; superellipse: superellipse $ x/a ^n + y/b ^n = 1$ (SE_N=4)
CORNER_R	1500	corner radius in plan
ROOF_N	2.2	"fullness" of the roof profile (2 = ellipse)
RHX, RVX	1600 / 1500	nose and stern taper: horizontal / vertical (Airstream look)
RHY, RVY	420 / 650	taper above the sides (at the sides the wall is almost vertical, where the legs and pylons are)
RB	150	bottom edge rounding
GL_*	—	side glazing band: sill +0.84 m above the floor, height 1.15 m; the nose is fully glazed forward of $x = 3.2$ m, from +0.3 m above the floor up to 3.55 m
VISOR	150	canopy overhang above the nose glazing (0 = no canopy)
FAIRINGS, SKIRT_OFF	True / 170	lift-actuator pylon fairings and the base skirt
STAIR	auto	stair: deployed / stowed; auto = deployed in the stand pose, folded in the tripod pose

Key dimensions: - body $7.9 \times 4.0 \times 3.1$ m, gross plan 29.4 m^2 ; - **net floor 27.1 m^2** (26.7 m^2 at a height ≥ 1.9 m); - volume $\approx 72 \text{ m}^3$.

How to build it in the workshop

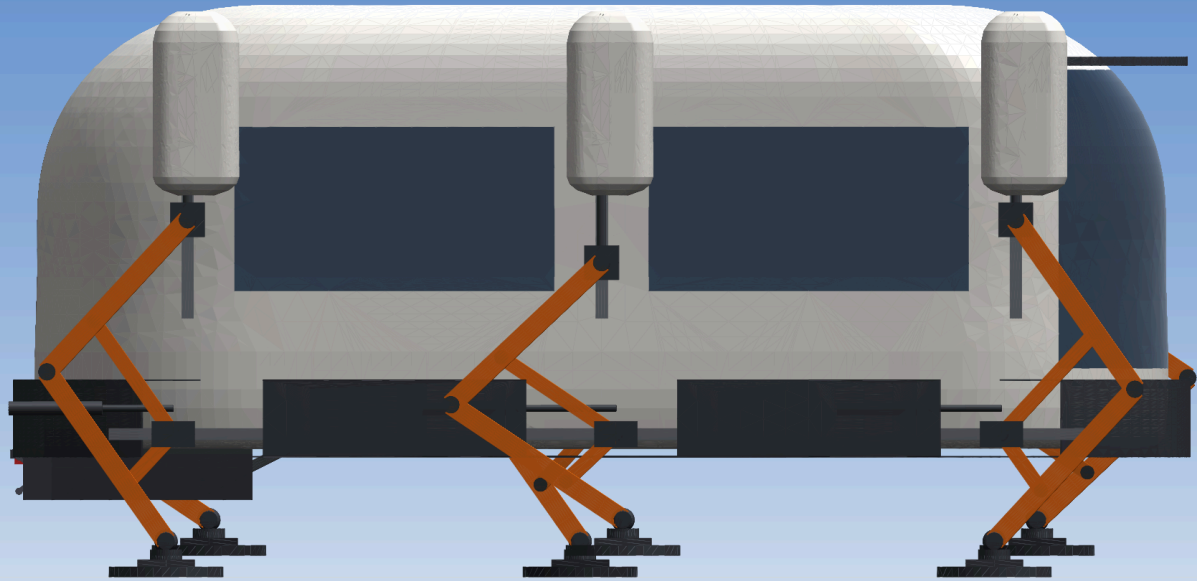
- **Frame: bent (roll-bent) tubes** (fig. v2_05):
- 8 transverse arches $100 \times 100 \times 4$. They stand in the leg planes (± 260 mm from the leg axis) and midway between the legs;
- 10 nose and stern ribs $100 \times 80 \times 4$;
- 3 horizontal rings $100 \times 80 \times 4$: sill, eaves and top;
- a $200 \times 100 \times 6$ base frame, roll-bent to the R1350 plan;
- cross beams in the leg planes and longitudinal members under the guides.

The arches share the same radii: they are bent on one three-roll bender to a template. If bending is not available, the curves are replaced with faceted segments of $5-7^\circ$ (welded on a jig, fixture made by CNC cutting). * **Envelope: 100 mm sandwich.** * Sides, nose and stern with radii ≥ 1.5 m use **Penoplex boards** with kerf cuts $2/3$ of the thickness every 50–80 mm. The boards are bent in place and the joints are foamed. * Tight areas (the roof transition above the sides, $R \approx 0.4-0.65$ m, opening surrounds) are made with **PIR segments** milled to a template or with **sprayed PU foam** in formwork. * Outer skin: aluminium composite or 0.7–1.0 mm sheet roll-bent to a single radius. Seam stringers along the arches (Airstream style); alternatively fibreglass + gelcoat. * Inside: 6–8 mm plywood on battens or bent gypsum-fibre board. * **Glazing ($\approx 19.5 \text{ m}^2$):** * nose: bent or faceted laminated glass / tempered double glazing. Faceted (5–7 flat panels) is noticeably cheaper and looks the same from a distance; * side band: flat double-glazed units.

Dark solar-control tint. * **Canopy** above the nose: 4 mm bent sheet on a frame, graphite. It shades the panoramic glass. * **Pylons** cover the lift actuator and its upper mount. * Fairings: fibreglass or 3 mm aluminium, removable. * Upper mount: the actuator hangs from a bracket on the top frame ring (2 gussets + a lug, 30–38 kN downward). * The lift actuator is vertical and works in tension, as in v1. * **Base skirt** (graphite): * hides the horizontal guides and the step actuators; * "arches" are cut into the skirt for the travel of slider B and the short pantograph links, with brush seals; * the skirt does not obstruct the legs: thigh and shank run outside it, in the plane $y = \pm 2.25$ m. * **Presentation colours:** * body: pearl white; * glass: dark tinted; * skirt, canopy, feet: graphite; * leg links: orange.

Side view (forward = right)

Right side, Tripod 1 (FL, MR, RL) raised by 150 mm and swinging; length 7.9 m, height 4.0 m, floor +1.16 m



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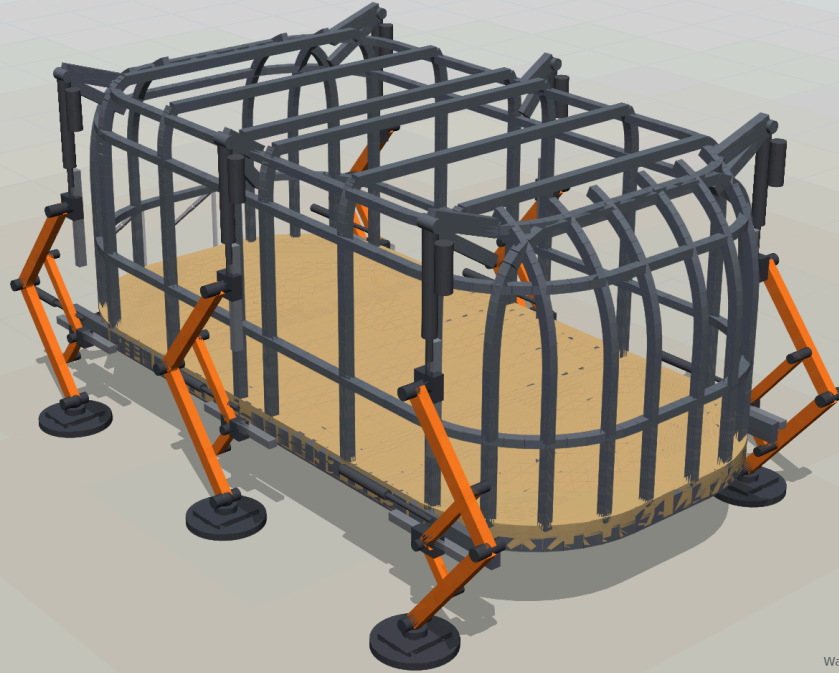
Front view: panoramic nose glazing



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Frame of bent tubes

Arches 100×100×4 (roll-bent), nose/stern ribs 100×80×4, rings, base frame 200×100×6



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What changed in numbers (v1 → v2)

	v1 (box)	v2 (capsule)	Comment
Frame, kg	2 625	3 472	arches, ribs, rings, pylon brackets. Optimisation reserve ≈ 0.5 t: 100×60×4 arches at 900 mm spacing
Envelope, glazing, door, canopy, kg	2 115	2 348	sandwich area 70.5 m ² , glass 19.5 m ² (was 11 m ²)
Fairings (pylons, skirt), kg	—	187	23 m ² of fibreglass/aluminium
Stair, kg	90	195	scissor type with actuators
Mass while walking	10.3 t	11.7 t (+13%)	W = 115 kN, CoG at 1.86 m (was 2.03 m)
Parked with snow	14.9 t	16.2 t	snow 1.5 kPa on a 29.4 m ² plan
Stability margin on a tripod (min. / worst)	0.92 / 0.71 m	0.92 / 0.72 m	lower CoG
Worst leg reaction	55.4 kN	62.6 kN	
Lift actuator, design force	33.2 kN	37.6 kN	LW63-RV1 (45 kN): yes; RV2 (33 kN): no
Step actuator	5.3 kN	5.9 kN	LW40 with ball screw, with margin
Guide B (upward)	83 kN	94 kN	size 55 profile rail guide or a roller carriage
Ø800 foot: pressure nom. / max.	67 / 110 kPa	76 / 125 kPa	Ø900 on weak ground
Wind: C _f ·A, K on a tripod (10 m/s), K parked (30 m/s)	32.9 m ² ; 14.5; 5.0	28.7 m ² ; 19.3; 6.5	streamlined shape + higher mass

	v1 (box)	v2 (capsule)	Comment
Peak power / energy	5.1 kW; 2.1 kWh per 100 m	5.6 kW; 2.3 kWh per 100 m	

Conclusion: the mass grew by 13%, but none of the decisions change. The kinematics, actuators (LW63-RV1 + LW40 ball screw), gait and speed of 0.86–0.95 m/min stay the same. The stability and wind margins even grew slightly.

1B. Deployable electrically driven scissor stair



Design: * **Cassette under the floor at the stern:** 1.6 × 1.2 m, 0.36 m high, 3 mm sheet. Inside: a carriage on rollers carrying the top pivot axis. * **Scissor mechanism ("lazy tongs"):** * two side chords of 4 cells each; 400 mm levers, 30×50; * the treads (4 pcs., 940 × 280, chequer-plate aluminium) sit on the nodes of the upper chord.

The opening of one cell sets the angle of all the others, so a single actuator is enough to deploy it. * **Keeping the treads level.** A second, "levelling" chord is offset 110 mm upward. Together with the main chord it forms parallelograms, so the treads stay horizontal at any inclination and extension. * **Tread heights.** From the threshold (+1.16 m): treads at 0.88 / 0.66 / 0.44 / 0.22 m, then the ground. Riser 220 mm, the first one from the threshold 280 mm. Going 280 mm, reach 1.1 m beyond the stern. * **Handrails:** * telescopic, on both sides, 0.9 m high; * the posts fold down and lie along the chord when stowed. * **Heel:** a support beam with rollers. It compensates for uneven ground and small body movements.

Actuators (24 V DC, powered from the house battery):

	Function	Type	Estimate
M1	extending the carriage from the cassette, 1.3 m stroke	24 V 200 W servo motor + rack, encoder	≈0.5 kN, 0.1 m/s
M2	tilting the stack down by ≈40°	24 V electric cylinder, 150–200 mm stroke, self-locking	≈2–3 kN
M3	opening and closing the scissors (across the 1st cell)	24 V ball-screw electric cylinder with brake, ≈250 mm stroke	≈2 kN

Deployment cycle 25–40 s: M1 → M2 → M3 until ground contact. Folding is the reverse order. M3's travel is force-limited: the heel is lowered until contact (by current or limit switch), not to a coordinate.

Limit switches and interlocks (PLC): * **S1 "folded / locked"**: the carriage is in the cassette, the mechanical latch is closed. **The leg actuators may only be enabled when S1 is active.** This "no walking with the stair deployed" interlock is hardware-based, through the VFD enable circuit (safe torque off), plus a software interlock. * **S2 "carriage extended"**. Enables M2 and M3. * **S3 "heel on the ground"**. A sensor in the heel: allows the door to open outward and clears the "danger" indication. * **Door open → walking disabled.** A separate door sensor in the same enable circuit. * A "stop" button at the door and outside at the stern. * On power loss the stair stays in its current position: M2 and M3 are self-locking or braked.



Limitations: * When folded, the cassette hangs below the underside: **clearance under the stern 0.54 m** (0.84 m along the sides). If this is not enough, the cassette can be recessed 150–200 mm into the entrance-hall platform. * A 220–280 mm riser gives the steepness of a "gangway", not of a domestic stair. Elderly guests need a 5th flight step: one more cell, +0.28 m reach.

Stern: entrance and deployable scissor stair

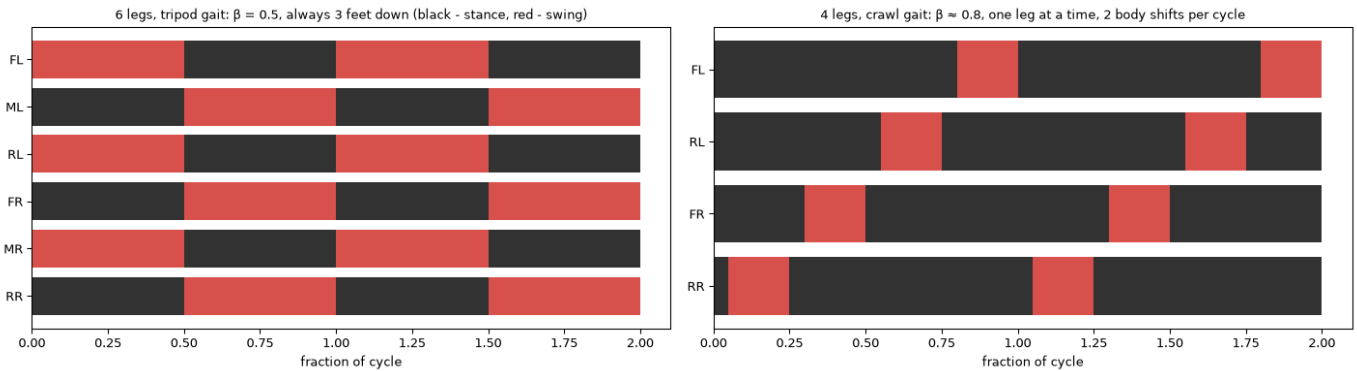
Electrically driven stair deployed: treads stay horizontal (parallelogram), handrails, limit switches, walking interlock



2. Why 6 legs rather than 4

	4 legs (8 actuators)	6 legs (12 actuators)
Gait	crawl: one leg at a time, the body moves separately	tripod: 3 legs in stance, 3 in swing, the body moves at the same time as the swing
Stability margin	$\approx 95 \text{ mm}$ (formula $(S/4) \cdot 2b / \sqrt{((2a - S/2)^2 + (2b)^2)}$)	$\geq 920 \text{ mm}$ nominal, $\geq 710 \text{ mm}$ worst case
Sensitivity	a 2° slope or wind are already dangerous	works on a 3° slope with wind up to $\sim 15 \text{ m/s}$ (wind margin $K \geq 14$ at 10 m/s)
Speed with the same actuators	$\approx 0.26 \text{ m/min}$: 4 swings + 2 body shifts = 136 s per 600 mm	0.95 m/min : 38 s per 600 mm
Single-leg reaction	up to $W/2 \approx 56 \text{ kN}$	up to $W/2 \approx 55 \text{ kN}$ (the middle leg on the side with a single leg in stance)
Statics	with support on 4 legs the problem is indeterminate, force control is needed	a tripod is statically determinate, the reactions are known
Actuator cost	8 pcs.	12 pcs., but these are cheap catalogue linear actuators

Conclusion: **6 legs**. Stability is an order of magnitude higher, speed is 3–4 times higher, and the extra actuators cost less than the stability is worth. The load on a single leg is the same as in the 4-leg layout.



3. The pantograph leg

$F = A + \lambda \cdot (B - A)$, $\lambda = AF/AB = 1.5 \times F = (1-\lambda) \cdot xA0 + \lambda \cdot xB \rightarrow$ depends only on slider B (step actuator) $zF = (1-\lambda) \cdot zA + \lambda \cdot zB0 \rightarrow$ depends only on slider A (lift actuator)

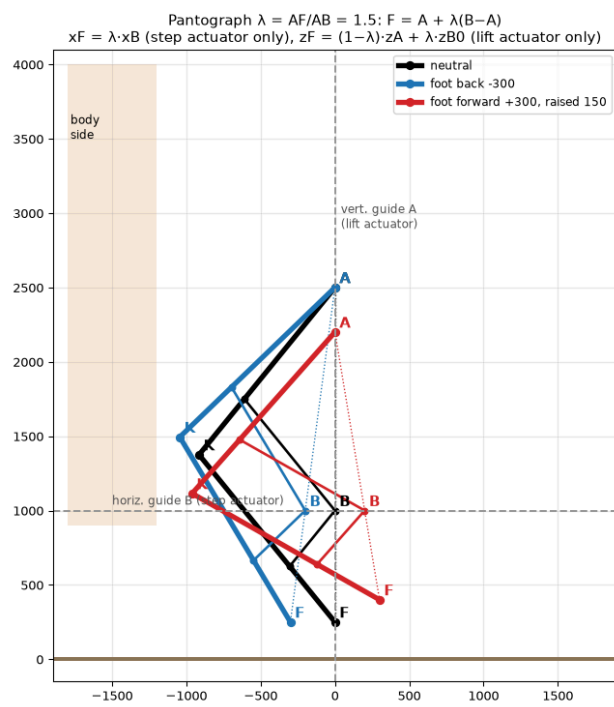
- **A** is a slider on a vertical guide on the body side, at 2.0–2.7 m. The lift actuator hangs above it from the top frame and works **in tension**, so there is no rod buckling.
- **B** is a slider on a horizontal guide at the base frame, at 1.0 m. The step actuator lies along the side.
- Links: thigh A-K and shank K-F (1450 mm each, 140×100×6 tube) plus the short links N-B and B-M (100×80×5). The parallelogram N-K-M-B keeps points A, B, F on one straight line.
- **Foot:** a ball joint, below it a transverse "floating" slider ± 75 mm with centring springs (needed for turning) and a $\varnothing 800$ foot pad.

Choice of λ . The actuator force and stroke depend on λ as follows:

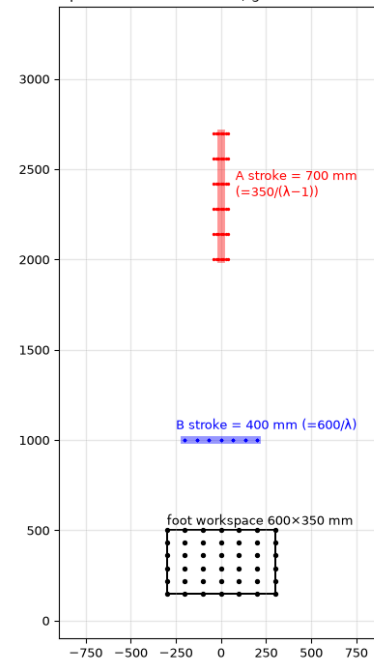
	Formula	$\lambda = 1.5$	$\lambda = 2$
Lift actuator force	$(\lambda - 1) \cdot Fz$	$0.5 \cdot Fz$	$1.0 \cdot Fz$
Lift actuator stroke	$\Delta z_{\text{foot}} / (\lambda - 1)$	$2 \cdot \Delta z$	$1 \cdot \Delta z$
Step actuator force	$\lambda \cdot Fx$	$1.5 \cdot Fx$	$2 \cdot Fx$
Step actuator stroke	S / λ	$S / 1.5$	$S / 2$
Vertical load on guide B (passive)	$\lambda \cdot Fz$	$1.5 \cdot Fz$	$2 \cdot Fz$

A house needs a small foot amplitude but a large force. Hence $\lambda = 1.5$: the lift force is half the foot load (33 kN instead of 66 kN at $\lambda = 2$), and the stroke grows to 700 mm, which is normal for a linear actuator.

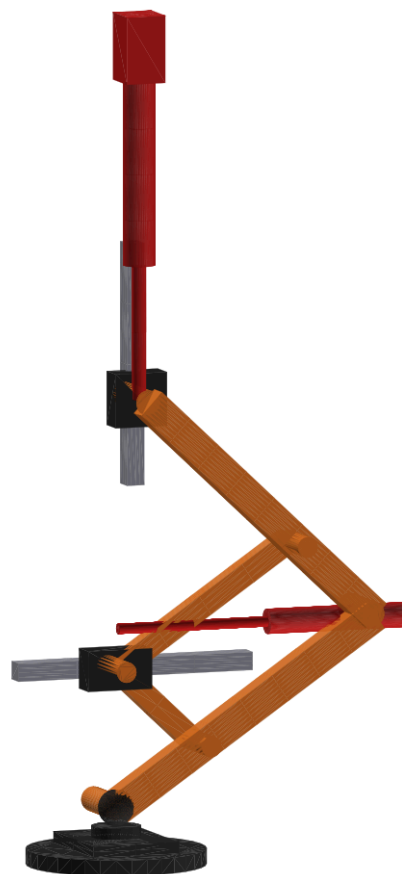
An important property: **in the stance phase the lift actuator does not move.** The body is moved only by the step actuator, and the vertical load is held by the self-locking trapezoidal screw. Current and heating in stance are zero. This is exactly why a trapezoidal screw is appropriate here.



Decoupled axes: a rectangular grid of foot positions
 $\leftrightarrow$ independent actuator strokes. Lift force $= (\lambda-1) \cdot F_z = 0.5 \cdot F_z$,
 step force $= \lambda \cdot F_x = 1.5 \cdot F_x$, guide B carries $\lambda \cdot F_z$



Close-up: RL pantograph leg in swing - A vertical slider, B horizontal slider, F foot



Red - actuators: lift (above A, pulling), step (along the side, moves B)

4. Mass and loads

Group	kg
Body frame: 200×100×6 base frame, 100×100×4 posts, ring beams, rafters, joists	2 625
Walls, roof (100 mm sandwich, 18–22 kg/m ²), 11 m ² glazing (35 kg/m ²), door	2 115
Floor: 100 XPS + 2×18 plywood + skin (39 kg/m ²)	1 442
6 legs: pantographs, guides, sliders, feet	1 558
12 actuators	480
Entrance stair	90
Welds, fasteners, paint (+5% of steel)	209
Interior and building services	1 500
Dead weight	10 019
People (4 × 80)	320
Walking, W	10 339 kg = 101 kN , CoG at 2.03 m
Snow (1.5 kPa × 30 m ² , $\mu = 1$), parking only	4 587
Parked with snow	14 926 kg = 146 kN

Reactions on a tripod. The problem is statically determinate; the reactions are found from 3 equilibrium equations. - The single middle leg (MR or ML) always carries $\approx W/2 = 50.7$ kN. The two outer legs carry 19–32 kN. - Including a 0.21 m CoG offset (3° slope: $2.03 \cdot \tan 3^\circ = 0.11$ m, plus 0.10 m from people) **the worst reaction is 55.4 kN.**

Leg designations: FL/ML/RL – front/middle/rear left, FR/MR/RR – front/middle/rear right.

Loads on the leg elements ($\lambda = 1.5$):

Element	Calculation	Load
Lift actuator	$0.5 \times 55.4 \times k_{\text{dyn}} 1.2$	33.2 kN , 700 mm stroke
Same, parked with snow on 6 legs	$0.5 \times 146/6 \times 1.3$	15.9 kN
Step actuator	$F_x = W \cdot (0.01 + 0.05)/3 \times 1.5 + 0.5$ = 3.5 kN per leg, then $\lambda \cdot F_x$	5.3 kN , 400 mm stroke
Horizontal guide B (passive)	$\lambda \cdot F_z$	83 kN upward. Heavy size 45–55 profile rail guide or a roller carriage in a channel
Top ring beam and posts at the legs	lift actuator reaction	28–33 kN downward at each leg

The frame must be checked for these concentrated forces.

Ground. Ø800 foot pad (0.50 m²):

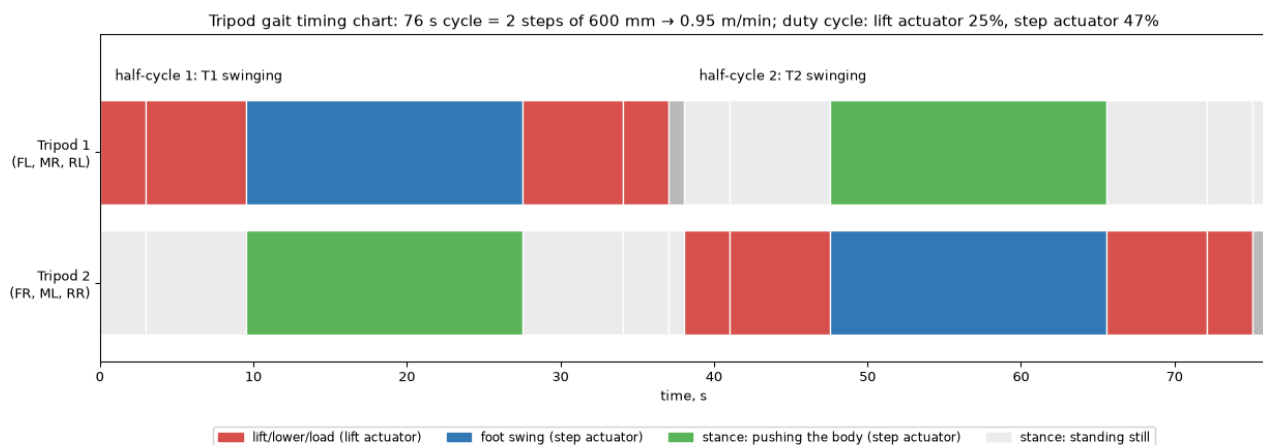
Mode	Pressure
Nominal, W/3 per leg	67 kPa
Worst case	110 kPa
Parked on 6 legs	63 kPa

For 150 kPa ground Ø690 is enough; for 100 kPa Ø840 is needed. On weak ground, strap-on "skis".

5. Gait, stability, speed

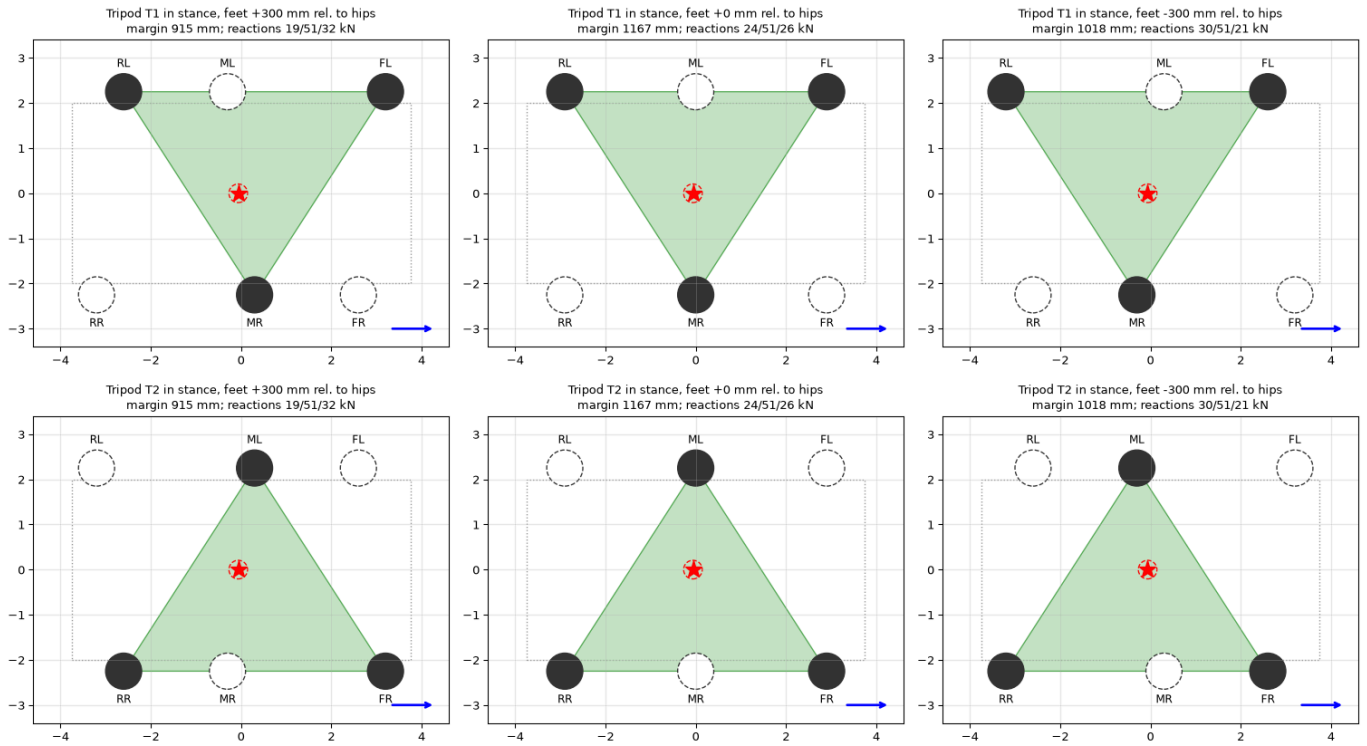
Tripod T1 = FL, MR, RL; tripod T2 = FR, ML, RR. While one tripod swings, the other pushes the body forward with the step actuators.

Phase (half-cycle)	What happens	t, s
1	Unloading T1: the load transfers to T2 (15 mm at the foot at 5 mm/s)	3.0
2	Lifting the T1 feet by 150 mm (A: 300 mm at 46 mm/s, foot 23 mm/s)	6.5
3	Swinging T1 by +600 mm; at the same time T2 pushes the body by 600 mm (B: 400 mm at 22 mm/s)	18.0
4	Lowering T1 to contact	6.5
5	Loading T1, levelling the tilt	3.0
6	Checking forces and tilt	1.0
	Half-cycle (600 mm step)	38 s → 0.95 m/min

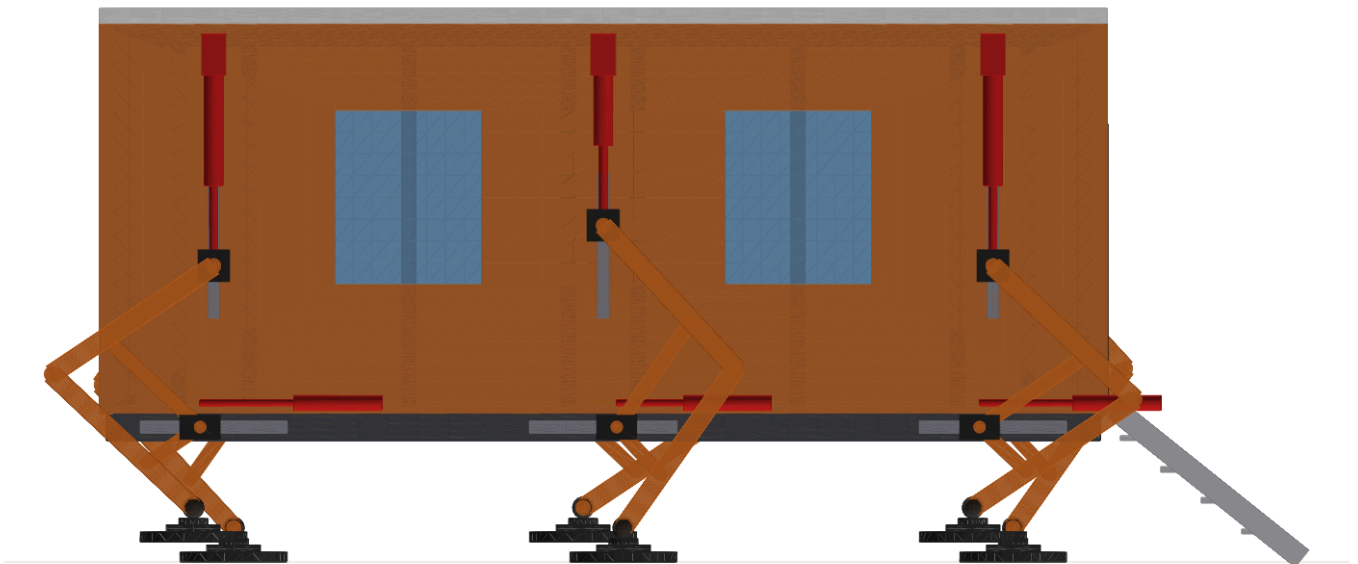


- **Stability margin by phase** (fig. 05): 915 → 1167 → 1018 mm with the feet at +300 / 0 / -300 mm relative to the hips. In the worst case (3° slope and occupants): **≥709 mm**.
- **Wind:** $C_f \cdot A \approx 33 \text{ m}^2$, lever arm 2.45 m.
- on a tripod at 10 m/s the margin is $K = 14.5$. Walking is limited to 15 m/s; this is a matter of comfort and sensors, not of overturning;
- parked at 30 m/s, $K = 5.0$. Suction on the roof is not included; anchors are advisable.
- **Levelling:** ±100 mm at each foot (included in the 700 mm stroke). The body stays level on slopes up to $\approx 2.5^\circ$, and, using the foot reach, on unevenness of ±100 mm.
- **Wave gait** (one leg swings at a time, 5 on the ground): margin over 2 m, about 3 times slower. A mode for poor ground.
- **Turning:** by different step lengths on each side. The limit is the floating foot travel of ±75 mm on a 2.9 m lever: $\Delta\theta \approx 1.5^\circ$ per half-step, $R \geq 23 \text{ m}$, a 90° turn takes ~38 min.

Tripod gait: support triangles (black feet - in stance, dashed - in swing). ★ - CoG, red circle - CoG offset
 due to a 3° slope and occupants (206 mm). Minimum margin 915 mm, worst case 709 mm. With 4 legs (crawl) the margin would be ~95 mm

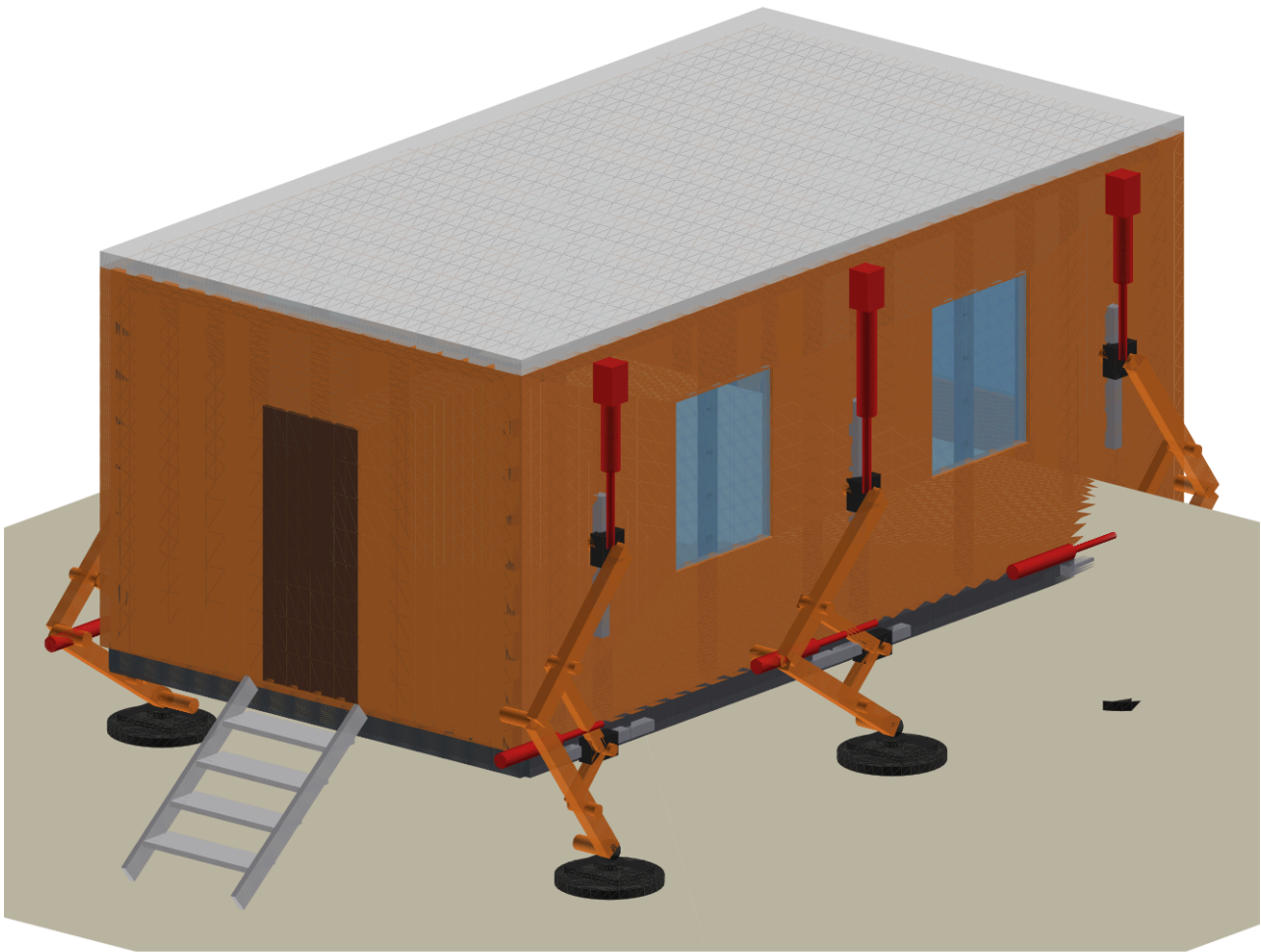


Left view (forward = left): tripod 1 (FL, RL, MR) raised by 150 mm and swinging



Near side - left: FL and RL raised, ML (tripod 2) in stance and pushing the body

Mid-step: tripod 1 swinging, tripod 2 in stance



6. Actuators: trapezoidal screw or ball screw, specific models

6.1 Trapezoidal (ACME) versus ball screw

	Trapezoidal (self-locking)	Ball screw
Holding without power	yes: self-locking. But under vibration and shock it can be lost (Tsubaki: https://en.tt-net.tsubakimoto.co.jp/tecs/pdct/sad/pdct_sad_2sjc.asp), so we fit a brake anyway	no, a brake is needed
Efficiency	≈25–40%. The Shenli catalogue gives a "self-locking coefficient" of 0.13–0.34	≈85–90%
Duty cycle	30% per 10 min (Shenli LW). Nut heating	60% (Shenli LW)
Service life	wear of the bronze nut	high
Where we use it	lift : moves only 25% of the cycle, in stance it stands still and holds the load	step : moves 47% of the cycle (swing + pushing), which is more than 30%

6.2 Selection (Wuxi Shenli catalogue, LW series, driven by a 3-phase induction motor)

Axis	Requirement	Model	Catalogue data
Lift ×6	33 kN dyn., 700 mm stroke, 46 mm/s unloaded and 10 mm/s under load, holding	LW63, RV1 gearbox, 3 kW 4-pole , trapezoidal screw; motor with brake, VFD, encoder	45 kN at 23 mm/s; static 50 kN (push and pull); self-locking coefficient 0.21; duty cycle 30%/10 min
Lift (alternative)	faster, no force reserve	LW63 RV2 3 kW 4-pole	33 kN at 46 mm/s; coefficient 0.32 (holds worse)
Step ×6	5.3 kN, 400 mm stroke, 22 mm/s, duty cycle ~50%	LW40, ball-screw version , RN2 0.55 kW; motor with brake, VFD, encoder	trapezoidal version: 10.5 kN at 23 mm/s, static 15 kN; ball-screw version duty cycle 60%, exact data from the manufacturer

LW63-RV1 operating mode: - under load: ≤ 50 Hz, up to 45 kN at 23 mm/s; - unloaded (raising and lowering the leg): VFD in field weakening up to ~ 75 Hz, about 35 mm/s at a force of ~ 30 kN. This **must be agreed with the manufacturer**.

Result: 42 s half-cycle, **0.86 m/min**. If exactly 1 m/min is required, use LW63-RV2 (33 kN at 46 mm/s), but then there is no force reserve.

Power:

Item	Value
Installed	$6 \times 3 + 6 \times 0.55 \approx 21$ kW
Running simultaneously	3 lifts + 6 steps
Real peak	≈ 5 kW (loading 1.1 kW $\times 3$ + step)
Supply	380 V, 15–20 kVA (with a reserve for starting currents) or battery + inverter
Energy	≈ 2.1 kWh per 100 m (low trapezoidal efficiency)

Duty. The lift duty cycle of 25% fits within the 30% limit. Walking for longer than ~ 10 – 15 minutes at a stretch requires temperature monitoring (a sensor in the motor). The alternative is a ball screw with brake for the lift as well: duty cycle 60%, a ~ 1 kW motor instead of 3.

Specification for the supplier (Lishuan or any other): - Lift: linear actuator, pull/push 35–45 kN dynamic, 50 kN static; 700 mm stroke; 10–40 mm/s; self-locking trapezoidal screw + motor with brake; encoder; IP65; $-30 \dots +40$ °C; duty cycle $\geq 30\%$; clevis ends with spherical bearings. - Step: ball screw, 10 kN, 400 mm stroke, 25 mm/s, duty cycle 60%, brake, encoder, IP65.

Verified equivalents of this class (for price comparison): Jstactuator S9, ball screw 18–350 kN, stroke up to 3000 mm (<https://www.jstactuator.com>).

7. Options with fewer or more actuators

Option	Actuators	Stability	Speed	Turning	Comment
V1: 6 pantograph legs × 2 (recommended)	12	tripod ≥ 0.71 m	0.86–0.95 m/min	$R \geq 23$ m (1.5° per step), floating feet	Real walking, each foot placed independently, levelling ± 100 mm

Option	Actuators	Stability	Speed	Turning	Comment
V2: V1 + an abduction actuator on each leg, as on the ASV	18	same	same	in place, sideways (crab)	+6 actuators and a leg-plane pivot. Only worth it if turning in place is required
V2-lite: abduction on the 4 outer legs only	16	same	same	in place (slowly)	a compromise
V3: two tripod frames: 6 lifts + 1 shuttle (+1 slewing ring for turning)	7-8	tripod ≥ 0.7 m	~ 1 m/min	$\pm 10-15^\circ$ per step (slewing ring between the frames)	Minimum actuators. But it is no longer a pantograph: the feet of a tripod move together, the lift actuator is direct (≈ 55 kN), the shuttle needs large guides. Essentially "scheme B on tripods" without the column
V4: 4 pantograph legs $\times 2$	8	≈ 95 mm	$\approx 0.3-0.5$ m/min	$R \geq 23$ m	Not recommended: small stability margin

Recommendation: V1. This is the essence of the ASV: independent legs, adaptation to terrain, 2 cheap catalogue linear actuators per leg. If minimum actuator count and budget matter and the terrain is flat, choose V3. If turning in place is required, V2-lite.

8. Comparison: scheme B (dome + plate) and concept 2 (ASV, V1)

Criterion	Scheme B: dome + central plate	Concept 2: ASV, 6 pantographs
Body	3V geodesic dome $\varnothing 6$ m	rectangular module $7.5 \times 4.0 \times 3.1$ m, 100 mm sandwich
Floor	≈ 27 m ² ($\varnothing 6.6$ m ring platform)	27.7 m ²
Volume	≈ 72 m ³	≈ 73 m ³
Floor / overall height	+2.76 / 6.3 m	+1.16 / 4.0 m
Mass while walking	11.6 t	10.3 t
CoG	2.76 m	2.03 m
Actuators	6 (4 lifts of 60 kN + shuttle + slewing ring)	12 (6 $\times$ LW63 + 6 $\times$ LW40)
Actuator class	heavy planetary roller screws/ball screws or 10 t jacks	catalogue linear actuators of 45 kN and 10 kN
Stability	4 legs or plate, ≥ 0.69 m	tripod ≥ 0.71 m (0.92 nominal)
Speed	0.92 m/min	0.86–0.95 m/min
Turning	in place, any angle	$R \geq 23$ m (V2: in place, +6 actuators)
Terrain	needs a level route under the plate ($\leq 3\%$)	unevenness ± 100 mm at each foot, slope up to $\sim 2.5^\circ$
Ground pressure	legs 73–113 kPa, plate 36 kPa	67–110 kPa
Under the house	column, 2.1 m clearance	clear, 0.9 m clearance
Control	simpler: 4 synchronous axes + 2	more complex: 12 axes, tripod logic

Criterion	Scheme B: dome + central plate	Concept 2: ASV, 6 pantographs
Manufacturing	geodesic dome, column, slewing ring	modular frame (your field) , 6 identical legs from plate and tube (CNC cutting)
Energy	≈0.9 kWh per 100 m	≈2.1 kWh per 100 m (trapezoidal)
"Walking castle" effect	dome high up on legs, as in the photo	a "walking cabin", but it looks like a real robot

9. Control (in brief)

- **Axes.** 12 axes:
- Z1-Z6: lifts, VFD or servo drive with encoder;
- X1-X6: step.

Controller: PLC (CODESYS + EtherCAT/Modbus) or LinuxCNC. Within a tripod the three X axes move synchronously, like the axes of a CNC gantry. * **Sensors:** * a 10 t load cell and a contact switch in each foot; * a 2-axis inclinometer; * absolute encoders, limit switches on all axes; * an anemometer; * "stair raised" and "door closed" sensors; * lidar or ultrasonic sensors around the perimeter. * **Logic before lifting a tripod:** * sum of forces on the other tripod $\approx W$; * CoG (from the force distribution) inside the triangle with a margin of ≥ 0.5 m; * tilt $< 1^\circ$.

On touchdown the foot is lowered to a set force, not to a set position. This is how the house adapts to the terrain. * **Safety.** On power loss the brakes and self-locking hold the current pose. Both gait phases are stable.

10. FreeCAD model

cad/asv_castle.py: parametric model, FreeCAD 1.0. * Run: `freecadcmd asv_castle.py POSE=stand` or `POSE=tripod`. N_LEGS=4 is also possible (option V4, for comparison). * Parameters: BODY_L/W/H, WALL, Z_BODY, LEG_X, LEG_OFF, LAMBDA, R_THIGH, R_SHANK, STRIDE, FOOT_LIFT, FOOT_D etc. They can be set at the top of the file, in `params.json` or on the command line. A copy is written to the "Parameters" spreadsheet. * Model contents: * groups "Body" (frame, XPS 100 envelope, glazing, door, stair) and "Pantograph legs"; * each leg contains links, guides, sliders A and B, the lift actuator, the step actuator and the foot.

Object names are in Russian; each object has a `Massa_kg` property. * Files: `asv_castle_6L_stand.FCStd/.step`, `asv_castle_6L_tripod.FCStd/.step`, `mass_*.json`, `mesh_*/` (STL). Rendering: `render_asv.py`.

v2: `cad/asv_castle_v2.py`. * Run: `freecadcmd asv_castle_v2.py POSE=stand` or `POSE=tripod`. Shape parameters are in section 1A, overrides in `params_v2.json`. * Files: `asv_castle_v2_6L_stand.FCStd/.step`, `asv_castle_v2_6L_tripod.FCStd/.step`, `mass_v2_*.json`, `mesh_v2_*`. * Model contents: groups "Body" (shell, bent-tube frame, fairings, stair) and "Pantograph legs". * Presentation renders: `render_v2.py` → `renders/v2_*.png`: perspective, sky, ground, shadows, highlights.

The model is conceptual: joints and axles are simplified, bodies intersect at the joints, welds and fasteners are not modelled.

11. Open questions

1. **Lishuan:** please send a link, catalogue or contact. I could not find such a linear actuator manufacturer. Perhaps a different brand is meant (Lichuan/立川? Shenli? Jiechang/JC35?).
2. Body: 7.5×4.0 m is oversize for transport (≤ 2.55 m on public roads without a special permit). Make 2 modules of 2.0 m joined on site? Or a custom "ellipse" body?
3. Is turning in place needed (V2 / V2-lite, +4...6 actuators), or is $R \approx 25$ m enough?
4. What terrain: lawn, gravel, slopes? This determines the levelling stroke and the foot diameter.
5. People inside while walking? Acceptable tilt and accelerations?
6. Power: 380 V mains / 15–20 kVA or off-grid?
7. Heating of the trapezoidal actuators: is the limit of " ≈ 10 –15 minutes of walking, then a pause" acceptable? Or should ball screws be used for the lift from the start (duty cycle 60%, ~ 1 kW motor, but a brake is mandatory)?
8. Budget: 12 catalogue linear actuators + 12 VFDs/drives versus the 6 heavy actuators of scheme B. Prices need to be requested (specification in section 6).
9. v2 exterior: which option to keep? - nose: bent or faceted glass; - skin: smooth or Airstream stringers; - accent colour: orange or graphite.
10. Stair: 4 treads (1.1 m reach) or 5 treads (shallower)? Is a 0.54 m clearance under the cassette acceptable?

12. Caveats

- All calculations are conceptual estimates:
- dynamics were not included in the calculation;
- fatigue was not checked;
- the frame, links and guides have not yet been analysed in FEM for the 28–83 kN concentrated forces.
- Actuator data are taken from the Shenli LW catalogue. The LW40 ball-screw version, VFD operation above 50 Hz and the 700 mm stroke require confirmation from the manufacturer.
- **Lishuan models were not verified:** the brand was not found.
- v2 masses:
- the bent sandwich panels were taken at 20 kg/m², glazing at 40 kg/m²;
- the frame was calculated from tube lengths without optimisation.
- The stair actuators are class estimates, not a selection.
- Snow and wind are taken in simplified form per SP 20.13330. A code-compliant calculation is needed for a specific site.