



ARACHNEA

Project by
**Roman Bitzinger | Markus Hintermeier |
Luka Pejic**

ABSTRACT

The primary objective of ARACHNEA is to treat orbital debris not as waste to be removed, but as material already in orbit and worth using.

At 800km altitude, Low Earth Orbit (LEO) holds the largest standing concentration of debris of any shell. As commercial activity in orbit grows, so does the risk posed by material already circling above it.

The station captures, sorts, and melts debris into feedstock, manufacturing it back into structure on-orbit. This allows the construction of components too large or fragile to survive an Earth launch, while offering debris removal itself as a commercial service.

A secondary aim of the project is to establish the economic and legal framework, split between remediation and material credits, needed to make debris recycling a viable market rather than a subsidised cleanup effort.

VISION AND MISSION SCENARIO



KEY INFORMATION

Topic : Orbital Debris Recycling and In-Space Manufacturing
Location : Low Earth Orbit (LEO)
Altitude : 800km
Crewmembers : 12 (3 month rotation)
Keywords : debris, in-space manufacturing, crew operations, orbital logistics

Crew:
2x command
3x systems
4x manufacturing
1x robotics
1x mechanical eng.
1x physician

A multi-tenant orbital industrial park for debris recycling and in-space manufacturing

At an altitude of 800km, Low Earth Orbit (LEO) holds the largest concentration of orbital debris. The project proposes to treat the debris not as waste to be removed, but as material that is already in orbit and worth using.

Branches are leased to separate operators, whose autonomous catcher craft retrieve debris. The material is sorted by composition, melted into feedstock, and manufactured back into usable structure.

The station has **2 aims**:

1. Debris removal sold as a service
2. Manufacturing structures that cannot be launched from Earth

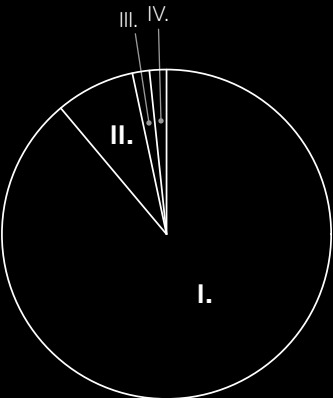
WHY 800km?

Driven by feedstock availability and permanence. This altitude coincides with the approximate peak in LEO debris population (Hayashi et al., 2025), and is where the most valuable targets sit, being rocket bodies most critical for removal in a cluster between 750 and 1000km (Anselmo & Pardini, 2016).

Unlike 400km, where atmospheric drag pulls debris downward and constituent masses grow tenfold to 2050, the 800km population remains stable across 2016-2050 (Hayashi et al., 2025).

COMPOSITION 800km?

- I. Al (s) - $7,7 \times 10^7$ kg - 89%
- II. Ti (s) - $8,1 \times 10^6$ kg - 8%
- III. Fe (s) - $2,1 \times 10^6$ kg - 2%
- IV. Cu (s), Al_2O_3 (s), etc. - 1%



(Hayashi et al., 2025)

Novelty in ARACHNEA's approach

Architecturally, ARACHNEA is conceived as an orbital industrial park. Its form follows the path of the material: debris enters at the capture end, and is sorted, melted, and manufactured back into structure as it travels the central spine. Habitation is present to service and monitor the process rather than to be ARACHNEA's purpose.

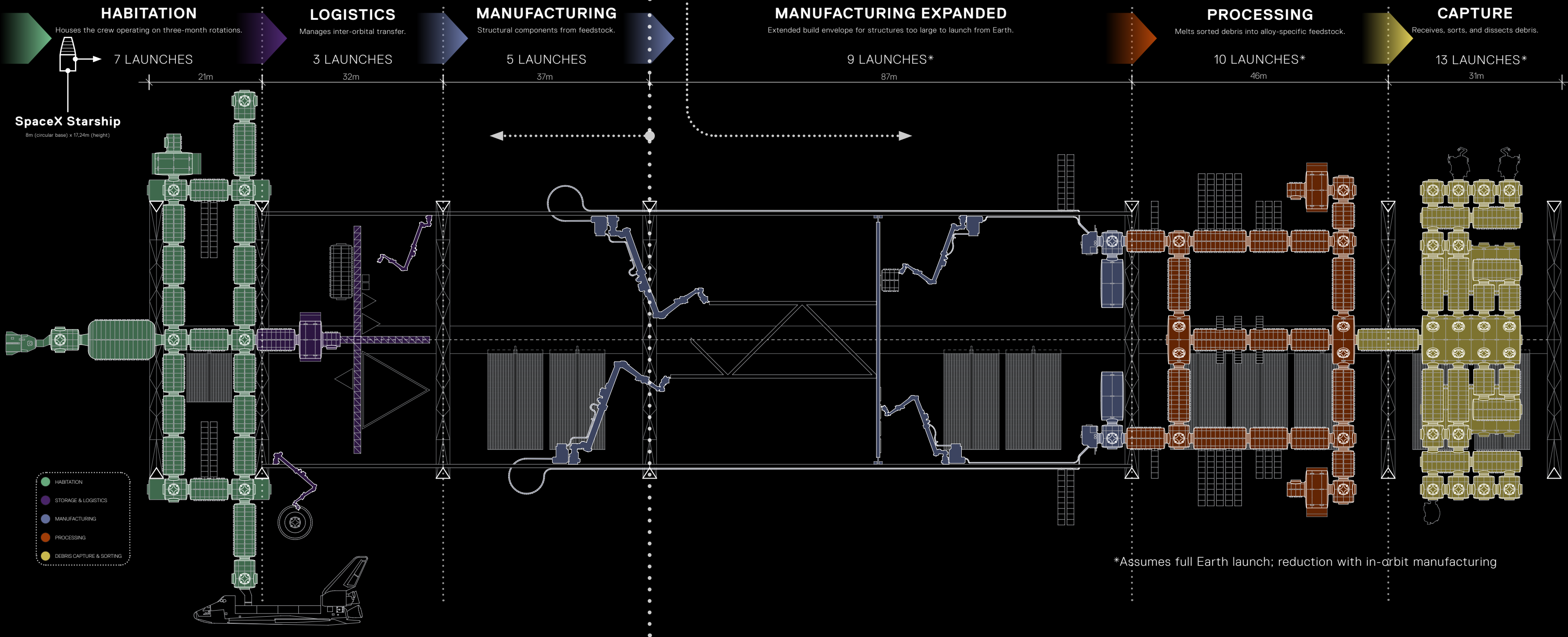
The multi-tenant approach is expressed directly in the built form. The station is partitioned into branches that separate operators lease and feed with their own catcher craft, all delivering into a shared material pool. Circulation between facilities is handled by a contactless electromagnetic carrier, the Glider module, using the primary structure as a path with no wheels or friction.

The station is designed to grow by self-similar repetition of its clusters along the spine, ultimately building its own extensions from the feedstock it produces, closing the loop between what it recycles and what it becomes.

ARACHNEA's contribution is not the recycling of orbital debris, which is a concept which is already well established from Matas's ORDER station (2020). What is new is the **economic architecture** built around it. ARACHNEA's approach reframes debris from waste-to-dispose or metal-to-sell into a shared orbital material stock, and constructs a two-product financial mechanism that makes both the manufacturing and the remediation independently bankable.

OPERATIONAL MINIMUM

FULL DEPLOYMENT



OPERATIONAL SCENARIOS

OPERATIONAL MINIMUM

I. Functional use case and operations

At this tier ARACHNEA is a crewed orbital factory, not yet a full recycler. Twelve crew on three-month rotations live in the habitation facility and move between structures on the glider module running the twin-lane spine. The logistics tier manages inter-orbital transfer and hosts the multi-tenant accounting. Manufacturing produces large structural components, but with no capture or processing done beforehand, with the feedstock being launched from Earth as wire.

II. Maintenance, repair, replacement

Maintenance is deliberately conventional. The mechanical engineer and robotics specialist, together with the glider module, cover inspection and intervention, with EVA for anything out of reach. Every module berths through a standardised interface, so a failed unit is swapped whole rather than repaired in place. The one early self-repair capability is provided by the manufacturing facility: it can print non-critical structural spares.

III. Expansion strategies

Expansion at operational minimum is simply the route to full deployment. Growth means bolting processing and capture onto the existing station and turning an orbital factory into a self-supplying recycling park. Envisioned rocket launches after the establishment of the operational minimum are estimated, since in-orbit manufacturing provides a potential reduction of launch necessity.

FULL DEPLOYMENT

I. Functional use case and operations

The loop closes and both aims of ARACHNEA go live. Tenants' autonomous catchers retrieve debris and dock at the catcher interface nodes. Fragments pass through the sorting array for compositional identification, afterwards being routed through the compositional sorting array to the raw material deposit. Processing melts the sorted streams into alloy-specific feedstock by electromagnetic levitation with a recirculation loop for off-spec material. Manufacturing runs on recovered material, and the same captured stage yields both economic products explained later in the accounting model.

II. Maintenance, repair, replacement

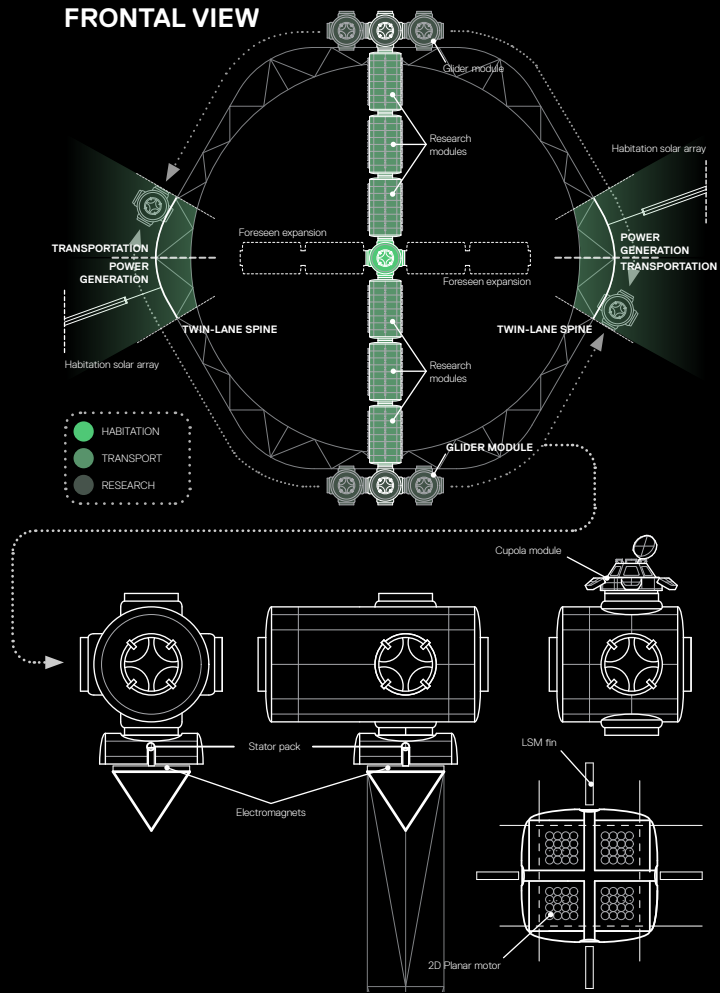
The full deployment makes structure from scrap, providing its own spares from recovered feedstock. The limit is honest and designed around: recycled melt loses volatile alloying elements and carries porosity, meaning the process verifies composition and tunes beam parameters before deposition, and the recirculation loop re-melts off-spec material rather than scrapping it, making recovered feedstock fit for defect-tolerant parts.

III. Expansion strategies

With the loop closed the station builds its own structure, making growth cost feedstock rather than launches. It scales in three ways: (i.) commercially potential tenants lease capture nodes, (ii.) leading to physical growth of the station according to demand, (iii.) leading to ARACHNEA building the structural components necessary for expansion and for a second-generation sister station, depending on demand and politics. Ultimately, ARACHNEA evolves from a single installation into a system.

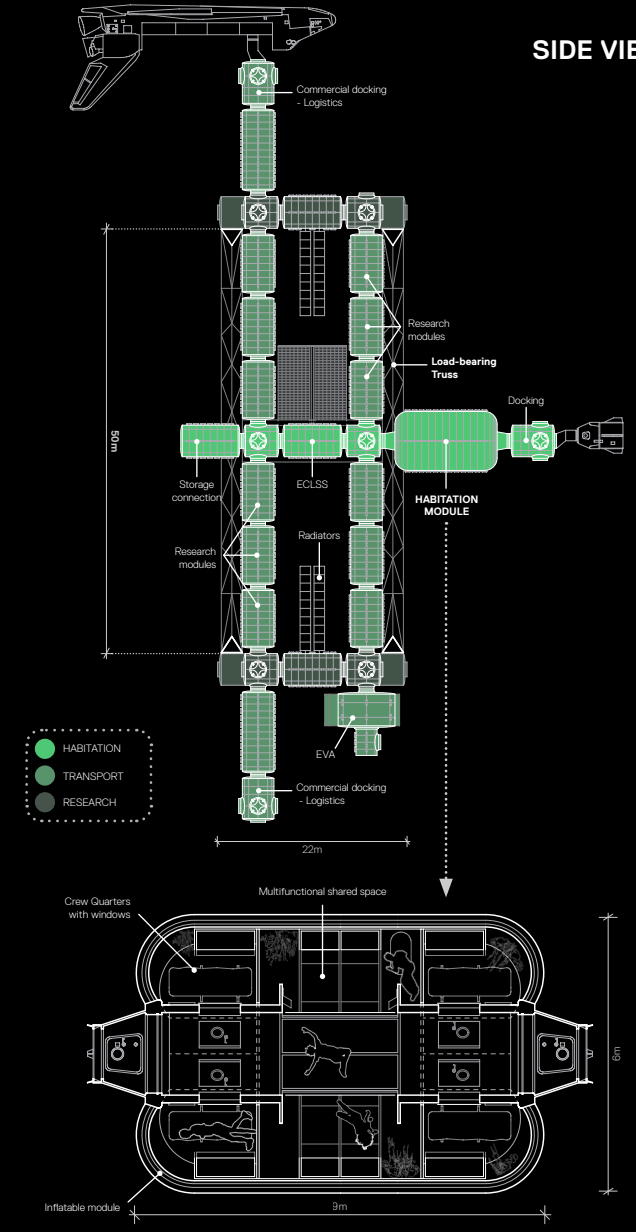
SPATIAL AND ARCHITECTURAL QUALITIES

FRONTAL VIEW



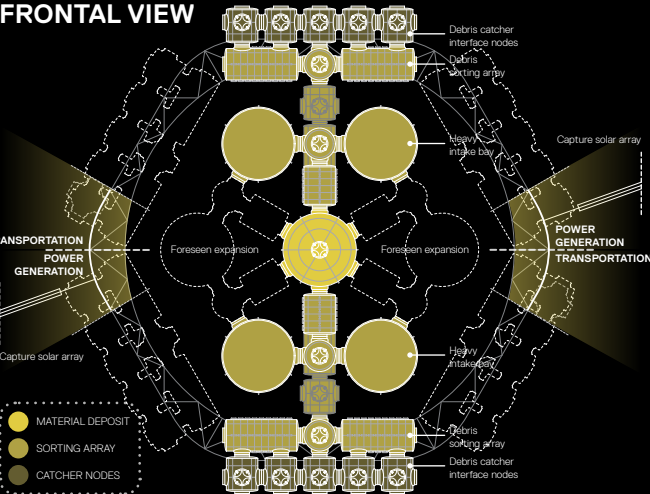
- **GLIDER MODULE** - a contact-free carrier riding the main truss, moving crew between facilities; its cupola serves supervision and maintenance
- **HABITATION** - an inflatable housing twelve crew members on three-month rotations, built around shared spaces and plant growth

SIDE VIEW

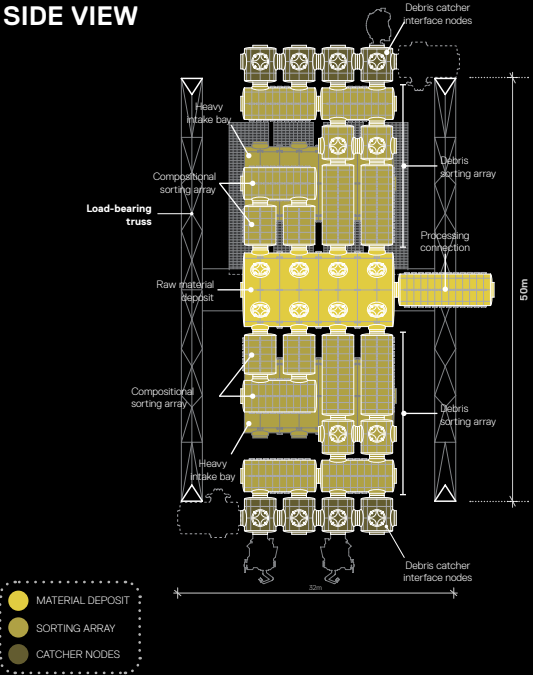


FROM ORBITAL ASSETS TO FEEDSTOCK

FRONTAL VIEW



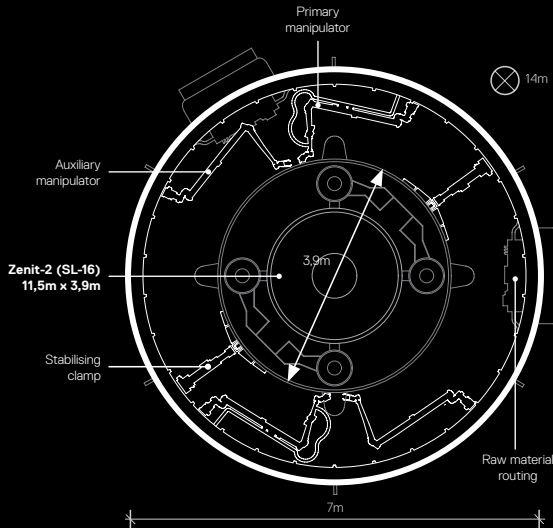
SIDE VIEW



Orbital debris comes in different sizes, thus the intake system treats small fragments and large intact objects differently (Matas, 2020; Leonard & Williams, 2023). Fragments are sorted before processing, while rocket bodies are handled in a separate Heavy Intake Bay (Leonard & Williams, 2023). This makes the system better suited to the material's size, condition, and predictability (Anselmo & Pardini, 2016).

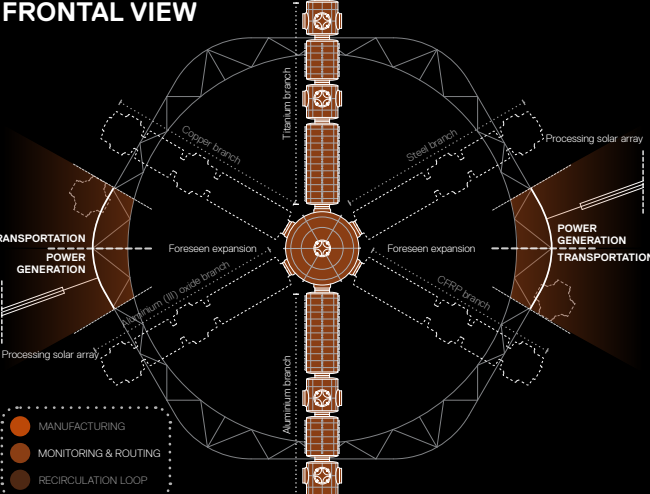
The Heavy Intake Bay is sized at 6.8m diameter and 14m length, matching the SpaceX Starship payload envelope, but also accommodating the largest and most important LEO rocket bodies identified by Anselmo & Pardini (2016), while leaving room for robotic clearance, manipulators, clamps, and electronics.

Incoming stages are held in place by adjustable pneumatic clamps, while two radial manipulator arms, each fitted with XRF probes, identify materials directly at the contact point, while preloaded dissection sequences guide the process using stage manifests from operators.

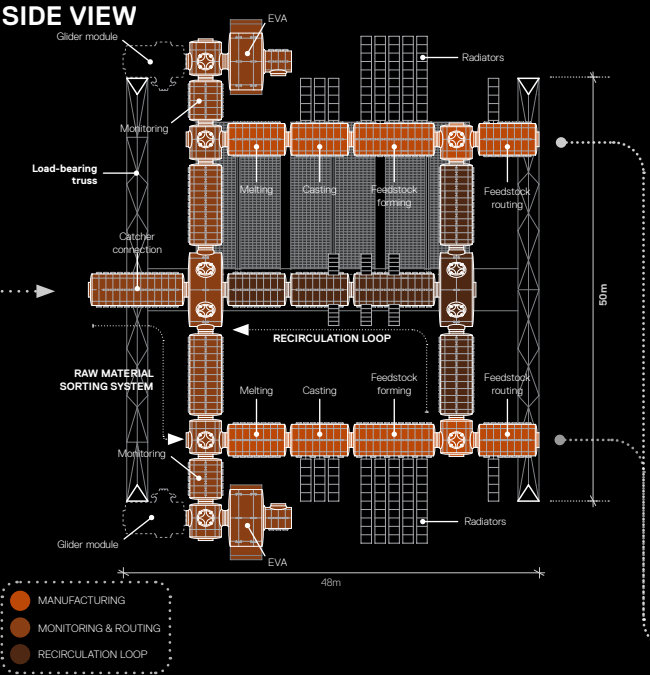


Heavy Intake Bay frontal view

FRONTAL VIEW



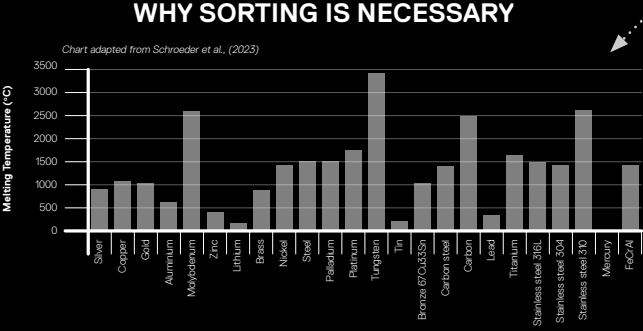
SIDE VIEW



Sorted debris is melted into feedstock using electromagnetic levitation melting, a contactless method based on the ESA/DLR levitation furnace flown on the ISS since 2015 (Schroeder et al., 2023). Alternating-current coils induce eddy currents in the conductive sample, which simultaneously heat it through ohmic losses and hold it in position by the Lorentz Force so the molten metal never contacts a crucible.

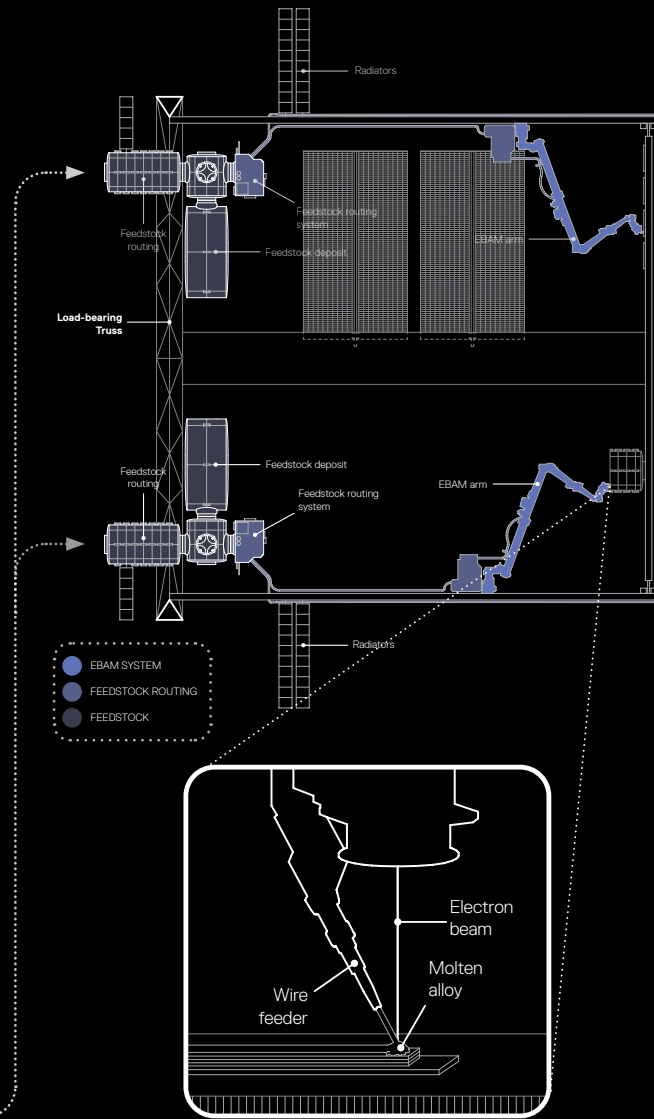
EML favours highly conductive, non-ferromagnetic metals such as aluminium and copper; ferromagnetic materials such as iron are harder to process, as they strongly interact with the coils. This spread of melting points and conductivities is why incoming debris must first be sorted by composition (Schroeder et al., 2023). The process is itself modest in power: 1kW can melt about 100g of Al (s) in roughly 200 seconds, which makes it compatible with solar power (Schroeder et al., 2023).

In microgravity, the melt becomes more microstructurally uniform because of the absence of convection or sedimentation. The main thermal challenge is that in vacuum, leaving thermal radiation as the only route to reject the melt's heat - the reason for the facility's dedicated radiator provision.



FEEDSTOCK TO STRUCTURE

SIDE VIEW

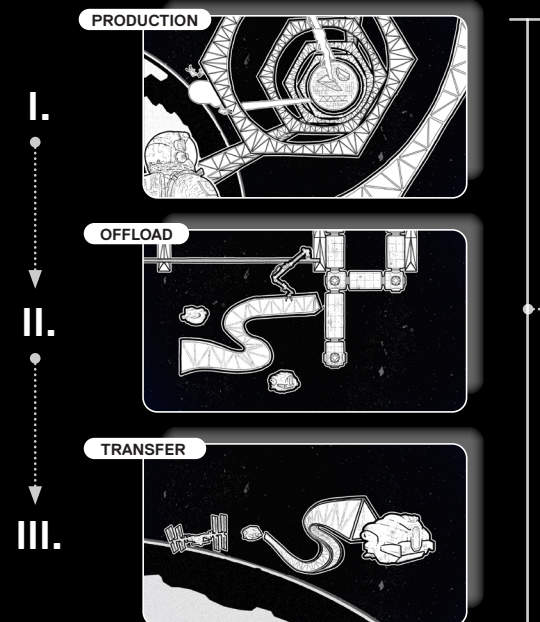


ELECTRON BEAM ADDITIVE MANUFACTURING

Sorted feedstock is drawn into wire and built by Electron Beam Additive Manufacturing (EBAM), a freeform process demonstrated by NASA as EBF³ (Hafley et al., 2009).

The process fits an orbital station naturally: wire is safer to handle than powder in microgravity, the electron beam couples efficiently with reflective metals (i.e. aluminium), and the vacuum it depends on is offered by the environment.

Two limitations are managed by design. Surface tension governs the molten pool, so wire-to-substrate distance is held precisely. Furthermore, a vacuum melt pool can lose volatile alloying elements through preferential vaporisation (Hafley et al., 2009; O'Donnell et al., 2023), countered by tuning beam parameters and verifying feedstock composition before deposition.



INTER-ORBITAL LOGISTICS AND LEGAL FRAMEWORK

ONE SOURCE, TWO PRODUCTS

ARACHNEA is multi-tenant: separate operators lease branches and run their own catcher craft, but the material they recover is melted together. Once mixed, the material cannot be traced to its source, thus ownership becomes a ledger entry rather than a physical claim. Two established supply-chain frameworks make this work.

MASS BALANCE governs the internal pool: each operator's contribution is logged at intake, adjusted for processing losses, and converted into a proportional share.

Example:

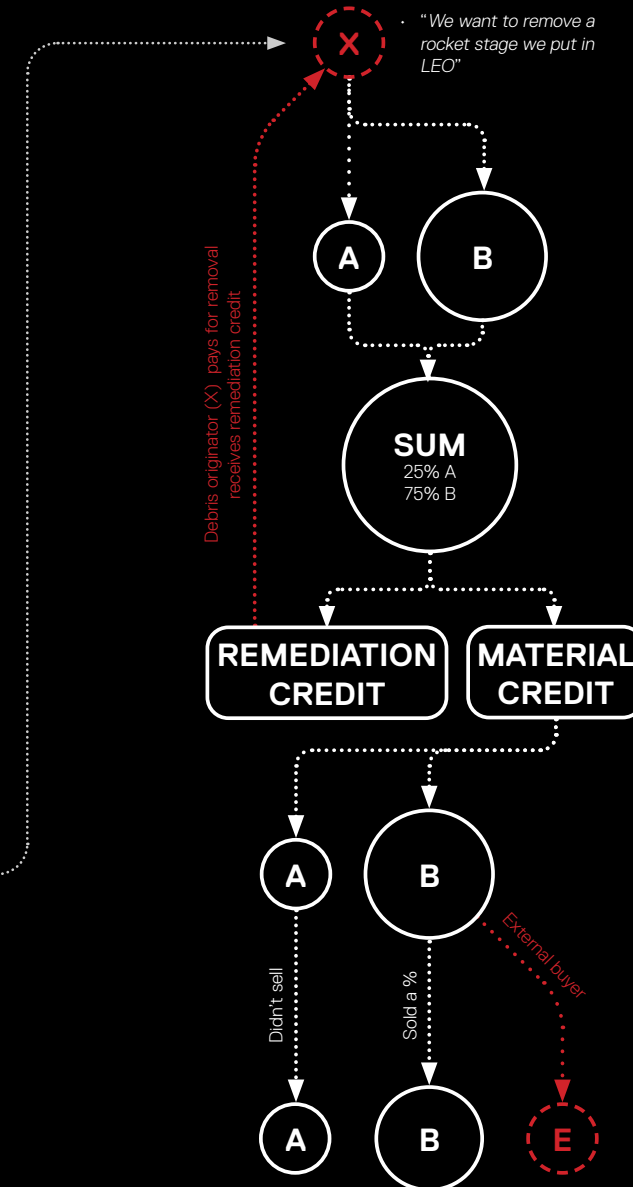
- I. Company A caught 100kg of aluminium
- II. Company B caught 300kg of aluminium
- III. After cleanup: A=95kg, B=285kg, sum=380kg
- IV. Ownership percentage: A=25%, B=75%

When material is sold, no material moves physically; only the ownership share is transferred digitally, referred to as a „material credit“.

BOOK AND CLAIM governs the external market and drives revenue. It separates tradable credits from the physical material, allowing value to be sold without direct interaction with the station.

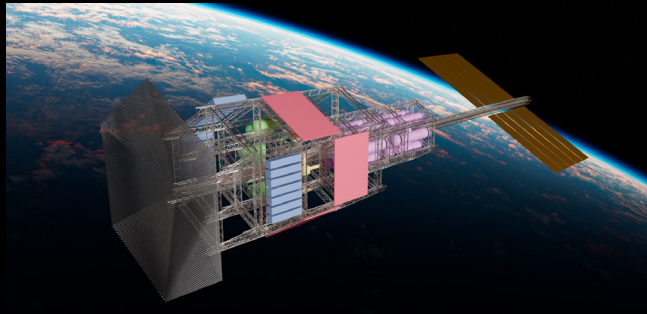
ARACHNEA generates two independent products. First, **material credits**: operators can purchase feedstock and receive manufactured parts in orbit. Second, **remediation credits**: removing debris becomes a tradable credit. Operators, insurers, or governments can buy this credit to meet mitigation obligations without handling the material.

Because these attributes are decoupled, a single captured object can produce both a material credit and a remediation credit, sold to multiple different buyers for multiple different reasons.

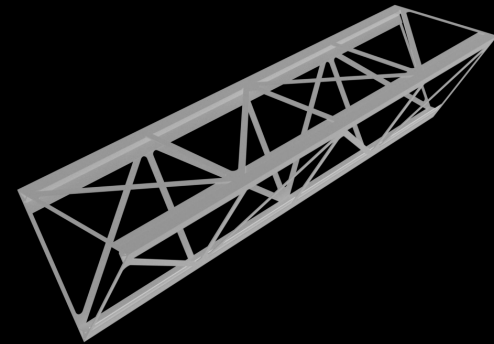


Material-to-Market Flow Chart

WORK PROCESS



First visualised concept



First load-bearing structure concept



Final Presentation photos

PERSONAL REFLECTION & REFERENCES

REFLECTION

„The course centred on interdisciplinary thinking and on communication with experts from various backgrounds, each bringing arguments that shaped ARACHNEA into an argument. What surprised me most was where the intellectual weight ended up. ARACHNEA is built heavily around its accounting model, which meant reading well outside architecture, into supply-chain frameworks that had never been pointed at orbit before. Working with my two colleagues was refreshing and rewarding, both brought conceptually interesting ideas that gave the project depth in the aspects that needed it. What I take from the course is that interdisciplinary thinking is what turns a structure into an argument.“ - Student 1

„Throughout the semester, I developed a systems-based approach to large-scale orbital architecture, learning how to organise spacecraft and station modules according to structural, thermal, operational and safety requirements. I refined concepts for modular design, power distribution and functional zoning in Earth orbit while exploring the relationships between individual systems and the wider station. I researched and addressed the challenges posed by the harsh orbital environment, including microgravity, radiation, extreme temperatures and pressure differentials. Through iterative design development and research into propulsion, guidance, control and safety, I strengthened my ability to translate architectural concepts into technically grounded, coherent and feasible proposals for complex orbital infrastructure.“ - Student 2

„The studio leaves the scope free to determine, based on your own project. As a result, the scope has to be managed by the team, which can be tricky at times, because new information opens previously unknown doors. The workload is spread evenly across the semester, with the workshop phase being one of the most rewarding parts of the course, where specialists from all over the world give detailed feedback on concept ideas.“ - Student 3

REFERENCES

1. Hayashi, F., Kioka, A., Ishii, T., Nakamura, T., 2025, „Waste Management 193“, p376-p385, „Unveiling the resource potential of space debris: A forecast of valuable metals to 2050“, Japan
2. Anselmo, L., Pardini, C., 2016, „Acta Astronautica 122“, p19-p27, „Ranking upper stages in low Earth orbit for active removal“, Italy
3. Matas, I., Häuplik-Meusburger, S., 2020, „Cleaning up the Final Frontier – Orbital Debris as a Potential Resource: The Story of Three Space Stations“, Austria
4. Leonard, R., Williams, I.D., 2023, „Waste Management 155“, p19-p28, „Viability of a circular economy for space debris“, UK
5. Schroeder, J.W., Calnan, G.D., Bogno, A., Mould, T.J.D., Pecher, R., Pawelski, J.W., Staats, K., 2023, „Handbook of Space Resources“, p309-p331, „Space Debris Recycling by Electromagnetic Melting“, Germany
6. Hafley, R.A., Taminger, K.M.B., Bird, K., 2009, „Electron Beam Freeform Fabrication in the Space Environment“, VA
7. O'Donnell, K., Quintana, M.J., Collins, P.C., 2023, „Materials 2023, 16, 6366“, „Understanding the Effect of Electron Beam Melting Scanning Strategies on the Aluminium Content and Materials State of Single Ti-6Al-4V Feedstock“, IA
8. Chaurasia, Sinha, 2021, „Investigations on Process Parameters of Wire Arc Additive Manufacturing (WAAM): A Review“, India