Roll SEED Roll: An Architectural Assessment of a Spherical Mobile Habitat for Mars (SEED_Spherical Environment Exploration Device)

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This paper aims to deliver the preliminary architectural assessment of a spherical mobile habitat for Mars surface missions, SEED (Spherical Environment Exploration Device). Appeared as one of the outcomes of MarsMobil Design Workshop in İzmir, Turkey, the spherical SEED design utilises a simple-but-challenging character of mobility and space. Based on a locomotion type of whole-body-rolling, SEED features a spherical layout, in which the habitable space is defined by a continuous surface. This spatial configuration offers different opportunities to its user for living in a compact habitat. Supplying a background of spherical-continuous loop habitat designs, the paper examines different options of locomotion system and their spatial and operational impacts. Ranging from the system scale down to details and human interaction solutions, the work takes possible integration into planetary architecture frames of major planetary exploration programs. The proposed work is structured on 3 segments; structure & locomotion, space and operation. Each segment presents the array of assessments conducted for the design development of SEED. The structure & locomotion segment conveys the options for the structural system (i.e. inflatable, rigid, hybrid) and its integration with the locomotion system. The configuration, materials and the use of spherical interior are studied in the next segment, where the architectural know-how on spherical/continuous terrestrial designs is presented via examples. An evaluation of the space through human factors scope is a part of this segment. The operational features and the integration into possible mission architecture frames are brought to examination in the third segment of the paper. All design options will be presented via depictions and assessment charts.

Nomenclature

SEED	=	Spherical Environment Exploration Device
EVA	=	Extra Vehicular Activity

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I. Introduction

Sphere, as a basic geometrical object, has always been attractive to designers in regard to its uniformity, the unique spatial effect and environmental control properties (e.g. acoustics). As an architectural space, beyond its advantage in space efficiency by providing the most volume for the given surface area (1), the designers have been motivated by the power of this simple and unique form on user experience to use perfectly round spaces in different sizes. Ranging from the monumental 150m diameter spherical cenotaph design of Etienne-Louis Boullee, down to experimental micro cabins (Figure 1), the popularity of spherical space in architectural design is evident. Furthermore, the favorable characteristics of the spherical structures in regard to the resistance to hostile conditions (e.g. temperature, pressure, winds, fire) led the designers of extreme environment habitats to use this basic form in various locations (e.g. polar, underwater, battle environments). Spherical planetary outpost designs, such as Tycho lunar habitat (2) have emerged as precursors of this design approach in extreme space conditions. Though not spherical in form, yet featuring the concept of flowing space, sustained by user action (3), numerous architectural designs such as The Endless House by F. Kiesler or The Möbius House by UN Studio point at the interest in dynamic space design. This architectural characteristic can be observed in a spherical structure in the simplest form.

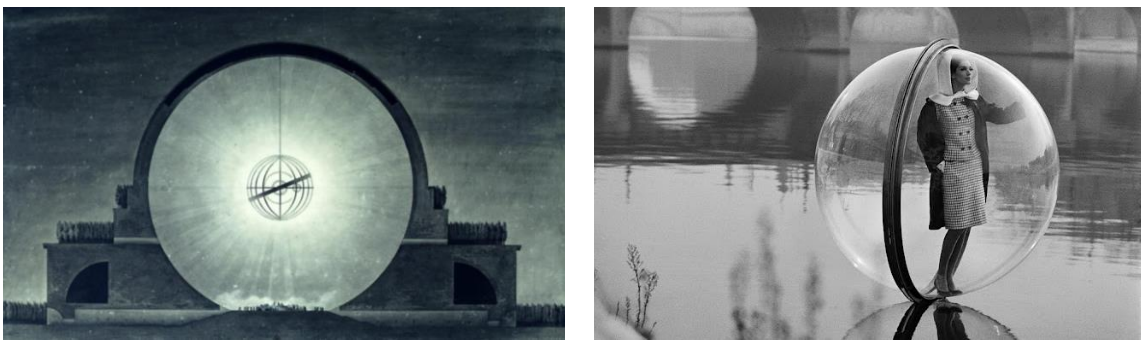

Figure 1. Two spheres in architecture. *The huge spherical cenotaph design of Étienne-Louis Boullée vs the micro sphere of Melvin Sokolsky (Credit: National Bibliotheque de France / Sokolsky M.)*

SEED (Spherical Environment Exploration Device), the object of the presented work, was appeared as one of the outcomes of the MarsMobil Design Workshop[3] in İzmir, Turkey back in 2010 (4). A unique response to the goal, set as a mobile exploration workstation concept for Mars surface missions, the spherical SEED design utilises a simple-but-challenging character of mobility and space. SEED design features a spherical body with a spherical interior space, was intended for one crew use. The uniformity of the sphere, as a form, was taken as a defining characteristic in the design, leading the design team to pursue a simple layout with ever-flowing surfaces and space. The presented paper provides an insight into the architectural design assessment, was done by the authors as a follow-up work to the workshop.

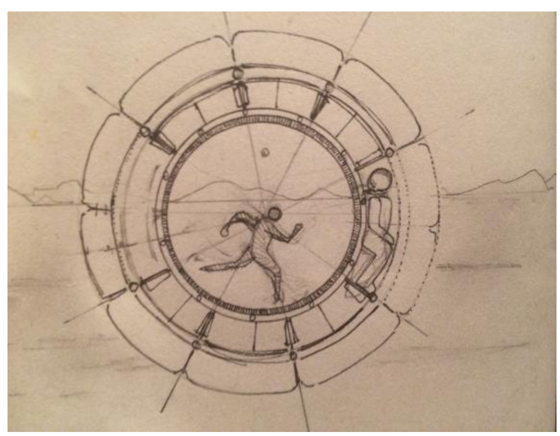

Figure 2. SEED. *Hand sketch (Credit: Ozdemir)*

[3] MarsMobil was a space architecture workshop for architecture students, coordinated by K.Ozdemir and held at Yasar University, Izmir, Turkey in 2010. The focus was on mobile systems for Mars missions. SEED team was comprised of Halici S.M., Cevizci E., Basdere S.S., Coban G., Gultekin M.

II. Main Layout, Space/Use (3 pages)

SEED, basically, is a rolling habitable ball for Mars surface. The design concept is dominated by the characteristics of a sphere, in regard to its simplicity and continuity in form and motion. Programmatically and physically, the user is at the center of the whole design. (Figure 3)

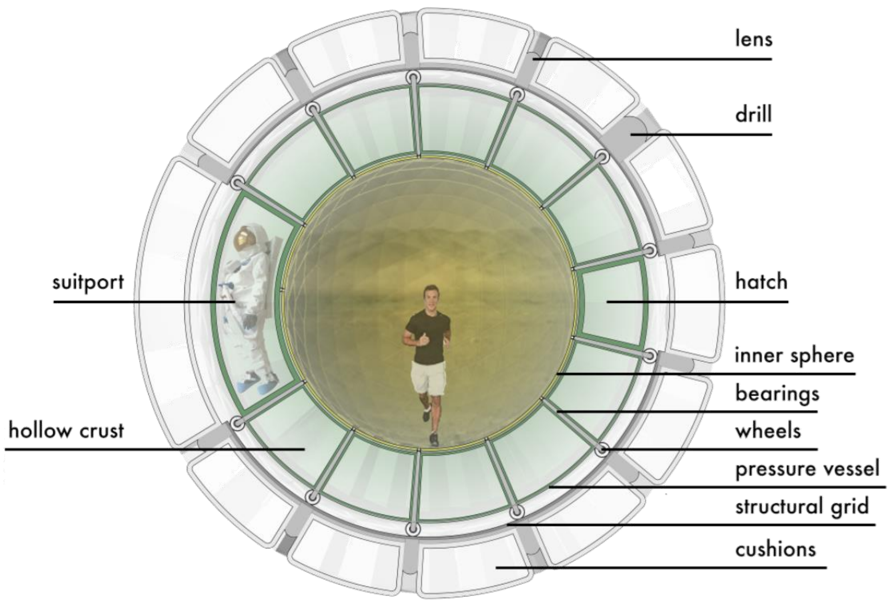

Figure 3. SEED Layout Section. (*Credit: Halici)*

SEED design features a perfectly spherical inner space, with no fixed walls or visible fixtures. All the required systems, equipment, devices and items are stored inside the systems and storage layer (i.e. hollow crust), which is covered by the inner sphere surface.

Basically, the SEED body is comprised of 3 components:

1. inner sphere
2. hollow crust
3. outer sphere

Inner sphere presents the main interaction surface to the user and contains a clean pressurized space of 4,5 m3. The access to the compartments of hollow crust is provided via the triangular covers, defined by the geodesic surface format of the inner sphere. The triangular surfaces are connected to each other by nodes, where ventilation inlets are integrated. The surface of the inner sphere is thought to be covered with a soft material that is capable of displaying images (e.g. OLED surface) The continuous surface of inner sphere gives the crew the perception of infinite space during static or dynamic modes. The inner surface can either be fixed on the hollow crust layer or set to roll freely on the bearings by user action (e.g. running) (figure 3) This mode serves to "free steering" of the station by running or walking in the desired direction in desired pace. This form of steering represents the direct human-machine interaction mentality of the SEED team. The user is, in order to drive the vehicle, free to move in the way that we learn in life, beginning with the toddling and this on a desired background. This augmented reality surface replaces the windows with all their issues of size and risk potential.

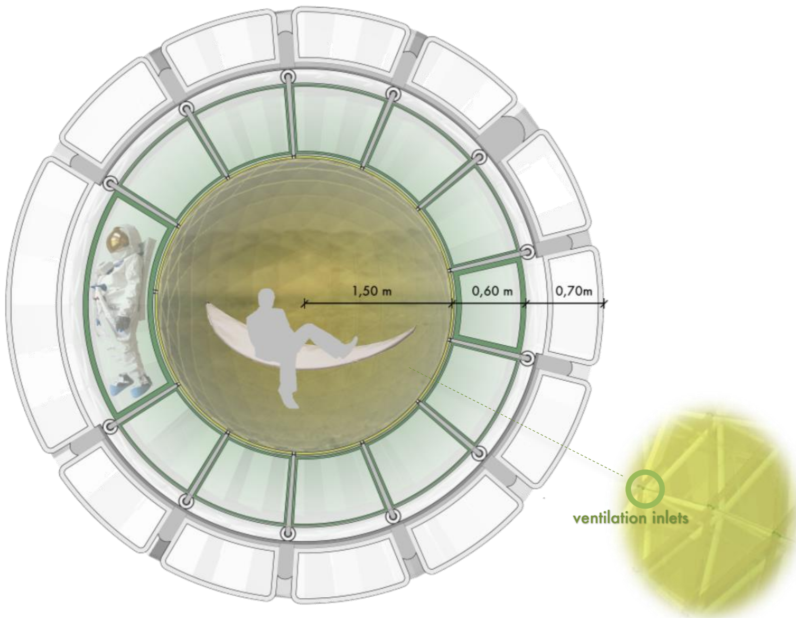

Figure 4. Inner Sphere Environment. (*Credit: Halici)*

The next and the heaviest component of the station is the systems & storage layer, the hollow crust. This pressurized layer contains the compartments for storage, hardware, deployable elements (e.g. seat, toilet), glovebox as well as the docking hatch and suitport. Different from the inner and outer spheres, the hollow crust is not set to move. It keeps its orientation all the time. The triangular prism compartments of this layer are accessed from the cabin interior by the correct positioning of inner sphere surface according to the hollow crust compartments. Since the inner sphere is a relatively thin shell, composed of triangular units, the hollow crust serves as a space to hold every possible item or hardware to keep the inner volume perfectly clean and reserved for its user. Expandable elements such as a fold-table or an inflatable toilet seat can be stored in this layer. This layer also holds the following interaction systems with the exterior:

- docking hatch
- suitport
- sample collection arm + sample airlock

	Inner Sphere	**Hollow Crust**	**Outer Sphere**
Static 1 (idle mode)	Locked	Locked	Locked
Static 2 (exercise mode)	Roll	Locked	Locked
Dynamic 1 (drive-by-wire)	Locked	Locked	Roll
Dynamic 2 (free run drive)	Roll	Locked	Roll

Table 1. SEED Mobility mode vs. Layer

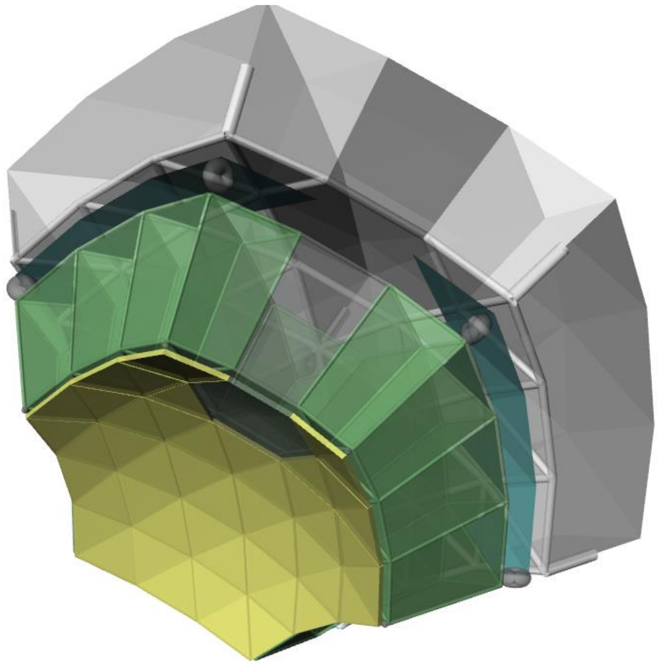

Figure 5. Hollow Crust Layer. *Storage & Systems Layer -marked green- provides room for items and hardware, as well as interaction ports (Credit: Halici)*

The outer sphere layer of SEED contains the surface of physical contact with the Mars surface and its structure. A geodesic sphere grid structure is designed to hold inflatable cushions of triangular prism form. The structure also provides the traction surface for the wheels of the locomotion system. In docking or EVA preparation mode, the outer sphere is adjusted precisely, matching its structural grid with the positions of docking hatch or suitport, to give way to unobstructed interaction with the exterior.

Summing up the layer composition part, SEED team proposes the following line-up of components:

- Inner Sphere interior finishing surface (grip, friendly, display material and arrangement)
- ——————- bearings ———————
- Hollow Crust (Storage, integrated cabin equipment, propulsion, life support systems)
- Propulsion wheels
- Traction grid
- Outer sphere (structure + cushions)

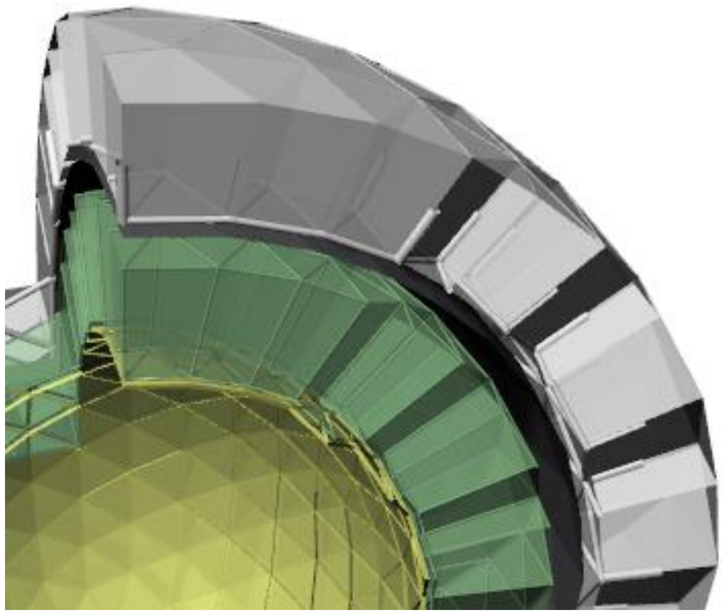

Figure 6. Outer Sphere Layer. *Outer sphere layer -marked grey- of SEED is a composition of a structural grid and inflatable cushions (Credit: Halici)*

III. Structure & Locomotion

Both the structural and the mobility system of SEED exploits the potential of a spherical form in the simplest sense. The structure is made up of a composition of layers, each with a different function to come together to form one single body. Inflatable systems are favored also in this design, regarding their advantages in mass and volume in addition to their natural compatibility with spherical forms (5)(6). The mobility type is the natural dynamic situation of a sphere on a surface, rolling.

In our design assessment, based on the layout of 3 layers, following options for structural system are considered:

component	structural type vs option		
	rigid	inflatable	hybrid
inner sphere	rigid shell	-	rigid grid + infl. cushions
hollow crust / pressure vessel	rigid shell	inflatable skin	rigid grid + infl. envelope
outer sphere	rigid grid or spikes	inflatable envelope / inflatable grid	rigid grid + infl. cushions

Table 2. SEED Structural Options Chart

The evaluation of structural options is as follows:

component	structural type vs evaluation		
	rigid	**inflatable**	**hybrid**
inner sphere	OLED integration + simplicity +	no access to hollow crust	friendly surface + OLED integration **-** complexity **-**
hollow crust / pressure vessel	simplicity + mass **-**	mass + rack integration **-**	mass + complexity **-**
outer sphere	rugged use + transport size **-**	mass + traction grid integration **-** hatch integration **-**	mass + flexibility + hatch integration **-**

Table 3. SEED Structural Evaluation Chart

In regard to the presented assessment, SEED team preferred to work on the red marked combination.

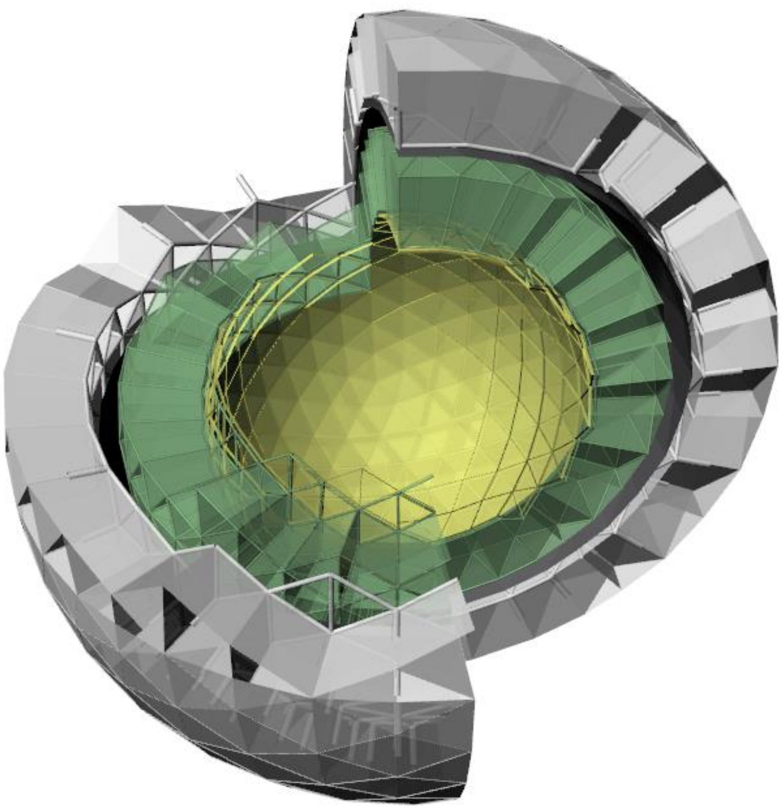

Figure 7. SEED Structural Layers. *The depiction of the preferred composition (Credit: Halici)*

In order to achieve a powered and controlled rolling of SEED, the design team came up with the following configuration for the mobility system:

- Inner Sphere: serves as a control interface akin to a “trackball”
- ——————- bearings ——————— : de-coupling to hollow crust
- Hollow Crust : contains the propulsion system
- —————— pressure vessel ——————-
- Propulsion wheels : attached directly to motors
- Traction grid : attached to outer sphere structure
- Outer sphere (grid + cushions)

The mobility system is based on a network of wheels, powered each by a separate motor, driving the spherical traction grid, attached to outer sphere, in the specified direction.

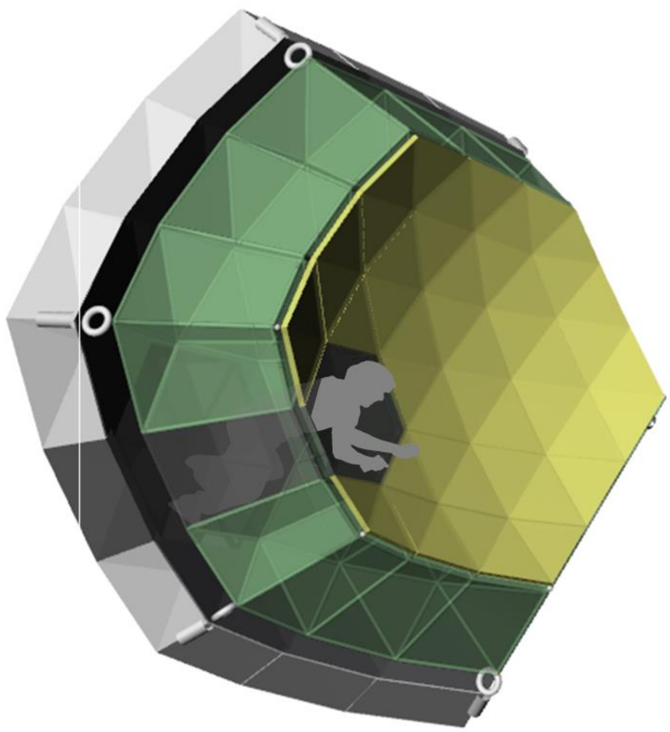

Figure 8. SEED Mobility System. *The driving motors for the traction wheels are integrated in the hollow crust layer (Credit: Halici)*

IV. Operation / Planetary Exploration Frame Integration

SEED is designed to operate as a single unit and in a team of other units. Though the basic mission configuration is one person crew excursion mission, coupling two or multiple SEEDs with connection modules via docking hatches can create mobile systems of multiple units. This way, clusters of up to 6 units can embark on excursions, even in connected configuration in en-route periods. More conservative approach would be to connect the units in their static mode. Furthermore, an external unit, in form of a drone can be integrated into the mission profile. This feature would feed the SEED with visuals for real time projection and navigation as well as acting as a communication relay.

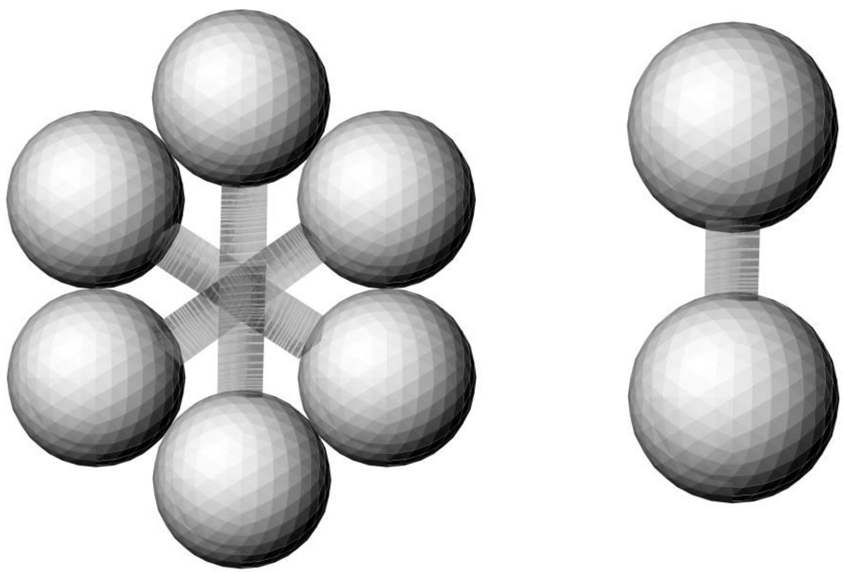

Figure 9. SEED Coupling Alternatives. *Extended versions can be obtained by connection tunnels (Credit: Halici)*

The compatibility of SEED with the existing planetary exploration architectures can be assessed, when given the opportunity for further research on the subject, under the following points:

- integration into the transport infrastructure:
- integration into the surface infrastructure network
- integration into the operational capabilities

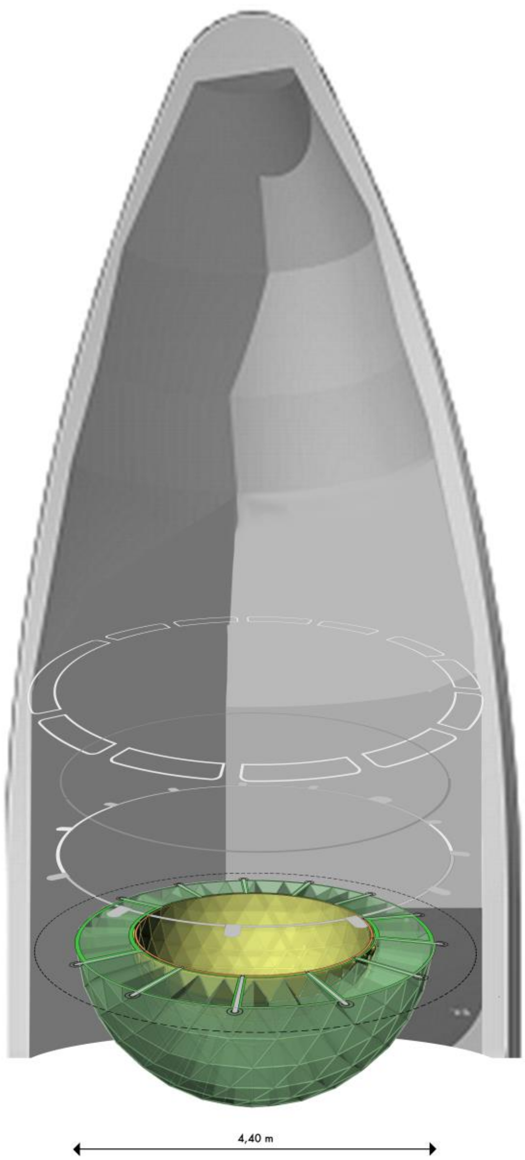

Figure 10. SEED Transport Layout *Note the transport diameter is under 5m (Credit: Halici)*

V. Conclusions and Outlook

SEED concept, as the result of the conducted architectural design assessment, appears as an attractive medium to incorporate architectural design enthusiasm with technical research and collaboration in the space architecture field. This assessment work has provided an overview to the potential of the design, indicating its strengths and challenges (see table x) Compared to other mobile outpost designs for planetary exploration, SEED comes forward with her simplicity in form and unique human-space-machine interrelation.

aspect	potential & challenges	
	strength	**room for improvement**
space & use	powerful spatial character dynamic use	• collapsible element research • new materials
structure	general integrity	• assessment of new options
mobility	simplicity	• integration into structural system • new technologies in propulsion • braking options to be assessed (e.g. magnetic counter weight, water inflated tire) • dust mitigation in airlock/suitport area
operation	possible popularity among crews practicability	• compatibility with existing planetary exploration architectures

Table 3. SEED Concept Evaluation Chart

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