Building the Test Bed SHEE- A Self Deployable Habitat for Extreme Environments Lessons Learnt and Exploitation Opportunities for the Scientific Community

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Building the test-bed SHEE – a Self-deployable Habitat for Extreme Environments
Lessons learnt and exploitation opportunities for the scientific community

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This paper presents preliminary results of the qualification and testing campaign for the Self Deployable Habitat for Extreme Environments (SHEE). Developed under a three year European Commission FP7 grant, the SHEE is a rigid segment deployable habitat test bed designed for use in space analogous environments. The objective of the SHEE project is to develop a self-deployable habitat test bed that will support a crew of two for a period of up to two weeks in duration. During this time the habitat will provide for all of the environmental, hygiene, dietary, logistical, professional, and psychological needs of the crew. Unlike most space analog habitats, the SHEE will use commercial transportation infrastructure, allowing for cost effective transportation to space analog sites across Europe. Once on site, the habitat will be autonomously deployed with no human intervention required, and will be able to re-pack itself with minimal human assistance. Qualification and testing of the fully outfitted SHEE test-bed began in April of 2015 at COMEX in Marseille, and will conclude in October of 2015 at the International Space University in Strasbourg. The testing campaign has included a shake-down of all subsystems, thermal analysis, stress analysis, a habitability study, acoustic tests and more. At the conclusion of the project in December of 2015, the SHEE will be made available to the European scientific community for analog space simulations. The first field deployment of the SHEE will occur in 2016 as part of the Moonwalk FP7 campaign in Rio Tinto, Spain. It is anticipated that elements of the SHEE design will find practical applications in any hostile environment requiring an extended human presence, on or off the Earth.

I. Introduction

The SHEE habitat is a simulator which offers significant opportunities for the further development and evolution of extra-terrestrial habitable structures and technology. SHEE is the first European habitat simulator and the first deployable habitat test-bed of its kind. The main objective of SHEE is the effective integration of architecture and robotics for autonomous deployment of a self-sufficient habitat for both space applications and extreme environments on earth. It is being developed for mission simulations where analogue environments are required. SHEE supports various crew activities and hardware tests.

To integrate human labor into construction on the lunar or Martian surface or disaster zones on earth is very risky, complex and costly. Self-deployable, autonomous habitats will mitigate construction safety risks, reduce costs and require minimal infrastructural systems and machinery. SHEE also provides a feasible solution for near term human space exploration. The habitat will be made available in 2016 to interested parties conducting mission simulations in analogue sites.

The project is a European collaborative effort comprising the following partners: International Space University, France; LIQUIFER Systems Group, Austria; Space Applications Services, Belgium; COMEX, France; University of Tartu, Estonia; Sobriety and Space Innovations, Czech Republic;

SHEE can be characterized and described briefly through the following features and capabilities:

Habitat Characteristics
- Accommodates astronaut crew of two
- Environmental Control and Life Support System (ECLSS) allows a mission duration of up to two weeks
- Workspaces can be adapted for various equipment/activity (laboratory, greenhouse, medical facility, etc.)
- Possibility of integrating EVA suitports for ingress and egress
- Additional access door to habitat is available

Key Features
- Transportable by land, sea and air
- Can be rented and utilized for various analog sites
- Environmental Control and Life Support System allow deployment in arctic and desert conditions
- Automatic (or teleoperated) robotic deployment
- Usable for testing hardware (Life Support System, EVA equipment, etc.)

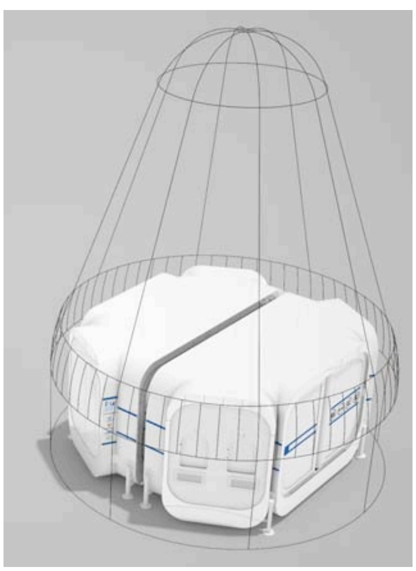

Figure 1. Two stowed SHEE habitats fit into a heavy lift launcher with a diameter of 6m, *credit: SHEE Consortium, visualization: LIQUIFER Systems Group, 2013*

This paper describes the building of the test-bed, lessons learnt and upcoming opportunities for the international scientific community to use SHEE.

II. Concept development

At the beginning of the project a set of requirements for space applications had been identified. All space requirements have been evaluated whether to be considered mandatory, optional or desirable for the SHEE habitat test-bed.

The baseline habitat concept was the result of repeated design iteration integrating several main design aspects: starting off with habitat dimensions (to fit into a cylindrical payload shroud – Figure 1 – as well as into terrestrial transport facilities), exploring deployment strategies, alternative internal lay-outs and structural concepts, integrating power, thermal and ECLSS.

A wide range of concept design options have been developed, and narrowed down with trade off criteria to a selection of nine concept designs. The trade-off criteria, as well as the developed concept options, were discussed in weekly technical telecoms to keep the consortium continuously informed and part of the important decision processes.

The final trade-off for the selected concept designs was performed in a personal meeting with all consortium partners where pros and cons could be discussed in depth (Figure 2).

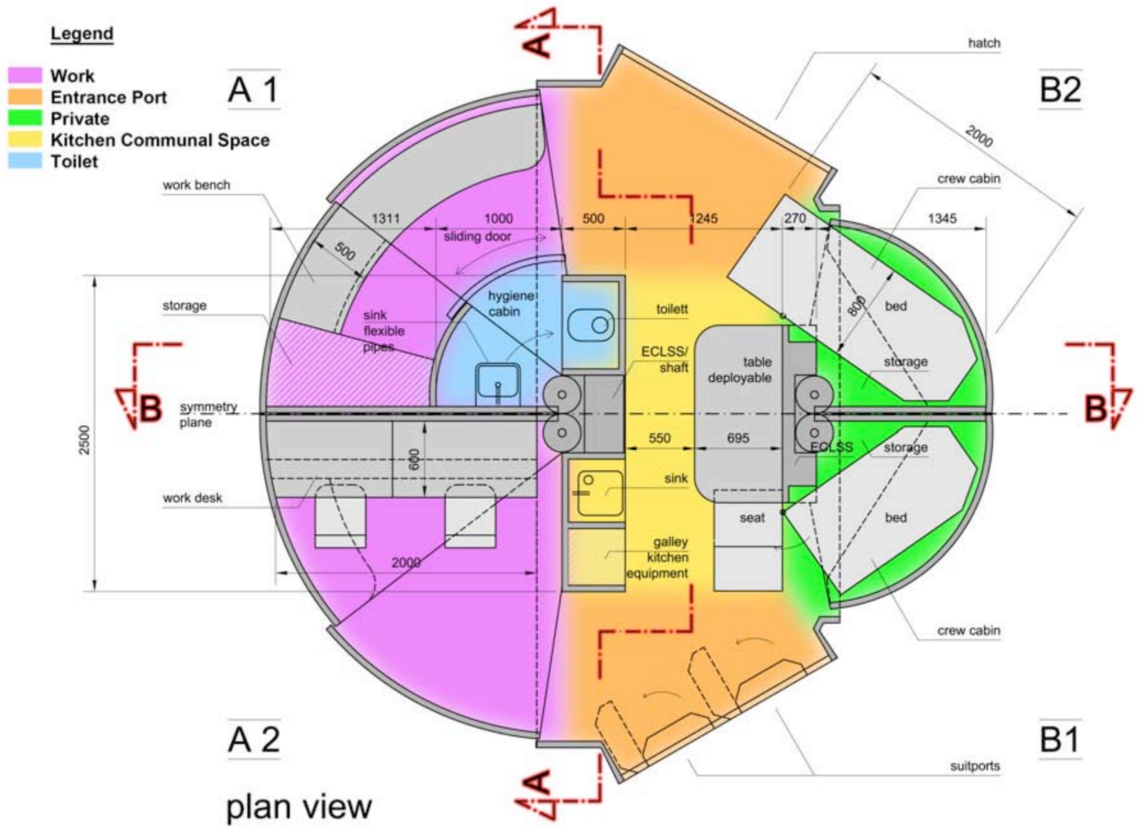

Figure 2. Final baseline concept, *credit: SHEE Consortium, visualization: LIQUIFER Systems Group, 2013*

Trade-off criteria had been weighted according to their priority: Deployment simplicity, structural simplicity, deployed/stowed ratio and structural robustness have been rated highest. Modularity, Re-packing simplicity, habitable volume, subsystem volume, deployed surface area, surface area/volume ratio, deployment mechanisms' default tolerance, overall habitat mass, convenience of maintenance, manufacture complexity, assembly simplicity where further trade-off criteria, apart from exterior and interior layout criteria, logistic capabilities, costs and schedule related criteria.

III. Building the SHEE test-bed

After the baseline design was agreed upon the immediate next step within the short amount of project time was the start of the building of the test-bed. This Section describes in detail the rationale and the construction of the deployable structure. It starts with the exterior shell, explains the overall geometry, implied design considerations and the actuation of the deployment mechanism. As infrastructural parts life support systems and the interior furnishings are explained.

A. Exterior shell

The shell design and manufacturing method is a result of the trade-off between the desire to create a perfect living space and the constraints of a deployable habitat. The selected manufacturing method is similar to building composite hulls for boats and yachts. The selected materials are likewise often used for building boats and other similar composite structures. There is a certain similarity between the composite shell of SHEE and nacelle housings built for wind turbines. The packed SHEE has a similar shape and size like a 2MW wind turbine. The nacelle housing served partially as an inspiration for the process design and material selection. Although the nacelles are not launched to space, they have to survive 20 years in offshore conditions standing on the top of a mast, an environment that certainly can be described as extreme. The shell has been built as a load bearing structure, there is

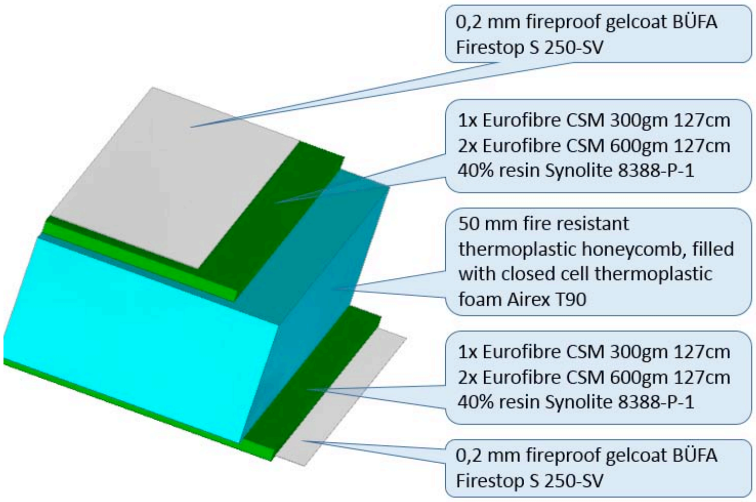

Figure 3. Default wall composition and used materials, *credit: SHEE Consortium, visualization: University of Tartu, 2014*

no load bearing frame and space filling paneling. As such the design has room for optimization, the first prototype was built without much change to the wall structure and composite lay-up.

In addition to improved fire resistance, the core material has also other good properties. It is a thermo-plastic honeycomb filled with closed cell thermoplastic foam. It combines the best properties from both schools. It inhibits the rip propagation, like honeycombs, and it has superior heat and noise insulation, like foam cores.

The aluminum rib structure under the floor and above the ceiling serves mainly for compartmentalization of the storage area and for supporting the outer shell cladding. The structural strength and rigidity is primarily provided by the composite panels.

All composite components are molded from two halves of identical base geometry, thus reducing the number of molds needed. The half shells are joined using aluminum girdle plates. The profiles are bonded to the components and joined using screws and brass inserts.

All flat surfaces around the various openings are faced off with a monolithic flat aluminum flange. These contribute strongly to the diagonal rigidity of the structure. The airlock and suitport walls are filled with bolted on flat sandwich plates. These can be easily removed and modified for various mission scenarios.

The structure itself is made of stiffened sandwich panels (60 mm thickness) of fiberglass facings with a core of foam material (Figure 3); it was manufactured in two halves attached together by means of an equatorial metallic flange. The petals were also manufactured as monocoque structures using the same principle as the main core with a thickness of 30 mm; they deploy by means of a deployment mechanism and transfer the loads to the main core through the deployment structure and the perimetric sealing system. In order to fasten the internal furnishing to the structure, hard contact points were provided by means of inserts and threaded devices embedded in the panel structure.

Figure 4. SHEE deployed and folded configurations, *credit: SHEE Consortium, photo: Bruno Stubenrauch, 2015*

B. Structural analysis

Structurally, the design of SHEE is a monocoque structure with six deployable appendages (so called petals, i.e. deployable compartments). Figure 4 shows the habitat in its deployed (operation) and stowed conditions (for transport or launch).

The structural verification that fed back into the preliminary design was performed by means of Finite Element Analysis (FEA) in order to validate the design hypotheses. This analysis took into account different load cases, for a range of different scenarios that were established as requirements for the design of SHEE. The FEA was performed with PTC Creo® Simulate software.

Stiffness and strength criteria were verified (for stowed and deployed configurations) using Safety Factors and recommendations extracted from widely used Industrial standards such as NASA-GSFC-STD-7000A-1 and MIL-STD-810F. The structural verification showed positive Margin of Safety for all the cases analyzed, thus confirming the choices made during the design.

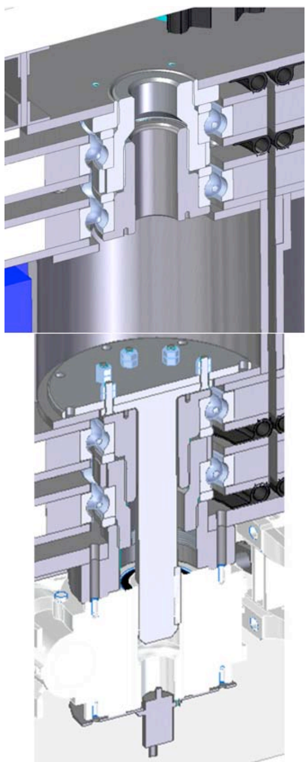

Figure 5. Actuation mechanism, *credit: SHEE Consortium, visualization: University of Tartu, 2014*

C. Actuation mechanism

All actuation consists of rotary motions. Several actuation methods were possible. The main choice was between driving from the perimeter and driving from the rotation axis. Driving from the axis was picked mainly because of the availability of tried and tested off the shelf components. It was also important that the drives are compact and are located in the floor and ceiling compartments, where they do not take up valuable habitable space. The further choice was between driving each petal individually or combining them in various ways. The final solution was to pair together the motion of the left and right petals on the driving motor level. This meant that each petal group has individual gearboxes, but a pair is driven by the same motor. This allowed saving on the motors and controls, but it leaves free an option to modify the design should the function of driving the petals individually become necessary. It was also not clear initially if the open C-shape of the petals would become a problem for the drives due to torsional deformations if driven from one end. The solution was to connect the two ends of the C-shape with a relatively large diameter hollow shaft, which provides the torsional rigidity for the petals (see Figure 5). The outer surface of the shaft also provided a good surface for insulation with the inflatable seals. The hollow shaft is not a complete cylinder; it is open from the habitat side, thus providing additional storage space and means for cabling the moving petals.

The mechanical design of the pivot points is such that it allows easy assembly of the separate petals. The bending forces generated by the dynamic loads and unbalanced weight distribution are separated from the torque provided by the drive, thus making life easier for the gearboxes.

The actuation is done by 800 W electric motors running on 24 V DC. The motors are connected to the pivot point through a 2 stage worm drive with reduction ratio 1:5000. After testing the motion, this was deemed to be not enough and a 1:3 stage was added, thus bringing the total ratio to 1:15000.

The position of the petals is tracked using a rotary encoder located directly on the pivot axis. The rotary encoder communicates with the PLC using CAN bus. There are mechanical limit switches for the closed position of the petals and inductive limit switches for the open position of the petals for backup.

The gaps between the moving petals and the shell are filled by inflatable seals. The seals are fully inflated after the habitat is deployed. The seals must be deflated using a vacuum pump during their motion. The outer petals of the large petals are freely turning and they are not permanently linked to the drives. The motion sequencing is done by selectively inflating and deflating the seals between the inner and outer petals and the shell, thus coupling the drives to different elements of the habitat. There is a set time limit in the program to finish the opening stroke. If the stroke is not finished in that time the motors are stopped and the seals are inflated regardless of the petal position. The habitat will still be operational with degraded capabilities even if not completely deployed.

The opening and closing functions are controlled by a Mitsubishi FX3u PLC. The habitat can also be opened and closed fully manually even with total power failure, by using external batteries or other power sources.

D. Environmental Control and Life Support System (ECLSS)

An Environmental Closed Loop Life Support System would ensure the biological autonomy of the crew while isolated on a planetary surface (or during an analog simulation mission). However, the total autonomy for humans in space is a long-term goal and has not yet been completely achieved. The SHEE ECLSS recycles water and regenerates consumed air and thus is able to cover the basic needs for a crew of two during a two-week mission. Some of the requirements related to the space environment (cabin pressurization, CO2 scrubber, O2 and N2 pressurized bottles, etc.) were simplified. All the components have been selected as trade-offs between compactness, mass and energy consumption.

Figure 6. SHEE control panel and unit, middle right: galley, far right: ventilation below the galley table; *credit: SHEE Consortium, photo: Bruno Stubenrauch, 2015*

The habitat was designed with all major elements of a Environmental Control and Life Support System: a water management system is included in the bottom of SHEE to recover used waters (from the sink and the internal air conditioning) and to recycle those in order to reuse those for the hygiene facility (and potentially for greenhouses that might be integrated in one of the sections in the future). As in the current ISS mission, it was considered that the astronauts living in SHEE would arrive with their fresh water (20l water bags are considered to be brought into the habitat before each mission). The water treatment chain is as follows: used waters from the sink are recovered into two grey water tanks (220l). From there, those are filtered through an osmosis filter. Theoretically the water would then again be drinkable; however it was decided to use the filtered water for the hygiene facility only (potentially for plant growth). The filtered water is stocked in what is called the clear-grey water reservoirs (42l). Once used by the hygiene facility the waters are evacuated into two black water tanks (220l) where they will wait for evacuation. SHEE is designed to work in gravity conditions, therefore most of the water flows rely on gravity with only some pumps needed for the transfer through the filter and the toilets. The overall distribution of the systems are shown in Figure 6.

The philosophy of SHEE was to design a foldable and modular system.

The requirement for modularity comes from the idea to be able to modify SHEE's functions depending on the mission. The prototype was developed for hosting two astronauts; future SHEEs, however, could include greenhouses, medical facilities, laboratories or workshops in the various sections.

The ECLSS components were therefore included in modular racks which could be replaced by other functional elements if needed. Figure 7 shows the integration of racks into the galley of SHEE: The kitchen rack of SHEE includes items that enable the astronauts to prepare and store food such as a microwave oven, refrigerator and a dehydration unit to reduce the food's size and recover water out if it. The hygiene rack on the other side includes a toilet (gravity based) and a sink for personal hygiene. On the other side of the galley are integrated two smaller racks that include the environmental monitoring system of SHEE, the air conditioning and two ventilation units. While the current prototype was not designed to be completely hermetical in terms of air-tightness, the integration of CO2 scrubbers are planned to reduce the CO2 content in the SHEE volume. However, air can be drawn from the outside through an external ventilation system which can be switched on and off.

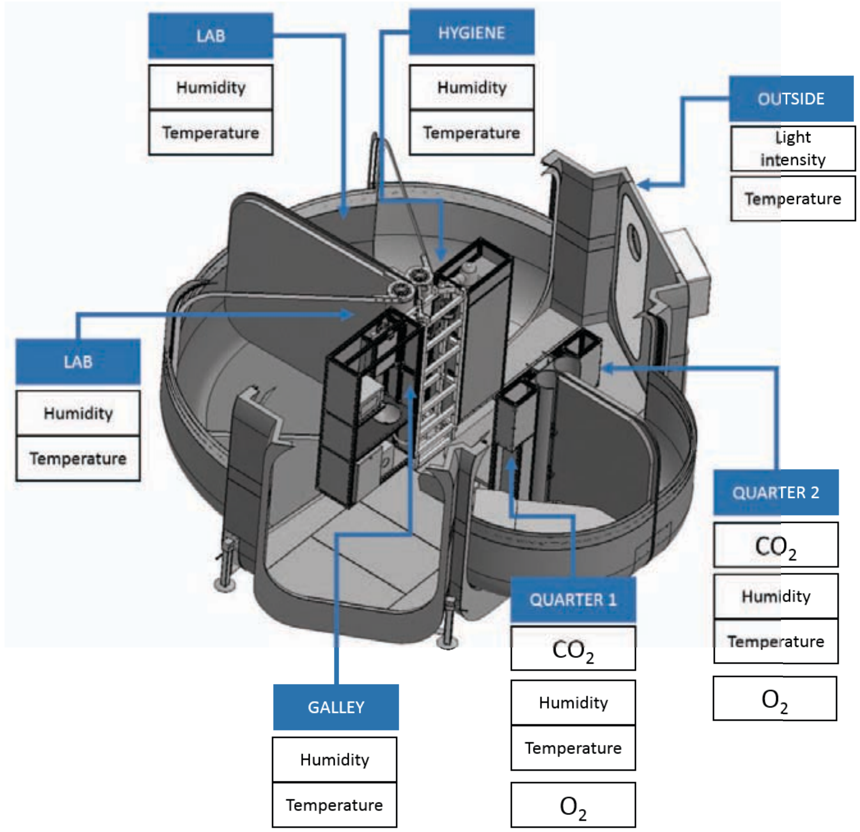

Figure 6. SHEE life support systems location and measurements; *credit: SHEE Consortium, visualisation: Comex, 2014*

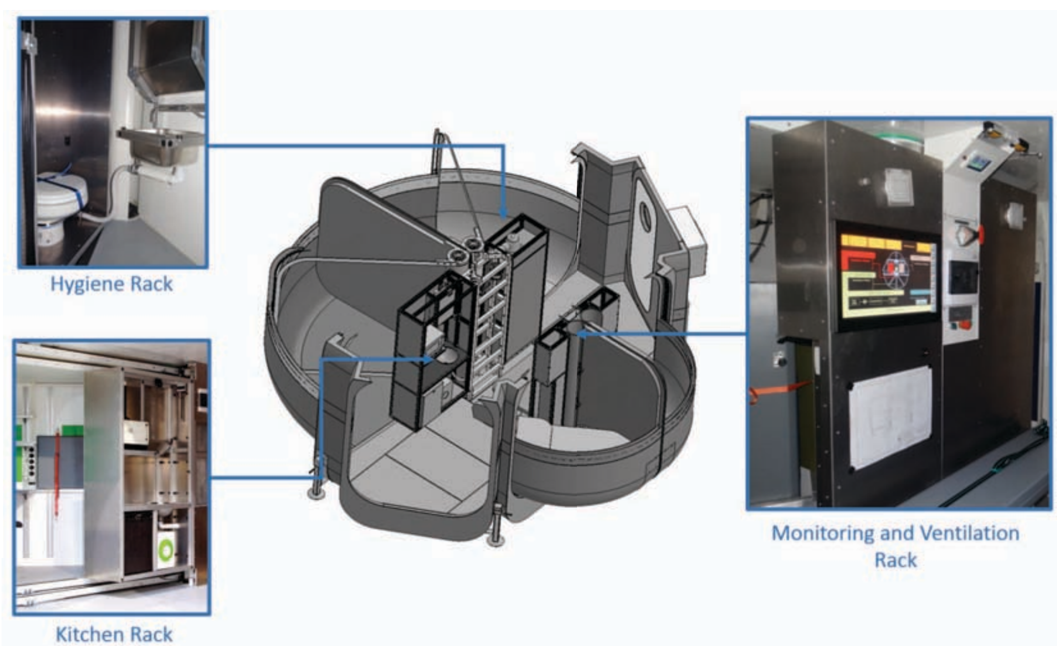

Figure 7. SHEE life support systems location and measurements; *credit: SHEE Consortium, visualisation: Comex, 2014; photos: Bruno Stubenrauch, 2015*

E. Interior

According to the design requirements established by the team with reference to existing standards the SHEE mission operational requirements foresee that one of the design concepts of the SHEE system shall be operated as a habitation unit (Figure 8). The habitable volume for a two-person crew was suggested to range between 20-25m³/person according to current NASA/ESA studies. The requirements have been considered together with volume for:

- Galley for food storage, food preparation and disposal,
- Hygiene facility including whole body cleansing, defecation, urinating, first aid kit, medicine box,
- Crew quarters for individual use,
- Working area, work bench
- Access airlock with a window allowing direct visual perception of the surrounding landscape.

Figure 8. Top row, from left to right: Galley, Crew quarter; Bottom row, from left to right: workspace, work bench next to hygiene facility, access airlock door with window; *credit: SHEE Consortium, photo: Bruno Stubenrauch, 2015*

IV.

V. Analysis and lessons learnt

In this Section the main critical topics such as exterior hull, sealing and deployment systems are discussed. Limitations of the systems inclduing the analysis of various environmental modelling scenarios are described to outline criticalities and capabilities to potential users. Some of the mentioned issues, especially in the area of interior furnishing also summarize lessons learnt and point to future upgrades to optimize SHEE and other such habitats.

A. Exterior hull structure and sealing

Structural issues are complex in deployable structures due to dynamic forces. Material strains under repeated deployment and redeployment procedures have to be considered, especially due to material expansion or shrinking in extreme environments.

Sealing turned out to be a main challenge with deployable structures. Air-tightness for the space application version was achieved through an additional exterior membrane protection during the sensitive deployment process; for the terrestrial test-bed, the inflatable sealing provided stability but only restricted air-tightness. In order to reduce the sealing zones as much as possible, the number of deployable hull elements has been restricted to six elements in the final design concept.

B. Deployment system

SHEE is the first test-bed to include this particular form of deployment which offers the great advantage of having to transport only a very small habitat. It has been a great challenge within the allocated timeframe and the budget constraints to design and manufacture the deploying petals. To create a continuous deployment mode required many detailed investigations and implementation skills. However, while deploying the petals of the habitat, discontinuous motion has been observed a couple of times. This is very likely to be attributed to a lower rigidity of the outer petals; they sag slightly due to gravity. Sometimes, the friction resisted the turning until the opening torque overcame the resistance. To mitigate this slip, they were supported and guided by plastic pads mounted to the floor and to the ceiling. It is advisable to increase the rigidity of the petals to avoid this glitch in future generations of SHEE.

C. Simulations and climate analysis in extreme environments

With respect to the intended real use of the habitat in terrestrial and extra-terrestrial conditions, a series of numerical simulations and thermal analyses was implemented based on the final status of the habitat structure. The goal was to evaluate the thermal comfort inside the habitat and determine requirements for the air-conditioning system. For this reason, areas with extreme climatic conditions were chosen, e.g. a summer day in Death Valley and a winter day in Antarctica.

Owing to the wide range of tasks to be solved, a combination of analytical approach, numerical simulations in own OpenFOAM® based solvers and solutions of thermal analyses in the EnergoPlus® software was chosen. By selecting this approach it was simultaneously possible to mutually validate the outputs.

Within the performed thermal analyses, heating and cooling issues of the habitat were primarily analyzed, while considering heat from sunlight and internal heat sources. It was also taken into account that the habitat is exposed during the day depending on the position of the Sun in the sky. All considered thermal analyses were performed using the EnergoPlus® software.

The next step was the creation of a 3D computer model of the habitat where numerical analyses of wall temperatures and the internal flow in the habitat were carried out with regard to the selected power and placing of the air conditioner (Figure 9).

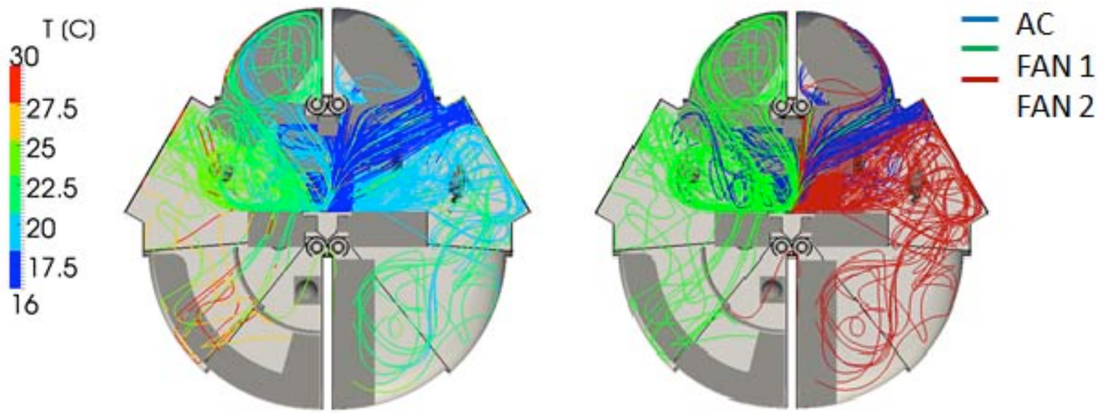

Figure 9. Thermal Analysis – Streamlines colored by temperature (left picture) and streamlines colored by source (summer day in Death Valley); *credit: SHEE Consortium, visualization: Sobriety, 2014*

The final steps in the above simulations and analyses were virtual testing of the habitat in the Mars and Moon conditions, where the aim was to gain insight into the behavior of the existing concept of the habitat in these extreme environments.

D. Interior furnishings

Deployable furnishing elements have been integrated after the hull was produced in Tartu, Estonia and the ECLSS has been integrated in Marseille, France. The importance of foreseeing sufficient tolerances proved during assembly, as high accuracy cannot be reached with a first prototype consisting of mainly hand-made elements. Necessary adaptations during manufacturing of the hull, integration of the ECLSS turned out to be a challenge for the integration of furnishing elements. Due to time restrictions elements were produced in parallel, and final integration proved to be demanding.

Interior furnishing will be used during test phases excessively. The budget for interior furnishings was low as not considered of high priority for a deployable habitat, where the hull and robotics was the main focus. Nonetheless a reasonable budget for the interior furnishing should be foreseen with future habitats of this kind to assure full functionality, robustness, easy and safe to handle and to clean. Light needs special attention, as well as personalization capacities.

The final layout includes two separate crew quarters, which was rated high especially for long-term missions. Windows in the deployable compartments have been ruled out for the first test-bed prototype due to cost restrictions.

However, a "virtual window" was integrated to change the light color, further capabilities like programmable audio and video applications would be possible in the future.

VI. Anticipated habitat operations

Between October 2015 and December 2015 the SHEE habitat will be tested in a laboratory environment. The following three fields of investigation are foreseen:

- Operations in terrestrial on surface conditions and short analogue missions
- Subsystems performance, interior operations
- Effectiveness of the SHEE habitat as a self-deployable and foldable autonomous unit.

A test-plan set-up is foreseen including respective procedures for a two-month study of habitat operations. Additionally, a safety operations protocol for complex robotic architecture will be proposed. The main aspects as part of the three above-mentioned fields of investigations will concern the following:

- ➢ Exterior testing
    - Logistics and set-up issues
    - Repeated deployment/stowing (possible external modifications tbd)
    - Human-machine habitat interaction
- ➢ Interior testing
- ➢ Logistics and set-up issues

- Repeated deployment/stowing (possible internal modifications tbd)
- Constraints on human internal operations
- Complex habitat testing
- Repeated system initiation/hibernation
- Autonomous operations

Testing of the habitat is broadly separated into two phases: 1) functional testing to the designed, built and integrated systems of the habitat; and 2) user-based testing of the experience and operations of the habitat. The functional testing serves to verify the design requirements that were developed to meet the original mission goals of the project, and range from major functions (e.g. testing of the automatic deployment of the habitat on site) to the specific (e.g. testing/monitoring of the atmospheric conditions inside the habitat during operations. In a project like this it is important to verify and review the original requirements, first to gain confidence in the design and later in the operation of the habitat, especially as this is a novel design and the first engineering model built to this design. Functional testing is ongoing but has not revealed any significant failures or performance issues. However, through this testing phase, a variety of assembly and integration issues were able to be identified and solutions developed before operations commenced.

Operational testing encompasses the broader operations of the habitat and the interactions of users with the habitat. Operational testing is carried out in two categories: 1) human (operator and user) interactions; and 2) performance and environment testing. For the human operations within the habitat, the International Space University is conducting an experimental study using a large number of participants to provide a study of the impact of biometrics (of the users) on the operations of the habitat. Outcomes of this study will validate design choices, identify operational limitations and provide data to update user guidelines and the risk assessment of the habitat. Performance testing will seek to run the habitat as an integrated system in standard operational modes and monitor the performance over time. In these tests deployment, set-up, use and repackaging of the habitat is performed. Throughout these operations, habitat system data and environmental data (thermal, acoustic, lux, air quality) is gathered. The data is monitored and analyzed against previous simulations and design calculations) to verify the overall performance of the habitat in future deployments.

VII. Exploitation opportunities for the scientific community

During the project development the team created first sketches for further uses of SHEE. One of the options is to refurbish SHEE into a laboratory where a medical unit is located in one area and where astrobiology investigations can be conducted with samples taken form the surface expeditions (Figure 10). The samples can be taken into a confined environment through sample exchange airlocks and operations on them are foreseen to take place through remotely- controlled robotic arms in sterile boxes. Additionally, a workstation is provided in this first concept.
Key features:

- The ECLSS system is integrated (further design iterations should be conducted to place the ECLSS in the core of the habitat)
- The medical facilities are positioned in one of the larger petals
- The work station /desk is positioned in one of the larger petals
- The sample / exit airlocks are positioned in the smaller petals
- The transit airlocks are positioned in the smaller petals
- The dry / wet labs (astrobiology investigation unit) are positioned in the core unit and will be attached after deployment

The design requirements have been taken from considerations that were summarized in papers by Marc Cohen (2000; 1999). Also the configuration suggested including a complex set-up of sample investigation in a protected environment could be found in his paper. The challenge was to implement these guidelines into the SHEE layout. Literature in this area of how to design such a laboratory including sample manipulation and a medical unit are very scarce. Therefore, this field presents excellent further study opportunities.

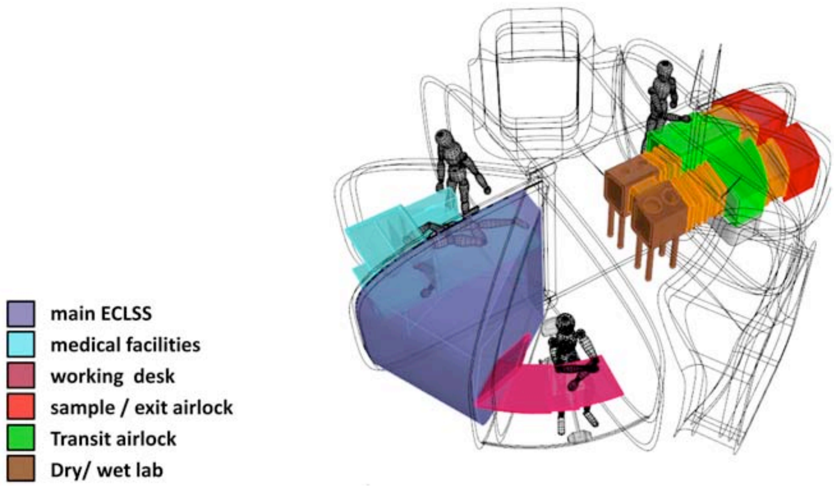

Figure 10. SHEE concept for an astrobiology and medical laboratory *credit: SHEE Consortium, visualization: LIQUIFER Systems Group, 2013*

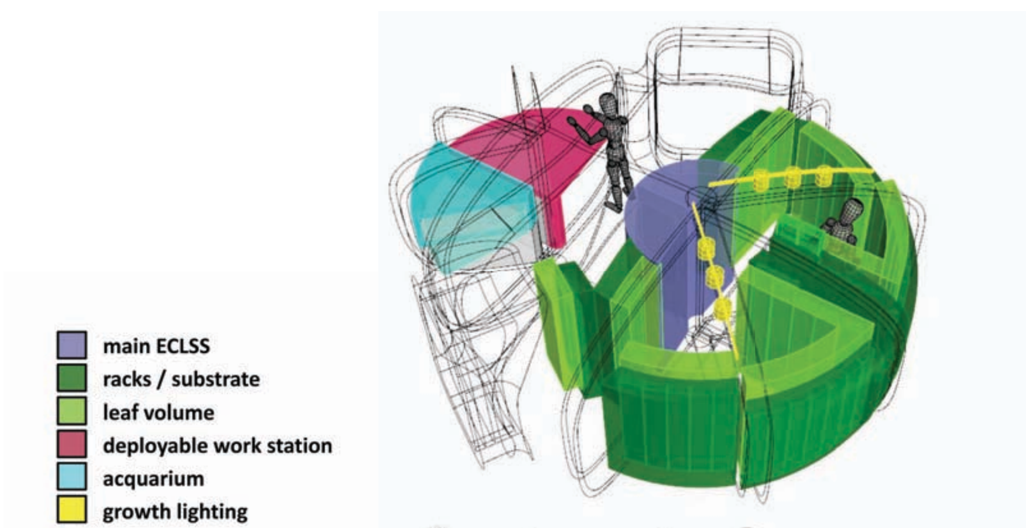

Figure 11. SHEE concept for a greenhouse *credit: SHEE Consortium, visualization: LIQUIFER Systems Group, 2013*

Another option would be to outfit SHEE as a greenhouse. For long duration missions on planetary surfaces a non-dependency on food delivered from home is a prerequisite. Greenhouses are being studied currently however, not within a restricted volume with a reference to an actual space module. The SHEE team developed several of concepts; one of which is displayed in Figure 11.

Key features:

- The main ECLSS system is integrated

- The substrate for the plants is positioned in racks following the walls of the large petals
- The leaf volume is oriented towards the center of each large petal
- The deployable work station is positioned in one of the small petals
- The aquarium and corresponding ECLSS is positioned in one of the small petals
- The positioning of the growth lighting directs the plant growth towards the petal center

Further investigation possibilities for exploiting the SHEE test-bed are regarding the logistics; e.g. transportation from a lander to a given site including a self-leveling mechanism in case of uneven terrain. This particular function could be realized using the same actuators and components that are used for deployment.

Another aspect is to improve the self-sufficiency of SHEE through integrating solar panels and expanding the life support system installed at this point. It is well known from the ISS that noise is a noticeable problem for the onboard crew. Complex habitats with all their machinery create noise to a certain extent. In order to mitigate these sources of disturbance follow-up studies can include noise studies and the mitigation of noise.

Regarding habitation some interesting topics for further research include light studies with the lights installed in SHEE and also changing light options of the "virtual window". Further development of the "fake window" to represent virtual view to the outside and corresponding studies could also contribute to the manifold options of investigations. Another possibility relates to the crew quarters and design options for shielding of the small personal rooms from the other crewmember for privacy.

VIII. Summary on exploitation of SHEE

A more general summary on SHEE exploitation efforts for an overview has been comprised in this section. As the testing and usability studies of SHEE are ongoing, numerous components, procedures and habitation activities are tested. A complexity of habitat functions yields also an intricacy of human behavior and potential errors. These are addressed by a human-system design that should maximize human-centered design (HCD) concepts. Although SHEE has been designed with several HCD considerations in virtual simulations, it is impossible to capture all possible situations that could evolve from living inside the confined habitat.

The utilization of SHEE and the simulation capacities of SHEE can be outlined by domains. While the comprehensive list of possible SHEE applications has been provided in the past studies (Doule et. al. 2014) it is open to the scientific community to identify the main domains of interest and point out the main benefits of this simulator that will be commercially available for research for the international research comunity. It's main benefit is transportability. Nonetheless, the endurance to repeated stresses by a variety of transport systems will be identified experimentally during missions planned for SHEE. The transportability means that the system can be used in indoor laboratories as well as in exterior environments or even in analog environments that are equipped with required infrastructure (road, power, sewage). The system endures nominal weather while allowing internal climate monitoring and conditioning. Its integrated air-system may be adapted for higher fidelity life support system and allows for atmospheric elements monitoring.

As the only easily transportable habitat simulator on the global market it is presumed that space agencies will be serviced as well as academia and private entrepreneurs. But its use has to be well planned and considered. SHEE is not an engineering model of a specific mission element based on pre-set mission strategy. On the contrary, it considers numerous mission scenarios and uses of a variety of planetary bases while emphasizing the basic architectural elements in its form and function. SHEE is also desgined such that it can be placed in extreme terrestrial environments as it targets applications on Earth as well. SHEE is a Lunar or Martian base simulator and addresses a variety of generic design requirements stemming from planetary human space flight (Doule et.al. 2013). SHEE can be characterised as follows:

- DEFINITION: The system is not a flight model but a physical representation and interpretation of selected design principles.
- DEVELOPMENT PHASE: The system is not a development or design stage but a simulator of a flight model design following human space flight habitat principles.
- SIMULATION FIDELITY: Analog simulations and experiments can be performed to a certain fidelity standard. The required fidelity has to be identified prior considering all SHEE systems and elements to rule out a misinterpretation of gathered data from a simulation.

The SHEE systems have many benefits by merging a variety of properties and SHEE is one of few architecture facilities designed purely for research. To fully understand the SHEE design and it's complexity a researcher's user manual will be provided to guide in science preparation and planning prior to SHEE utilization.

IX. Conclusions

The SHEE test-bed is a unique structure developed by a European consortium of industry and research institutions to serve the international research community for habitation simulation tests. Further, SHEE was constructed so that it can be easily transported by land, sea and air. The dimensions fit a prospective future planetary exploration mission; even two of the stowed SHEE configurations can be fitted into a heavy lift launcher of a diameter of 6 meters.

Simulation research has been a growing field of research within the last 10 years and it provides excellent opportunities to prepare for future exploration. As with every test-bed of this kind SHEE has been designed, built and outfitted within financial limits and improvements in various areas as outlined in the Section 'Analysis and Lessons Learnt'. However, it is made and furnished so that real simulations can be conducted. Since most parts are modular and can easily be arranged differently, the versatility of habitat operations tests can serve a larger community, especially in Europe to advance current research in this direction.

X. References

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