SHEE – a Self-deployable Habitat for Extreme Environments
Exploitation and lessons learnt from testing

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The first European space simulation habitat, the Self-Deployable Habitat for Extreme Environments (SHEE) was built by a European consortium within three years (2013 – 2015) under an EU framework 7 contract. Coordinated by the International Space University, France, the team was composed of LIQUIFER Systems Group from Austria, COMEX from France, Space Application Services, Belgium, University of Tartu, Estonia, and Sobriety and Space Innovations, both from the Czech Republic. SHEE is a rigid segment deployable habitat test-bed designed for use in space analogous environments. The objective of the SHEE project was 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. For habitat simulation purposes and for other research, SHEE can be moved to various terrestrial analogue sites by standard commercial, thus cost effective, transportation. Testing of the habitat included subsystems performance, interior operations, and effectiveness of the SHEE habitat as a self-deployable and foldable autonomous system. This will be the focus of the paper. It will further be described how these tests can inform future anticipated operations in the field and any other future exploitation opportunities. One example is the SHEE deployment as part of the Moonwalk FP7 campaign in Rio Tinto, Spain in April 2016. Rio Tinto is an internationally recognised Martian analogue site, mainly because of the presence of extremophile aerobic bacteria that dwell in the water. The project Moonwalk focuses on human-robot interactions and the team will conduct simulation missions in two analogue sites as preparation of future exploration missions. It is currently planned that the SHEE habitat will be one of the elements to be tested as part of the Mars related simulation in Rio Tinto.

Definitions/Abbreviations

CAD = *Computer Aided Design*
CFD = *Computational Fluid Dynamics*
DLR = *German Aerospace Center*
EAC = *European Astronaut Centre*
ECLSS = *Environmental Control and Life Support Systems*
ESA = *European Space Agency*
ESOL = *European Surface Operations Laboratory*
ISU = *International Space University*
GSP = *General Study Programme*

LEO = *Low Earth Orbit*
LSS = *Life Support Systems*
MCC = *Mission Control Centre*
NBF = *Neutral Buoyancy Facility*
SHEE = *Self-Deployable Habitat for Extreme Environments*

I. Introduction

The space agencies of the world are thinking about the next steps in space exploration especially in view of the termination of the International Space Station Programme after 2024. ESA's General Director Jan Wörner has proposed the "Moon Village" concept, an idea that offers new space exploration horizons for surface operations as well as in-space platforms. From a crewed perspective Europe is also looking at ISS lessons learnt and going beyond – after the ISS's life-span will have been terminated – towards other human-tended bases established not only in space but also on extra-terrestrial grounds such as the Lunar or Martian surface. For preparing these missions we need analogue facilities and simulations to test and train future astronauts and operational personnel to gain more insight into the topics of Habitability, Human Factors and Life Support Systems (LSS).

SHEE can become an integral part of new developments in this direction, contributing to the hardware needed for future human exploration missions beyond LEO. SHEE is the first European space simulation habitat. As it is autonomously deployable SHEE can be used in remote areas which are not easily accessible since no human labour is needed to set up a fully functional habitat.

The US company Bigelow Aerospace (Bigelow Aerospace, 2016) is currently flying an inflatable habitat prototype, called BEAM, to the ISS based on the TransHab technology that NASA developed in the late 1990s (Adams 2000). Inflatable habitats are a possible option for crewed volumes on extra-terrestrial surfaces. The primary advantage of inflatables over traditional static volume cylindrical modules is that their final volume is not limited by the diameter of the launcher faring. They can be efficiently packed though it is challenging to attach interior furnishings and other equipment to the outer envelope.

SHEE presents an alternative approach not yet explored: a habitat deployable using rigid shells. This paper describes SHEE as hardware, discusses the analyses undertaken, and outlines the tests performed including future opportunities at hand. SHEE is a module that can be exploited in various ways for advancing Human Factors Habitability and LSS, adding to integrated simulation facilities as envisioned by the European Space Agency (Hoppenbrowers et.al 2015).

Figure 1:. SHEE mission patch, credit: SHEE Consortium, 2015, graphic design: LIQUIFER, SPIN, 2015

II. SHEE, a general overview

SHEE is autonomously deployable. It has a size of 5.9 m by 2.4 m by 2.8 m in stowed configuration and an approximate diameter of 6 m in the deployed state, more specifically 5.9 m by 6.5 m by 2.8 m.

The habitat has a deployed volume of 50 m3 and weighs 5.5 metric tons excluding consumables. SHEE is configured such that in stowed condition it can be easily transported by land, sea and air to various sites. The dimensions in this configuration are similar to those of a standard shipping container. Further, this stowed configuration allows two SHEEs to sit back to back on a heavy lift launcher. Thus two habitats could be transported to an extra-terrestrial surface at once. Two or more SHEE habitats could also be joined together to create a SHEE village. Once on the moon or on Mars the habitat/s would deploy autonomously before the crew would have landed. When the systems are set-up and running, the crew could safely start living in the habitat/s. Each individual SHEE module is configured for a two-person crew for a mission duration of two weeks.

The following Sections describe SHEE through the sub-topics listed below

- SHEE envelope: exterior hull
- SHEE robotics: autonomous actuation for deployment
- SHEE Life Support Systems (LSS) for a two-person crew for a two-week simulation
- SHEE interior outfitting

Further two examples of analyses are described

- Human Factors through specific 3D software with the manikin extension used for Human Factors analysis for ISS
- Moon/Mars environmental modelling

The SHEE habitat is a simulation habitat made for use on Earth to train astronauts for future Lunar and Martian surface missions. Therefore, the overall structure has no overpressure and provides no micrometeorite or radiation shielding. Figures 2 to 5 show the stowed and deployed and packed configurations from external and internal perspectives.

Figure 2:. SHEE in deployed mode, credit: SHEE Consortium, photo: Bruno Stubenrauch, 2015

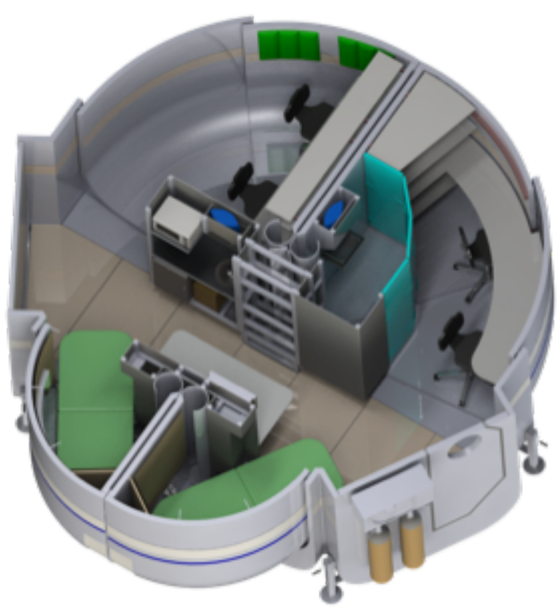


Figure 3:. SHEE in deployed mode without top, credit: SHEE Consortium, visualizations: Sobriety, 2015

Figure 4:. SHEE in transport mode, credit: SHEE Consortium, photo: Bruno Stubenrauch, 2015

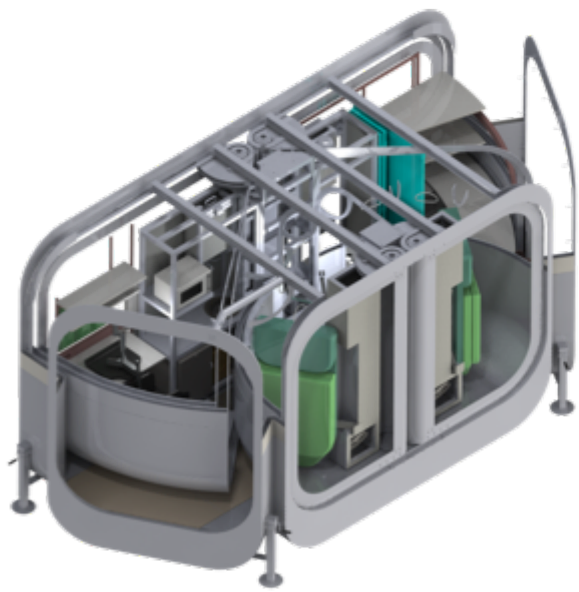


Figure 5: SHEE in transport mode without hull, credit: SHEE Consortium, visualizations: Sobriety, 2015

III. SHEE envelope

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 the budget and schedule. The selected manufacturing method is similar to building composite hulls for boats and yachts. The selected materials likewise are often used for building boats and other similar composite structures. The shell has been built as a load bearing structure. A question has been often asked during interviews and discussions in public forums why is the habitat not inflatable, since after the movie "Martian" the public preception is that all space habitats are inflatable structures. The answer is quite simple. The inflatable habitats have better opened and closed area ratio, but the habitat is not launched empty, it is packed full with mission materials and the resources must be already inside the habitat when the crew arrives. So the habitat is also a cargo container in the transit phase.

The shape of the habitat was selected to provide on one hand the structural rigidity, but on the other hand to simplify manufacurting by minimizing the need for different moulds.

The space above the ceiling and under the floor is divided into subsystem compartments with aluminium ribbing. All flat walls outside are faced off with 10mm aluminium flanges that provide additional rigidity. The flat end panels can be easily repurposed as airlocks or docking ports, or interfaces to the next habitat module.

Figure 6. SHEE under construction, credit: SHEE Consortium, photo: University of Tartu, 2014

IV. SHEE robotics

Deployment is achieved through rotary motion about four columns. The motion is tracked with rotary encoders directly mounted on the pivot axes. All gaps between the moving parts are filled with inflatable / deflatable seals. The small petals and the inner big petals are directly connected with the drives, located under the floor. The outer big petals are free to move if the seals are deflated. The opening and closing sequence is determined by the order in which the seals are inflated or deflated. This way the free outer petals are coupled either with the actuated inner petals or with the stationary outer shell.

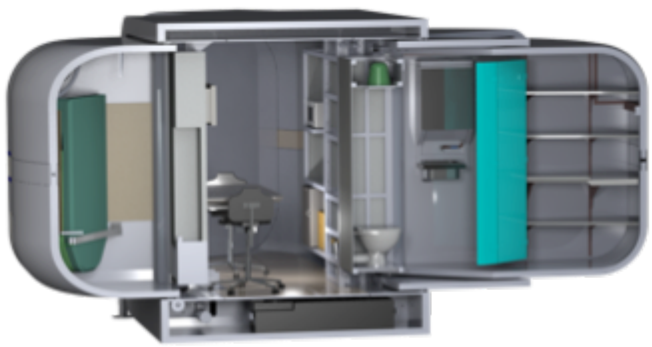


Figure 7. SHEE 3D section showing the rotary axis and actuation bottom left, credit: SHEE Consortium, visualizations: Sobriety, 2015

Sealing the habitat with moving sections constitutes a major challenge. The current testbed is not sealed during the opening and closing process. It is only sealed when all the seals are inflated in the start and end positions. The habitat can be sealed in any position, if for some reason the habitat does not open the full cycle. A real space habitat would require special subsystems that would seal it during the opening stroke. A likely candidate would be an inflatable film envelope. The matter is further complicated by the requirement for reverse deployment of the habitat test-bed. The real space habitat would not be repeatedly deployed and the seals could be forced to keep the contact by filling them and the gap with chemically activated foaming agent, thus removing the danger of losing the pressure in the seals.

V. SHEE Life Support Systems

The Environmental Control and Life Support System (ECLSS) of SHEE has its objective to ensure the autonomy of a two person-crew during a two weeks isolated mission either in an extreme terrestrial environment or on a planetary surface. The current prototype is not intended to work on a planetary mission. The ECLSS works on an open-loop basis, meaning that the habitat uses air and consumables brought from outside to maintain the crew alive inside. However, even with these trade-offs SHEE can serve as an operational scenarios and hardware test-bed for future missions. The SHEE ECLSS is designed as a partially regenerative system to highlight the necessity to design closed-loop ECLSS for long duration space mission in the future. It can be divided into six main areas: the air revitalization system, the monitoring system, the water management system, the hygiene facilities, the food preparation facilities and the waste management. The spatial distribution of the ECLSS is based on the creation of different, independent and modular racks that host one or several functional subsystems of the ECLSS. The major components of ECLSS have been accommodated through the non foldable SHEE interior parts and all the components have been selected as trade-offs between compactness, mass and energy consumption.

The water management system provides potable water at the kitchen sink assembly (for consumption and food preparation) and at the hygiene sink. The resulting grey water is partially recovered through a reverse osmosis filter, automatically controlled by the current level of the upstream and downstream reservoirs via the ECLSS controller. The filtered grey water is used for operating the toilet. As this water is potable, it could also supply greenhouses in future versions of SHEE. The outlet of the electrical toilet located into the hygiene rack is finally pumped into the black water reservoirs.

The atmosphere revitalization management is the most critical requirement for the crew and provides them with a comfortable internal temperature (thanks to a remotely-controlled air-conditioning unit). It has been designed for two operating modes: a closed air loop achieved with two scrubbers designed (but not manufactured) for a 24 hour demonstration and an opened air loop, the rest of the time, achieved with some closable fresh air inlets/outlets from the outside. The main components prevent air stratification inside the habitat through internal fans, an active ventilation system hidden in O_2 and N_2 dummy pressurized bottles, a toilet air extractor aiming at cooling batteries in the ceiling, and passive ventilation grids.

In this framework, the SHEE ECLSS monitors and displays to the crew a visualization of some ECLSS parameters. These are measured by sensors placed throughout the habitat with 6 temperature and humidity sensors, 2 x CO_2 and 2 x O_2 sensors located in the vicinity of the crew cabin, an external temperature sensor and a luxmeter. The SHEE controller operates the water filtration process relying on the level probes' status of the reservoirs. This controller is supplied with a tactile human-machine interface screen located in the monitoring rack and displays/records measurements and alerts if threshold values are reached.

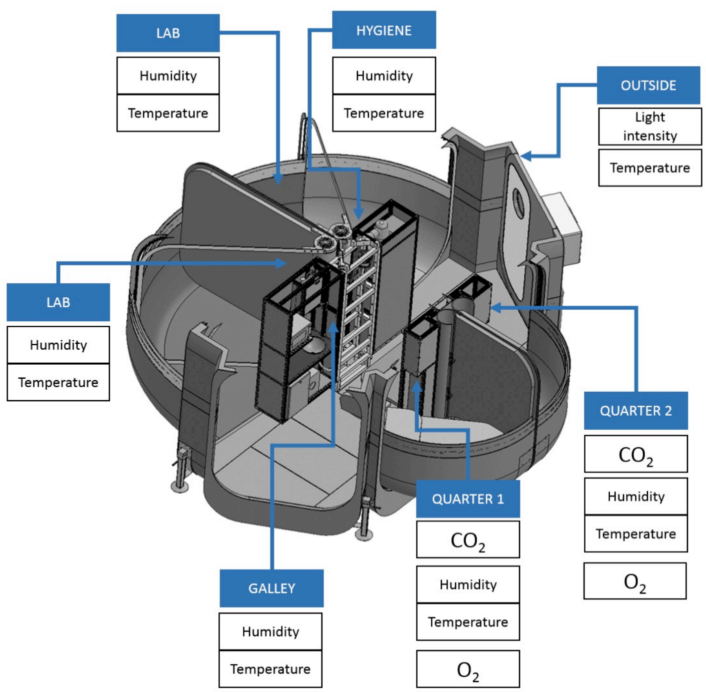


Figure 8. SHEE Life Support Systems location and measurements; credit: SHEE Consortium, visualisation: Comex, 2014

For the crew's convenience, hygiene facilities and kitchen facilities have been integrated and are limited to those services available during spaceflight. They are hosted in two modular racks. The hygiene rack is composed of an electrical compact toilet and a sink assembly. The kitchen rack contains a mini-fridge, a working surface, a compact micro-wave oven and a dehydrator device for dry organic waste.

VI. SHEE interior outfitting

Figure 9 shows a ground plan of SHEE. The interior of SHEE comprises the functions of a central meeting space equipped with a minimal kitchen and a dining table (Figure 10), two crew cabins for private retreat (Figure11) a workspace for two people, a workbench for laboratory type of work and a hygiene facility (Figure 12). By folding the table of the meeting zone the main central translation area can be enlarged whenever needed. In this habitat configuration one side of the translation area leads to the suitport, the other one to a connector door (also emergency door now used for entry and exit).

All of the interior outfitting is completely integrated and tailored to the deploying petals of the habitat. They are easy to remove or to reconfigure and, therefore, allow quick adaptations to different simualtion scenarios (also greenhouse, laboratory, etc.). During operation most furniture elements can be adjusted to accomodate individual needs, e.g. the foldable foot part of the beds can be folded to serve as a side table, or each bed can be rotated into vertical position to create additional space. The partitioning wall between the hygiene cabin and the workbench is foldable so that the two spaces can be joined - allowing for a more spacious interior work zone.

The colour concept utilizes neutral colours like grey and white for walls and floors as well as for the general furniture elements. All textile elements can be selected according to personal preferences and fulfil several functions. They are noise dampening, create a comfortable interior through their soft surface and allow for individually selected colour ranges.The adaptive capacity of the lighting system adds to the positive habitability of the space. The lighting concept is based on slim flexible LED-units which can be directed to the ceiling or directly onto a surface. Indirect light situations can be created as well as spotlight arrangements which can be modified and tailored to the crew preferences. In addition, the personal crew compartments are outfitted with colour-controllable light panels which enable personalisation of the interior colour atmosphere to alleviate sensory deprivation.

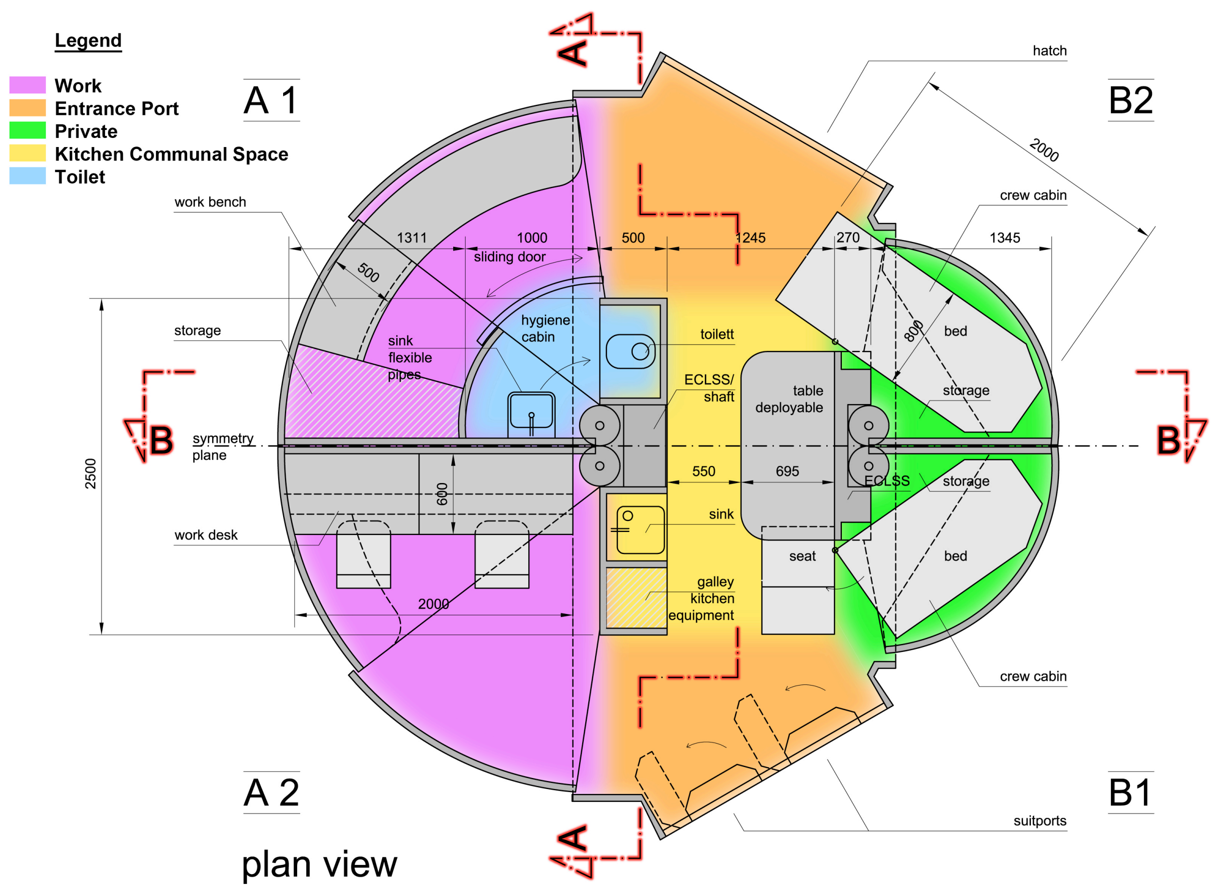


Figure 9. SHEE plan, credit: SHEE Consortium, visualization: LIQUIFER Systems Group, 2014

Figure 10. SHEE galley, credit: SHEE Consortium, photo: Bruno Stubenrauch, 2015

Figure 11. SHEE crewquarters (left and right, credit: SHEE Consortium, photo: Bruno Stubenrauch, 2015

Figure 12. Left: SHEE workspace, right: hygiene facility and workbench, credit: SHEE Consortium, photo: Bruno Stubenrauch, 2015

VII. SHEE analyses

In the following, two main analyses conducted as part of the SHEE development are presented. One is in the area of Human Factors and the other is about simulating the SHEE habitat in the lunar and Martian environment and shows thermal qualities of the inside space in these environments.

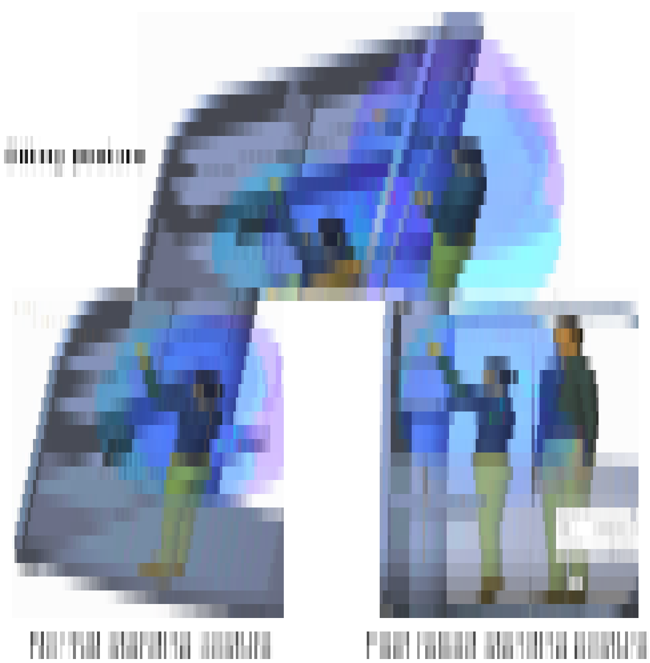


Figure 13. Analytical evaluation of human factors - reachability analysis, credit: SHEE Consortium, visualisation: Space Applications Services, 2014

A. Human Factors

Prior to the manufacturing of the habitat, the consortium carried out an evaluation of the SHEE design in terms of human factors, to ensure that the proposed concept and the planned internal layout (furniture, etc.) would be ergonomically sound. This mainly consisted in the following:

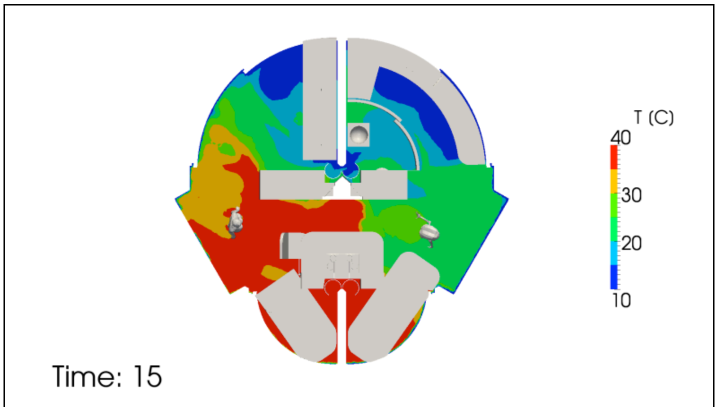
(1) An analytical evaluation of the concept, based on the 3D CAD models (structure and internal layout) of the habitat. For this purpose, the Creo CAD tool was used together with a Manikin extension (PTC, Ergonomics/Human Factors tool). The evaluation included an analysis of various postures for given scenarios and use cases, a reachability (illustrated on Figure 13) and line of sight analysis considering e.g. comfort, clearance and accommodation, a composite lifting analysis, plus some complementary considerations (e.g. risks of injury if jumping inside the habitat) (NASA-STD-3001, 2011; Akin, 2012; Salvendy, 2012). A NASA 5-95% percentile anthropometry (NASA/SP-2010-3407), complemented by the CAESAR for Dutch people was used. The structure and internal layout were globally found to be well thought out for users, with just minor comments

and recommendations (e.g. height in the deployable compartments would leave a low clearance (3 cm) for taller crews, height of the upper shelves to be adjusted for shortest crew members, height of displays in the work space to be set between 1250 and 1500 mm).

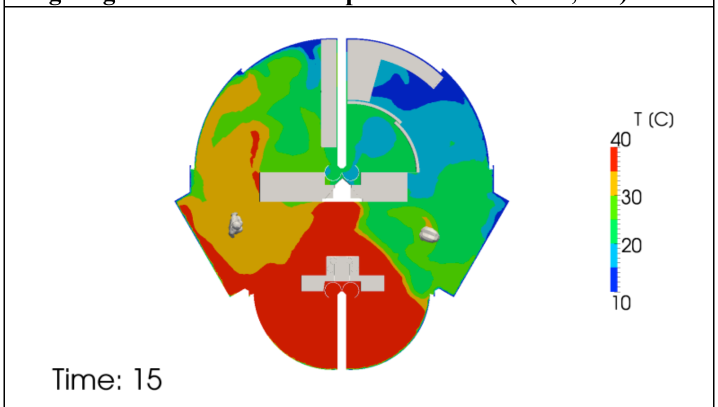
(2) A qualitative evaluation of the concept, relying on an Oculus Rift based immersive Virtual Reality software application. A dedicated virtual tour application has been developed purposely with Unity 3D allowing users to visit SHEE and virtually interact with the mobile components inside the habitat. A sample of users among consortium partners and the project's advisory board, in particular, have been experiencing this virtual tour, and got a more qualitative impression of what future crews would experience will the actual habitat. Figure 14 and Figure 15 below illustrate this virtual tour application, which can also be viewed through the SHEE web site.

Figure 14. SHEE virtual reality tour, credit: SHEE Consortium, visualisation: Space Applications Services, 2014

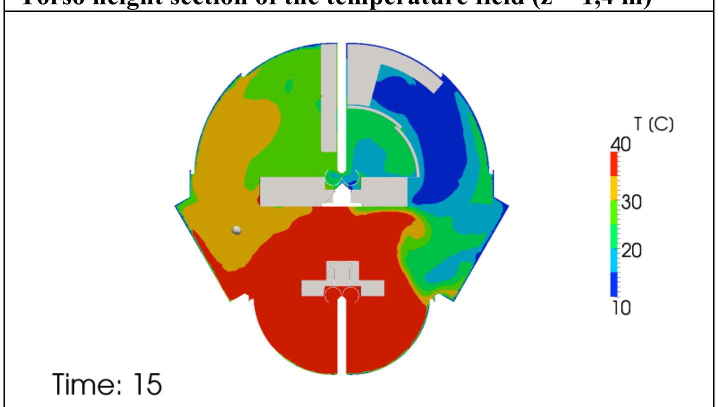
Figure 15. SHEE virtual reality Oculus Rift immersive interface, credit: SHEE Consortium, visualisation: Space Applications Services, 2014



Leg height section of the temperature field (z = 0,7 m)



Torso height section of the temperature field (z = 1,4 m)



Head height section of the temperature field (z = 2,0 m)

Figure 16. Inside temperature fields – Example of Mars cold case, credit: SHEE Consortium, visualization: Sobriety, 2015

B. Moon/Mars modelling

The objective of Moon/Mars modelling was to perform CFD thermal analyses for the worst scenarios that can arise during the habitat's stay on Mars and Moon surfaces. Extreme hot and cold simulations have been conducted for both of these spaceflight scenarios. The goal of the simulation was to determine the level of thermal comfort inside the habitat during extreme conditions and, in case of need, set the recommendation to the air-conditioning system design. Due to the nature of the selected regimes (temperature extremes on the Moon and Mars) thermal comfort of high quality is not expected but rather an option to survive these conditions in the habitat.

Figure 16 shows the inside temperature map during the Mars cold case. For the simulation the habitat was placed to the North Pole on the day of the Winter solstice during the polar night. Outside temperature was set to -150°C as measured on Nov 11 2001 and wind with speed of 30 m/s corresponding to the wind storm formed the Mars worst scenario. A/C unit outlet air temperature was set to 40°C.

The big temperature differences within the habitat were caused by considering the fans serving to better air distribution to the work area A1 and A2 as switched off during the worst case.

VIII. SHEE testing in a laboratory environment

The laboratory testing carried out at ISU served two purposes: 1). A series of tests of the functionality and performance of the habitat were carried out; and 2). The habitat's design was tested by a number of participants looking specifically at the usage of the facilities and the general experience of living and working in the habitat. These tests were carried out in a controlled environment inside the ISU high-bay.

The functional testing was an important aspect of this project, providing verification and validation of the majority of the original design requirements. To this aim, a verification matrix was developed and a minimal set of tests were formulated that would produce either compliant, partially compliant, or non-compliant results. In this way the aspects of the habitat design were examined, including mechanical performance, ECLSS system functionality, lighting performance, noise assessment and thermal performance. Of note, the habitat performed well with no major non-compliance issues.

The experience testing was designed to address two goals: 1). The validation of the design based on the human factors modelling and analysis; and 2). The assessment of the habitat as a functional living and working area. The methodology used was a blind study using a population of participants with a mix of biometric parameters. This population size was 18, giving a level of statistical relevance to the results. The study considered the ergonomic factors of use such as reach, visibility, mobility and comfort perception. The participants were required to fill in a questionnaire specifically gathering data on these aspects of the habitat. Results from this study showed a generally consistent assessment of the performance of the habitat. Most aspects of the usage were deemed to be either good or excellent. The only notable exception was the interface with the ECLSS system, which was found to be more difficult than expected or required. Based on these results, minor changes to the habitat have been planned.

In addition to the statistical study, target scenarios have been played out in the laboratory environment. These have included sleep studies, work simulations, scientific exercise simulations. Again the results from these scenarios have been generally positive.

IX. SHEE exploitation approach

The utilization of SHEE and its simulation capacities are mainly directed towards the scientific community, space agencies, academia and pure outreach activities during exhibitions or fairs, presenting SHEE to a broad public.

SHEE was statically verified against: a) Wind loads, b) Static Internal payloads, c) Lifting Loads (with payload) and d) Transport accelerations. We consider that the Safety Factors adopted and the results of the analysis provided a high margin of safety (at least 1, in the most demanding load case which was identified as being the one related to the transport of the habitat). No fatigue study was made regarding repetitive loading cycles (transport for instance) since stresses are too low to trigger fatigue issues for the foreseen use of the SHEE prototype.

SHEE's main benefit is its transportability. This means that the system can be used in indoor laboratories as well as in exterior environments or even in analogue environments that are equipped with required infrastructure (road, power, sewage). The system endures nominal weather while allowing internal climate monitoring and conditioning. Nonetheless, the endurance of the habitat, which is exposed to repeated stress by a variety of transport systems, will be tested during the future SHEE missions.

SHEE is the only easily transportable habitat simulator on a global scale and its use has to be well planned and considered. SHEE is not meant for a specific mission based on pre-set mission strategies, rather it is modular and can be adapted to a variety of mission scenarios including a greenhouse and an astrobiology laboratory.

In the following two SHEE showcases are presented: the first is a Mars mission simulation in Rio Tinto, Spain, and the second an integration of SHEE into a planned simulation facility at ESA-EAC in Cologne, Germany.

A. SHEE showcase A: Rio Tinto

SHEE will be utilized as a part of the EU-FP 7 project Moonwalk that is to develop and test technologies and training procedures for future human missions to Moon and Mars. Moonwalk will focus on astronaut-robot cooperation applied to Extra-Vehicular Activities (EVA) on planetary surfaces. Two field trials will be conducted as part of project Moonwalk. One will take place in underwater in Marseilles, France in a lunar analogue environment under 1/6th gravity and the other will be conducted in Rio Tinto, Spain an internationally- acknowledged Martian analogue environment. Here, SHEE will reside for two weeks serving as the habitat for the mission simulation. Analog astronauts will start their exploration activities from the habitat through the SHEE suitport which was built and integrated as part of the Moonwalk project. The two components described hereafter are the suitport and the Gandolfi suit to which the interface was fitted.

Figure 17. Suitport mock-up installed on SHEE in the High Bay of the International Space University, credit: International Space University, 2016

1. Rio Tinto component 1: SHEE suitport

A suitport is an interface between a pressurized and a non-pressurized environment. It is a door to the outside from the inside of a habitable space through a spacesuit. The concept was developed as an option to prevent contamination once humans will set foot on Moon or Mars. On Mars, for example, humans are supposed to look for traces of life but need to be careful not to contaminate the samples they are taking with life they brought with them from earth. Therefore, the outside of the suit needs to stay as pristine as possible.

A mock-up suitport is built for SHEE that accomodates the Gandolfi 2 simulation space suit developed by COMEX and described as the second component. This mock-up is connected to the core of the habitat opposite the hatch and in the current configuration allows one Gandolfi 2 suit to dock to the habitat. The simulation astronaut enters through the open backpack of the suit from the inside of the habitat and once in the suit pulls the handles outside SHEE at hands-height, moves the upper torso to the front with a small tilt of the body, unlocks the latch and steps away.

This wall of SHEE where the suitport is installed can be easily exchanged for a variety of experiments and hardware; one example is a suitport, another would be docking another (SHEE) habitat, installing a robotic arm or a sample exchange box. The modular approach of SHEE caters to different set-ups and thus a diverse range of options for extending its simulation capability.

Figure 18. SHEE in Rio Tinto as integrated mission elment with suitport, credit: Bruno Stubenrauch, 2016

Figure 19. Walking tests Calanques National Park in Marseilles, 2016-01-20, credit: COMEX SA, photo: COMEX, 2016

2. Rio Tinto component 2: Gandolfi 2 simulation space suit

In the framework of the Moonwalk project, COMEX has designed and manufactured an EVA training spacesuit that simulates movement constraints of a real pressurized spacesuit. Named Gandolfi 2, this new training suit is designed to perform simulations in both terrestrial and underwater configurations. This last configuration involves a diver with a LSS gear and allows buoyancy adjustment to simulate reduced gravity. The novel training suit is based on the same architecture as the US American Z-series of EVA suits. It is made of an exoskeleton that includes hard-shell elements in composite material and flexible joints, covered with an oversuit. Some Human Machine Interfaces developed by Space Applications and a biomonitoring system developed by Airbus Group will be added to the suit for project Moonwalk simulations. The training suit will be installed on a suitport developed by COMEX that will be integrated into the SHEE panel as mentioned in the previous section.

For terrestrial simulations in Rio Tinto, walking capabilities have been tested in Marseille to obtain an estimation of the Gandolfi 2 operating range for a dry use. The current weight of the suit is 34kg. An undersuit composed of joint protections will be used to soften contacts between the astronaut and the mechanical parts of the suit.

B. SHEE showcase B: ESA Science Operations Laboratory (ESOL)

A second potential utilization of SHEE is in the framework of the European Surface Operations Laboratory (ESOL) at the European Astronaut Centre (EAC) in Cologne, Germany.

The LUNA study (ESA GSP in 2014-2015) identified needs and gaps in worldwide and European analogue capacity, identifying a series of 16 major gaps, and proposed a concept named the European Surface Operations Laboratory (ESOL), which would address these gaps in preparation for European missions to the Moon.

The utilization of the SHEE habitat is at the core of the ESOL concept. SHEE in conjunction with a regolith lunar terrain, simulant with realistic properties, an MCC, communications simulations (delay, bandwidth), relevant environmental characteristics (partial gravity), software for system-level simulations, egress/ingress hardware, and Virtual Reality simulation of realistic views has been identified as a way to address five of the major worldwide and European gaps.

One of the ESOL unique selling propositions is that this Artificial Analogue is designed such that the SHEE habitat is completely integrated with a full motion simulator and the regolith simulant testbed via a suit port module. That is, astronauts can enter/exit the regolith simulant testbed from/to the SHEE habitat or the traverse simulator and perform EVA surface operations activities in their EVA suit mock-ups without having to enter the 'outside world'.

In addition, ESOL is composed of a variety of elements that will work in synergy with existing facilities at the EAC like the Neutral Buoyancy Facility (NBF) and various control rooms and mock-ups, and nearby on the DLR premises, like envihab.

Future enhancements foreseen for SHEE in order to fulfil the requirements of the concept would include the simulation of realistic window views, plug and play interconnectivity to external systems and airtightness.

EAC has as a strategic goal to establish itself as a Centre of Excellence for Astronaut support and operations, Space medicine and Training. The SHEE can support research and testing in those three areas:

- Operations: The SHEE can support simulation campaigns to test operational products (like ODF procedures) and emerging technologies and strategies to support astronauts on their daily activities (like 3D ViT, mobiPV, Oculus applications…); to perform Experiment Sequences Tests for scientific payloads and nominal system maintenance activities; to asses if an operation should be executed by embedded automatic mechanisms, robotic systems, crewmembers or remotely from ground. (e.g. Dust removal or Regenerative Life Support Systems related operations).

- Training: The SHEE habitat could be used to train the astronauts and in particular to verify proficiency training and knowledge retention of practical skills; to assess the requirement of Basic Training needs of the future astronauts; to train Ground Personnel.
- Space Medicine: SHEE can support evaluations of wearable devices utilizations to monitor physiologic parameters; test systems of telemedicine and support the definition of Astronaut's Selection Criteria for the upcoming Moon missions.

X. Conclusion

The EU Framework 7 Programme provided a platform where a consortium within a certain context – in this case analogue technology – could submit a proposal for project. This particular call had 50 times more entries than could be funded. This can be seen as a strong indicator of the demand for a European simulation habitat to fill a gap in European capabilities in preparing for future human missions.

In addition to its capabilities as a spaceflight simulator, SHEE was built to be used in terrestrial extreme environments, e.g. in Antarctica as a research station or as an independent high-tech habitation unit during disaster relief situations. Technology in support of spaceflight which at the same time serves terrestrial purposes.

Through the SHEE design a new typology of a rigid shell-deployable habitat was introduced to the space community which adds to the existing typology of cylindrical and inflatable modules and thus will allow for future comparisons about the relative usability and advantages/disadvantages of this design solution.

SHEE now is ready for the European space community to conduct studies for isolation, habitability, Human Factors and a variety of simulation studies in preparation of future human surface exploration.

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