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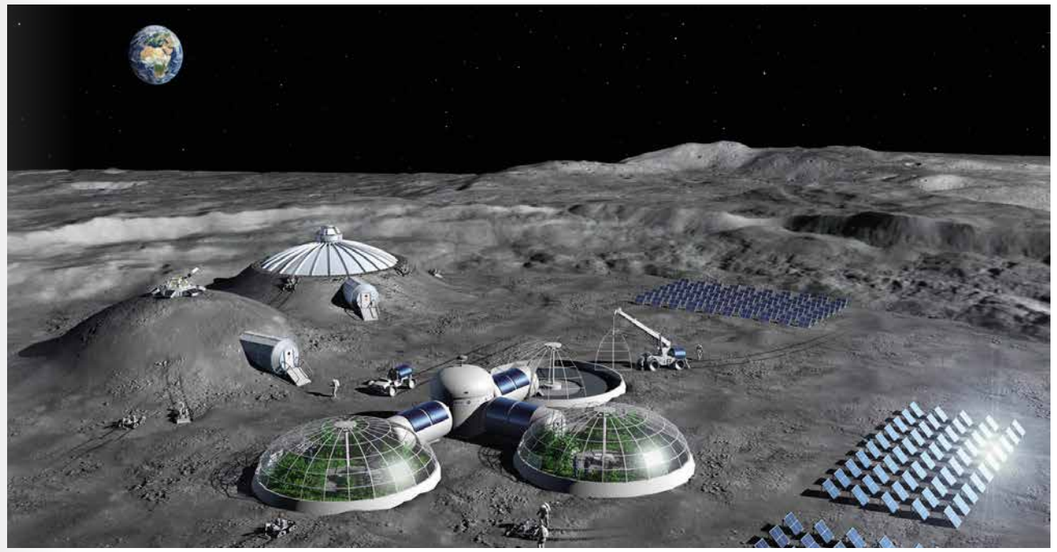
HIGHLIGHTS 2021

YEARLY STATUS REPORT
PLANETARY INFRASTRUCTURES

DLR

Cover: EDEN ISS greenhouse entrance after a stormy night



Future lunar base with solar arrays for energy generation, greenhouses for food production and habitats shielded with regolith
[Source: ESA; P. Carril]

THE YEAR 2021

…and we thought 2020 was crazy! As the pandemic keeps progressing and continuously putting out new variants, we tried to somehow establish a normal work life. Nevertheless, the year 2021 marked the starting point of the group's transformation. Eventually, human space exploration envisions a permanent presence on the Moon and Mars. This paradigm does not only foresee the creation of closed-loop habitats but also the utilization of local resources. This combined approach (reclamation and recycling) is the key for future human space exploration. Therefore, 2021 marked the starting point of expanding the group's research focus to adjoining R&D fields such as In-Situ Resource Utilization (ISRU). In order to manifest this new direction, the research area Planetary Infrastructures will be created. Inside this new organizational structure and besides the already existing EDEN research group, a new research group was created, called Synergetic Material Utilization (SMU), which is led by Dr. Paul Zabel. In the future, the Planetary Infrastructure research area will investigate all aspects of surface-related human activities on the Moon or Mars.

One of the major highlights of 2021 was most certainly the fourth EDEN ISS overwinter campaign in light of the new NASA-DLR collaboration. Within this joint mission, NASA sent one of their plant scientists, Jess Bunchek, to take part in the 2021 Antarctic winter season at Neumayer Station III. With the support of the EDEN ISS mission control center in Bremen, Jess operated the research greenhouse by carrying out daily tasks and multiple scientific activities.

Many more highlights within the group rounded out 2021, such as the new 3D printing farm for advanced rapid prototyping, the re-opening of the DLR laboratory after intensive renovation work, and the successful accomplishment of many milestones within multiple internal and external R&D projects of the group.

Continuing to develop the group's pathway with excitement and motivation by its staff members, guest scientists, and students, we are looking forward to a successful future of human presence on the Moon and Mars!

Dr. Daniel Schubert
Research Area Leader -
Planetary Infrastructures

EDEN ISS “Chimayo” peppers

EDEN ISS greenhouse in Antarctica

PLANETARY INFRASTRUCTURES

For a successful human exploration strategy, resources such as water, oxygen, food, and also rocket fuel, energy, habitat building materials, and many different types of consumables will need to be generated and adequately recycled within future extra-terrestrial outposts. Combining the two approaches reclamation and recycling is the key focus of the Planetary Infrastructures research area. The group is administered by the Department of System Analysis Space Segment (SARA) at DLR Institute of Space Systems in Bremen (Germany). The department operates the Institute's Concurrent Engineering Facility (CEF), as well as the Planetary Infrastructures laboratory, including the Space Habitation Plant Laboratory (EDEN Lab), the ISRU Breadboard (SMU Lab), the 3D Printing Farm, and the EDEN ISS research greenhouse in Antarctica.

DLR Institute of Space Systems, Bremen (Germany)

THE EDEN INITIATIVE

In 2011, the DLR Institute of Space Systems launched its research initiative called EDEN: Evolution & Design of Environmentally-closed Nutrition-Sources. The research initiative focuses on Bio-regenerative Life Support Systems (BLSS), especially greenhouse modules, and how these technologies can be integrated in future space habitats. It is the goal of the EDEN team to further advance the latest cultivation technologies and to adjust these developments into space related applications. Even though present scenarios for future human missions to the Moon and Mars are still several years from coming to fruition, the development of these technologies needs to start today. Only this way, highly-reliable and resource-efficient BLSS will be ready for implementation into the mission architecture for humanity's journey to the Moon and Mars.

SYNERGETIC MATERIAL UTILIZATION

The Young Investigator Group Synergetic Material Utilization (SMU) was founded in 2021, after winning a DLR internal competition. The group focuses on the development of technologies for in-situ resource utilization (ISRU) on the Moon and Mars and how to establish synergies between ISRU and Life-support systems. The group consists of two PhD candidates, several student assistants, and group leader Dr. Paul Zabel. The current research focus is set on three areas: 1) Regolith Beneficiation and Utilization, 2) In-situ Propellant and Consumables Production, and 3) Development of shared ISRU-LSS infrastructures. In the first area, a beneficiation breadboard is under construction to pre-process lunar regolith before utilization. The goal of the second area is the development of a prototype for extracting water from the lunar surface. The third area focuses on a shared water-hydrogen-oxygen infrastructure for a future space habitat. All three areas are of high near-term importance for space exploration and high priorities in European and international roadmaps.

THE RESEARCH TEAM

DR. DANIEL SCHUBERT studied at the Technical University of Berlin and has an engineering diploma in industrial engineering with an emphasis on aerospace and production techniques. In 2011, he initiated the EDEN group at the DLR Institute of Space Systems for technology investigations on Bio-regenerative Life Support Systems and has since served as the team leader of this group. His research expertise is set on habitat interface analysis and plant accommodation and dynamic plant production planning.

DR. PAUL ZABEL studied aerospace engineering at the Technical University of Dresden and has a doctorate from the same university. He joined the EDEN team in 2012. Since 2021, he has lead the Synergetic Material Utilization group at the DLR Institute of Space Systems. Dr. Zabel is also the deputy manager of the Planetary Infrastructures Laboratory. His research expertise is in ISRU research and innovation and also in Life-support systems.

RIEKE FREER is a PhD student working in the Synergetic Material Utilization research group. Her research focuses on a shared hydrogen-oxygen-water infrastructure to exploit synergies between the ISRU and LSS effectively. Before undertaking PhD studies, she completed her Master in process engineering at the Technical University of Hamburg with emphasis on water treatment technologies.

VINCENT VRAKKING studied at the Technical University of Delft in the Netherlands and holds a M.Sc. in aerospace engineering. He began working with the EDEN team on and off in 2012, before joining the team full-time in 2015. Within the EDEN group, he focuses on structure and subsystem design and the development of 3D-printing prototypes.

MARKUS DORN is a horticulture expert and holds a M.Sc. in plant sciences (University of Natural Resources and Life Sciences, Vienna, Austria). He joined the EDEN team in 2017 and consults in horticultural questions. He has evaluated different plant candidates and also developed cultivation methods for fruit trees for use within planetary habitats. His main responsibilities are organizing the EDEN plant laboratory and conducting experiments.

LUCA KIEWIET is a PhD candidate in the Synergetic Material Utilization research group and develops water extraction methods for the Moon and Mars. He holds a 2nd-level Masters degree in Space Systems Engineering from the Politecnico di Torino and a double degree in Space Science and Technology from Luleå University and Université Paul Sabatier Toulouse. He joined DLR in 2021. His expertise is ISRU and space mechanisms.

JESS BUNCHEK is a plant scientist at NASA Kennedy Space Center, Florida (USA). She is a visiting guest scientist at DLR, who joined the EDEN team in July 2020. Her visit is part of the larger collaboration agreement between NASA and the EDEN group for advancing the knowledge of plant cultivation in space. She will be the on-site operator of the EDEN ISS research facility at Neumayer Station III in Antarctica for the 2021 isolation campaign.

CONRAD ZEIDLER has been a member of the EDEN research team since January 2011. For his industrial engineering diploma at the Technical University of Braunschweig, he specialized on aerospace engineering and has profound knowledge of trade-off analysis techniques (e.g. AHP). He is an expert in simulation methods and control software. Within EDEN, he is responsible for monitoring and controlling the plant growth and environmental parameters.

KARTHI SAVUNDARARAJAN is a student assistant and studies industrial engineering and production technology at the University of Bremen. He joined the EDEN team in mid-2020 and supports the team in organizing the laboratory and is involved in multiple projects. Karthi is also responsible for the 3D-printing farm, overseeing the production of different prototypes.

AYLIN BAYLAN studies communication and media at the University of Bremen. She joined the EDEN team in July 2021 as a student assistant and supports the team in tasks regarding PR and outreach. Her daily work routine includes different organizational processes such as contacting interested persons, collaboration partners, and PR teams from other DLR departments. Her area of responsibility also includes supporting several social media accounts and overseeing the yearly report.

CHRISTIAN SCHNORR studied Food Technology at the University of Applied Sciences in Fulda and currently holds a M.Sc. in food processing. He is a guest scientist within the EDEN group and is currently working on his PhD thesis investigating the utilization of inedible biomass from plant cultivation by rearing mealworms (Tenebrio molitor, L.), including efficient ingestion, digestion, mass gain and fiber reduction.

DR. LUIGI GIUSEPPE DURI is working at the Department of Agriculture of The University of Naples Federico II (Italy). During his Ph.D., he was focusing on In-Situ Resource Utilization for food production in space. He is a horticulture expert, and his studies are focused on the reuse of different waste streams from a BLSS system to improve the growth features of Lunar and Martian “soils”. During his time as a guest scientist at DLR (Oct.-Dec. 2021), he was involved in the MEPA project.

MAINTENANCE MISSION

FOURTH SUMMER SEASON IN ANTARCTICA

The 2020/21 Antarctic summer season was unlike any other. With the ongoing global pandemic, flights from South Africa to Antarctica were not an option. Instead, the Alfred-Wegener-Institute organized to transport a small summer team directly from Germany to Antarctica onboard the research vessel Polarstern. After a hotel quarantine in Bremerhaven, the summer team left Germany on the 20th of December 2020. The four-week journey across the Atlantic and Southern Oceons ended on the 19th of January 2021, when Polarstern began unloading people and cargo to the shelf ice - a short distance away from Neumayer Station III.
Once on-site, NASA guest scientist Jess Bunchek and Vincent Vrakking (DLR), began preparing the EDEN ISS research greenhouse for the upcoming 2021 isolation phase. Among the work which had to be done was a leak repair of the LED thermal cooling loop, as well as adjusting the plant cultivation rack setup in the main cultivation room. While carrying out the various cleaning, maintenance, and repair tasks, hands-on training was completed to prepare Jess Bunchek for her role as greenhouse operator during the 2021 winter season.

Jess Bunchek preparing the Plant Cube for return shipment to Germany

The Polarstern research vessel departing the Antarctic

EDEN ISS equipment and consumables stored in the Neumayer Station III gallery

Passengers unloading from Polarstern onto the Antarctic ice

Jess Bunchek participating in a safety drill on the Polarstern during transit to the Antarctic

Safety first. Vincent Vrakking wearing a helmet for a Skidoo trip in the Antarctic

The 41st Overwintering team was (from left to right):
Front row: Linda Ort, Theresa Thoma, Timo Dornhöfer, Jess Bunchek. Back row: Florian Koch, Tanguy Doron, Peter Jonczyk, Paul Ockenfuss, Markus Baden, Lorenz Marten.

A helicopter returning to land on Polarstern following an exploration flight

HIGHLIGHTS 2021

A beautiful view of EDEN ISS (the safety guideline is visible on the left) and the Antarctic landscape from Neumayer Station III

Markus Dorn working in the Planetary Infrastructures Laboratory

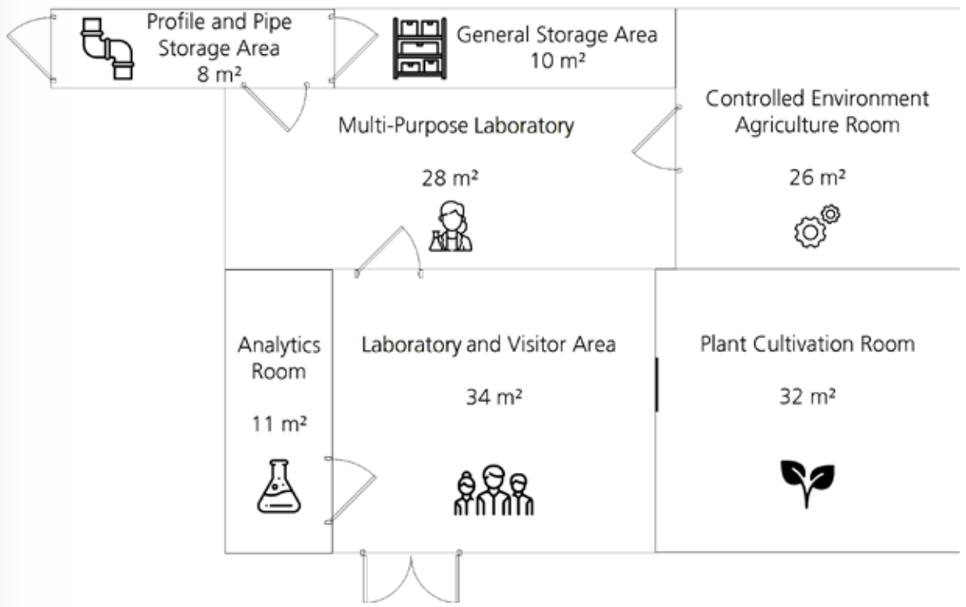
THE NEW LABORATORY

OUR LABORATORY SHINES IN A NEW FORM

Huge effort was made to upgrade the old EDEN laboratory to the newest standards concerning work and fire safety regulations and get it ready for a new phase of technology development in the domain of human spaceflight systems. The original laboratory area has almost doubled in size from its original 75 m² up to 150 m². Next to the already existing laboratory spaces (e.g. analyzing room, visitor & media area room, main cultivation room), a new multi-purpose laboratory area was created with several work benches in order to carry out the upcoming ISRU (In Situ Resources Utilization) experiments. The former Closed-Loop-Test-Facility (CLTF) was expanded and a dedicated Controlled Environment Agriculture (CEA) control room was created. This laboratory room houses all CEA breadboards which are connected with the adjoining cultivation room. Fast and direct access to the various CEA systems is now possible without entering the main cultivation room.
In addition, a new laboratory air supply and distribution system was implemented in the infrastructure, and the complete laboratory floor was sealed with a two-component epoxy layer and additionally outfitted with an ESD standard for electrostatic dissipation.

CEA control room prior to outfitting

Multi-purpose lab area prior to outfitting



Floorplan of the new Laboratory

Jess Bunchek enjoying a moment inside the EDEN ISS greenhouse

EDEN ISS: THE JOINT DLR-NASA MISSION

NASA GUEST SCIENTIST JESS BUNCHEK OVERWINTERS IN ANTARCTICA

For the second time, after 2018, the Neumayer Station III overwintering crew in 2021 included an extra overwinter crew member, dedicated solely to the operation of the EDEN ISS research platform. Jess Bunchek, a guest scientist from NASA, travelled to Antarctica and stayed there throughout for all of 2021 and early 2022, isolated from the world outside Antarctica. Aside from general station keeping tasks, and an array of experiments in which all winter crew members participate, Jess' primary tasks involved operating the greenhouse and carrying out an ambitious science program which had been defined by NASA and DLR prior to the mission.
With an even larger variety of available crop types and cultivars (e.g. dedicated NASA seeds), a novel plant cultivation system developed by NASA, new psychological questionnaires, and a fresh supply of plant and microbial sampling equipment, Jess worked to gather valuable data for future space-based plant cultivation systems. As in the years before, a positive side effect was the provision of fresh food to the crew of Neumayer Station III. After an uncommonly cold winter season, with record-breaking storms and dramatic activity, Jess is scheduled to return from Antarctica in February 2022.

Jess Bunchek while "Amoroso" tomato harvest and pruning

Jess Bunchek in the Antarctic storm on her way to the EDEN ISS greenhouse

Portrait of Jess Bunchek in Antarctica

Very first sunlight on the EDEN ISS greenhouse after the Polar Night

Jess Bunchek appreciating the intoxicating smell of thyme

Mizuna harvest with Jess Bunchek and Timo Dornhöfer

Salad Buffet in Neumayer Station with Lettuce from the EDEN ISS greenhouse

EDEN ISS cucumbers

EDEN ISS ‚PAT orange' (left) and ‚Joy Red' (right) cherry tomatoes

All 4 pepper cultivars from the EDEN ISS greenhouse ready to eat

Jess Bunchek harvesting Mizuna

Frozen surface of the thermal control piping system on the roof of the EDEN ISS greenhouse

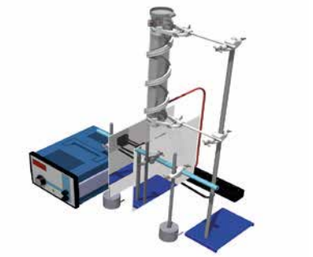
Jess Bunchek in the Neumayer Station showing fresh EDEN ISS greenhouse lettuce

Freezers from Antarctica are ready to go to ship

Frozen EDEN ISS harvest from Antarctica

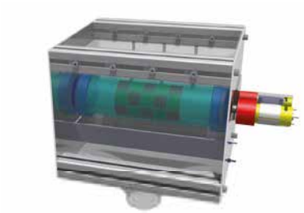
HIGHLIGHTS 2021

EDEN ISS Chimayo peppers that were harvested in the EDEN ISS greenhouse during isolation phase 2021



Electrostatic separation component of the Regolith beneficiation experiment

Vibratory sifter for particle size separation in the Regolith beneficiation experiment



Magnetic separation component of the Regolith beneficiation experiment

SYNERGETIC MATERIAL UTILIZATION

A NEW RESEARCH GROUP – THE FIRST YEAR

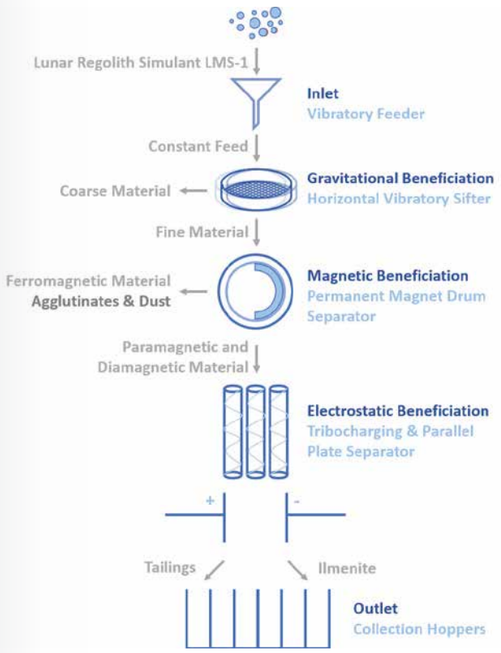
The development of a laboratory test stand for the beneficiation of lunar regolith simulants was one of many important activities within the scope of the SMU research group in 2021. Over the course of six months, a vague idea was transformed into a solid concept, and eventually turned into a detailed design. The test stand employs three different beneficiation stages (gravitational, magnetic, and electrostatic separation) in order to reliably and efficiently concentrate an ilmenite-rich feedstock (regolith), that is chemically and physically suitable for further ISRU steps.

Furthermore, laboratory experiments were started to explore the behavior of lunar regolith simulants in aqueous solutions. The goal of these experiments is to get a better understanding of how lunar regolith might react when coming in contact with water, for this can happen when extracting water from the lunar surface. This extracted water needs to be purified to ensure proper conditions for subsequent processes. Consequently, a profound understanding of the behavior of lunar regolith and its constituents in water is necessary to ensure a reliable water treatment system. Future plans are to test various water treatment systems on their capabilities to purify lunar raw water.

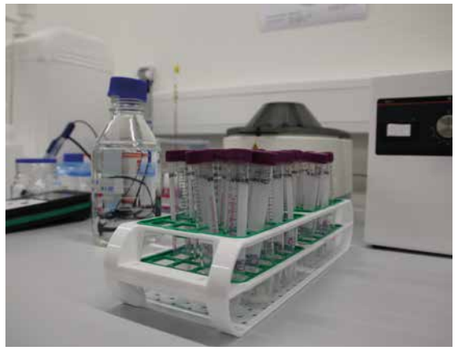
Another activity that started in 2021 is the development of a water extraction process for the deployment on the Lunar surface. Initial concepts have been created, but since this activity only started in the last quarter of 2021, no details can be described yet.

CAD model of the multi-stage Regolith beneficiation experiment

Rieke Freer running experiments in the new laboratory

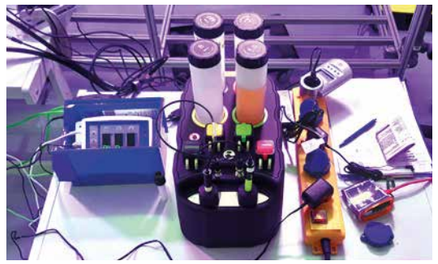


Schematic of the different beneficiation steps incorporated in the experiment setup for regolith beneficiation



Test tubes for experiments in the laboratory

Markus Dorn inspecting the MEPA plants



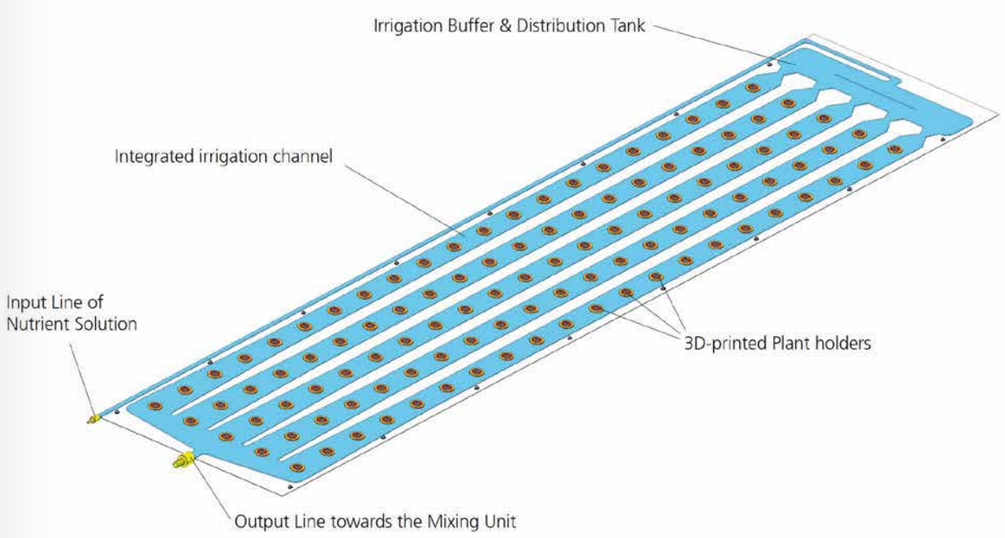
A preview of the nutrient delivery system

Lettuce growing on prototypes of the Seed Cultivation Mat (SCM)

THE EMERGENCY FOOD PROVISION SYSTEM: MEPA

THE PROTOTYPE STARTS TO TAKE SHAPE

The EDEN group made significant progress in the development of its rapid deployable plant cultivation system, MEPA, which is intended to assist in restoring food production and food security in disaster areas as well as refugee camps.
In 2021, a number of prototypes were developed of the Seed Cultivation Mat (SCM), which will serve as the low-weight, deployable, plant irrigation system. Multiple plant cultivation experiments (lettuce) were carried out, within the upgraded main cultivation room of the laboratory, to assess and optimize the performance and design of these SCMs. Furthermore, the design of the automated support unit, which will supply the SCMs with water and nutrients, was finalized. Assembly, integration, and testing of this support unit will start in the first quarter of 2022, before testing of the overall system in a relevant environment in the Middle East/ North Africa region.



Graphic Illustration of the SCM

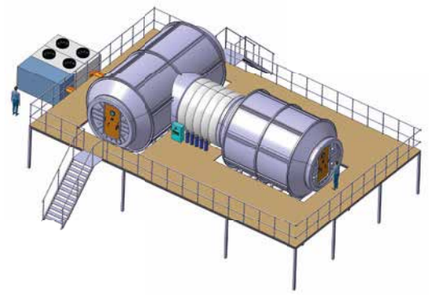
First true leaves emerging from the growth media

Lettuce growing on prototypes of the Seed Cultivation Mat (SCM)

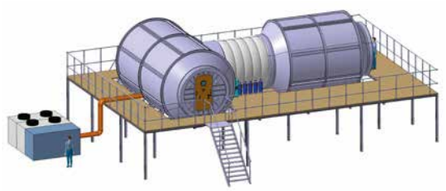
Markus Dorn measuring the light intensity on the SCM

HIGHLIGHTS 2021

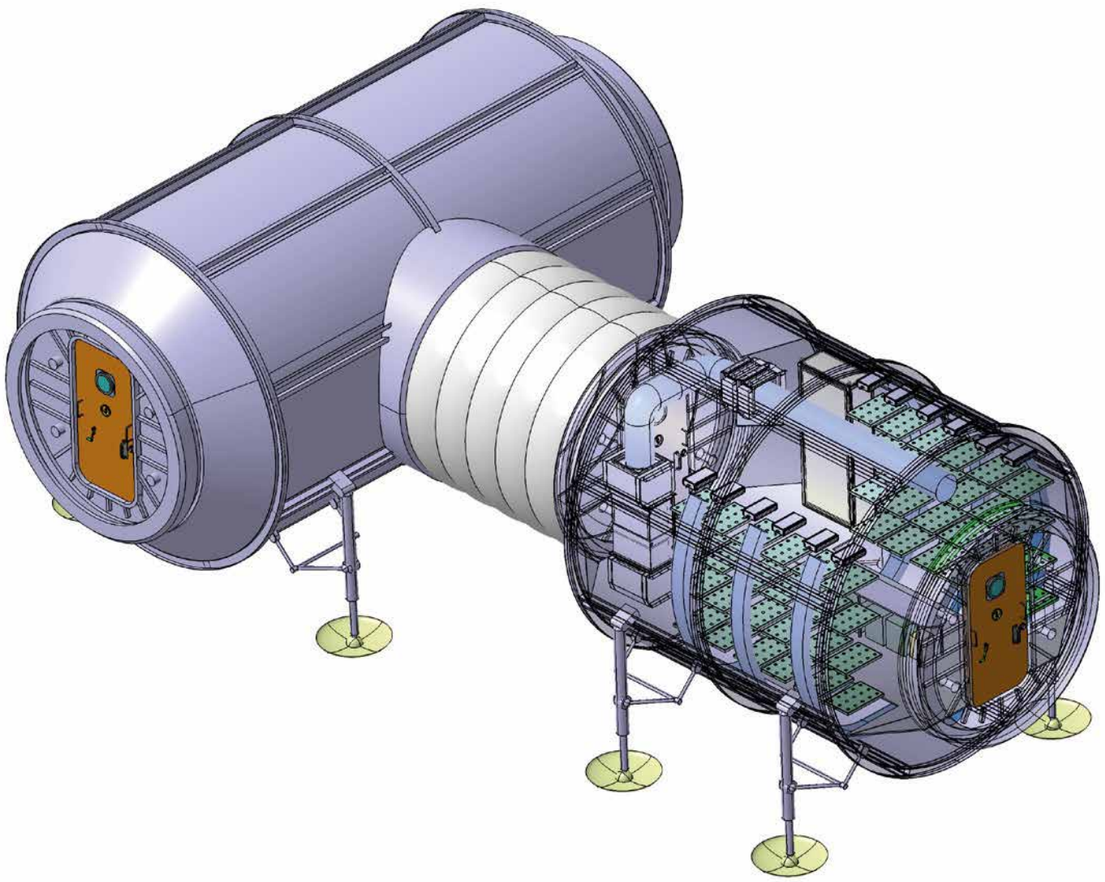
MEPA lettuce harvest from the Seed Cultivation Mat (SCM). This mat has been developed by DLR, using an inflatable Nutrient Film Technique (NFT) system.



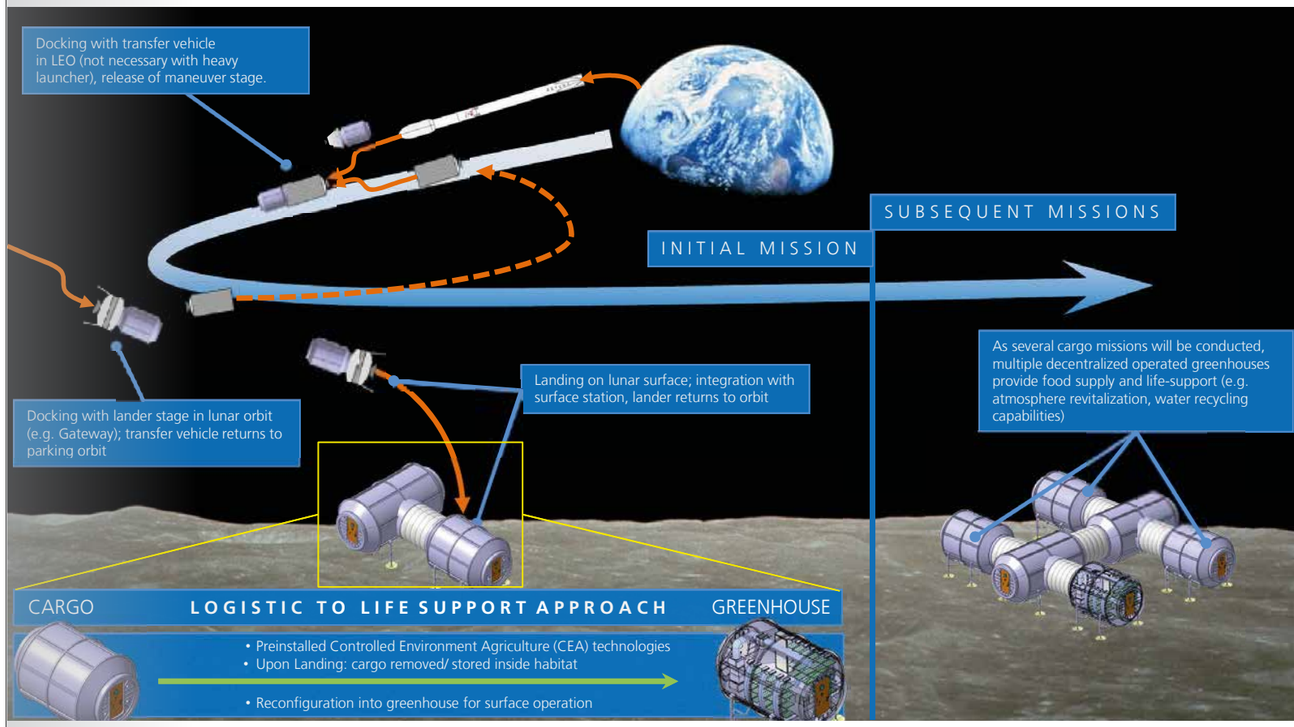
The EDEN NEXT Gen greenhouse demonstrator connected to a habitat demonstrator on a test platform



A CAD model image of the envisioned green-house demonstrator test set-up



A view of the greenhouse demonstrator interior, while connected to a habitat demonstrator

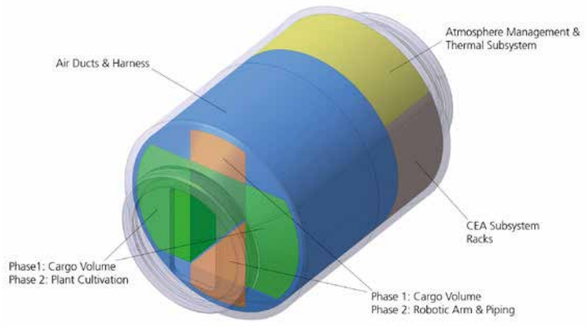


A schematic depiction of the logistics-to-living mission scenario of the EDEN NEXT Gen lunar greenhouse

ROADMAP FOR BIO-REGENERATIVE LIFE SUPPORT

DEVELOPMENT OF THE GROUND DEMONSTRATOR BEGINS

As outlined in the 'Roadmap for the development of Bio-regenerative Life Support Systems (BLSS)', in 2021 the development process of the EDEN NEXT Gen ground demonstrator began with the definition of the mission objectives, followed by a detailed functional and requirement analyses.
Based on discussions with international partners, as well as considering the likely development pathway of a crewed lunar mission, several design changes were made to the original greenhouse design. The main design decision was made to develop a rigid module in favor of the original hybrid (rigid /inflatable) design. Along with this rigid module, the team settled on a logistics-to-living approach, where the rigid module will initially serve as a cargo transport unit for resupplying a potential human outpost. Once emptied, the former cargo module shall be transformed (with minimal outfitting efforts) into a greenhouse module, providing essential life support functions to the habitat.
Furthermore, initial considerations with respect to the test campaign were discussed. Foreseen is a simplified habitat simulator which will be connected to the greenhouse ground demonstrator in order to simulate all necessary interfaces, in particular gas exchange, between the greenhouse and the future habitat.



A volume allocation of the greenhouse interior for initial design discussions

MEALWORMS IN SPACE

USING MEAL WORMS FOR INEDIBLE BIOMASS PROCESSING

As a guest scientist, Christian Schnorr joined the EDEN group in 2020 (Further information on page 6). He investigates the general use of mealworms within future life support systems. Current studies focus on the utilization of inedible biomass from plant cultivation by rearing mealworms (*Tenebrio molitor, L.*), including efficient ingestion, digestion, mass gain, and fiber reduction. Mealworms are held in stainless steel containers within a climate chamber at controlled temperature, humidity, and photoperiod. Preliminary experiments showed that a salad root diet increased mealworm mass gain compared to the standard feed wheat bran. Further results aim to substitute wheat bran and find optimal proportions of ingredients available in currently planned Bio-regenerative Life Support Systems (BLSS). Results from these studies can then be used to evaluate rearing of mealworms within a BLSS to improve waste management by degrading fiber, providing "animal" protein, as well as possibly supplying fertilizer through insect frass.

Newly hatched larvae at 3.75x zoom under a laser scanning microscope

Light climate chamber with cultivation units made out of stainless steel; Right: Christian Schnorr holding a single larva

Matured beetles on wheat bran

Freshly harvested salad roots during preparation as feed

Static larvae in preparation for pupation, pupae and a freshly hatched beetle

Different life stages of *Tenebrio molitor*

HIGHLIGHTS 2021

Larvae and pupae on partially digested salad roots

NEW COLLABORATION WITH PRIVA

NUTRIBATCH: A UNIQUE PROTOTYPE FOR MONITORING AND MAINTAINING HYDROPONIC NUTRIENT SOLUTION

After more than one year of a successful design & development phase in collaboration with the global technology company Priva, two new prototypes of a nutrient mixing system were finally delivered and stationed at DLR Bremen. Located in the Netherlands, the company Priva is the world leader in horticultural technologies in climate control, energy saving, and optimal water usage in commercial greenhouses.
Within the design process, Priva's Nutribatch system was downscaled so that it can be used for more small-scale applications such as EDEN plant cultivation experiments, as well as for future greenhouse applications on the Moon and Mars eventually. The two breadboard prototypes are designed to fit on a frame the size of a Euro pallet - the systems were installed in the new CEA control room of the laboratory and are prepared for the upcoming trial and optimization period.

New prototypes of the nutrient mixing system

PRIVA-DLR collaboration- left to right: Daniel Schubert (DLR), Markus Dorn (DLR), Edgar Konijnendijk (PRIVA), Ruben Oosterwijk (PRIVA), Jan Westra (PRIVA)

Overview of Print Farm

3D PRINT FARM

FAST R&D THANKS TO RAPID PROTOTYPING

The printing farm originated during the early days of the pandemic. In 2020, a highly motivated team of DLR members were involved in the containment of the COVID-19 pandemic by producing special face masks for the local crisis teams of the state of Bremen (e.g. hospitals, firefighters, and police). More than 100 face masks could be produced per day within DLR's main satellite integration hall. Resulting from this ad-hoc support effort, the idea of a centralized 3D print farm was launched in 2021 by the departments System Engineering & Project Office as well as the Planetary Infrastructure Group (EDEN & SMU).
The 3D print farm uses fused deposition modeling (FDM)
The 3D print farm uses fused deposition modeling (FDM)
3D printers. At present, two different models are used: 5x Ultimaker III Extended with a build space of 21.5 x 21.5 x 30 cm and 4x Artillery Sidewinder X1 with a build space of 30 x 30 x 40 cm. In the near future, the print farm will be expanded with a large-format 3D printer, with a build space of up to 100 x 100 x 100 cm. This way, the group is able to produce larger components such as interior structures, custom-designed water tanks, or complex holding mechanisms.
So far, the 3D print farm has already contributed to many internal and external research projects of the group and also provides rapid prototyping services to other DLR research departments.

Modix Big Meter with a print surface of 1010 x 1010 x 1010 mm

Several prototypes produced by 3D printer

FURTHER HIGHLIGHTS

MORE HAPPENED DURING THE YEAR – FIND OUT WHAT:

Small-scale growth chamber inside the Botanika exhibition

BOTANIKA

Since 2019 the Botanika (Bremen) hosts the ongoing exhibition ‚Plants in Space' in its Open Laboratory. Different challenges of space greenhouses, the analogue test campaigns of the EDEN group, and future vertical farming projects are featured in this exhibition room. A main component is the small-scale growth chamber that illustrates the technologies used in the EDEN ISS greenhouse in Antarctica. During 2021 numerous crops have been successfully grown, and the chamber is always a highlight for visitors at the Botanika exhibition.

INTERCHANGE CANADA

In March 2021, Conrad Zeidler (EDEN group) joined the Space Exploration Strategic Planning team at the Canadian Space Agency (CSA) within the framework of Interchange Canada. At the CSA, he mainly worked on the Naurvik Initiative and as the technical lead on CSA's Deep Space Food Challenge. In addition, Conrad is coordinating the collaboration between DLR's BLSS Roadmap and the CSA Food Production Initiative

Recycled shipping containers in Gjoa Haven, Nunavut, were retrofitted to grow fresh produce all year round within the frame of the Naurvik project.
(Credit: Arctic Research Foundation)

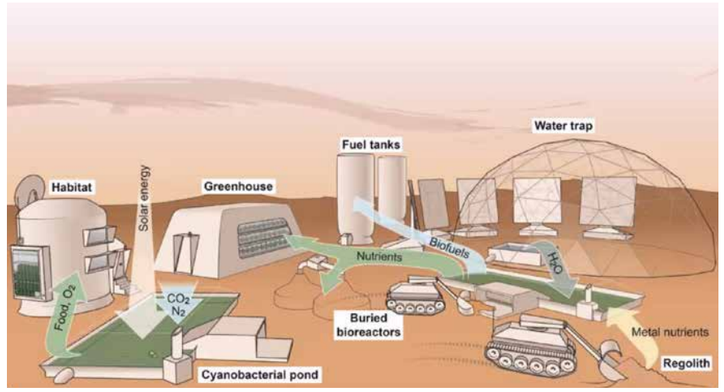
Special plant cultivation holders for the greenhouse of Cubes Circle

CUBES CIRCLE

The EDEN group is always looking to expand its network of partners across industry, research, and academia - both nationally and internationally. One such unique collaboration is the CUBES Circle project under the direction of Humboldt University in Berlin, where the EDEN group joined the research consortium in 2021. Here, the group designed special plant cultivation holders and produced over 100 copies within its new 3D print farm. The 3D printed cultivation holders are planned to be integrated into the closed-loop greenhouse system of the research group.
https://cubescircle.de/en/

MAPEX

"Setting the ground for sustainable bio-production in a Martian settlement" is the title of the seed project organized within the MAPEX initiative of the University of Bremen. Under the leadership of Dr. Cyprien Verseux (ZARM, University of Bremen), Prof. Dr. Sven Kerzenmacher of the Environmental Process Engineering (UFT, University of Bremen), and the EDEN group, the focus of this new project is to analyze different options to combine cyanobacteria, Microbial Electrochemical Systems (MES), and higher plants. Different possibilities will be investigated in order to utilize Martian soil for various bioprocesses. The project will start in early 2022 with a duration of three years.



Envisioned Martian infrastructure elements of the Mapex project

EDEN for Kids School Project with plants

EDEN FOR KIDS: KICK-OFF IN FIVE DIFFERENT HIGH SCHOOLS

The EDEN for Kids project, which is organized by the DLR_School_Lab in Bremen, is the main public outreach project of the EDEN group, teaching about different aspects of plant cultivation in space. In 2021, dedicated plant cultivation experiment kits were distributed to five high schools in Bremen and Osterholz-Scharmbeck. Despite the pandemic, DLR_School_Lab was able to switch to a hybrid mode with presence and online sessions so that the project could be completed safely and successfully. The school students used plant systems in the schools and went through a number of different research phases.

UNIVERSITY LECTURE

In 2021, Dr. Daniel Schubert and Dr. Paul Zabel held the lecture "Human Space Exploration and Habitation" at the University in Bremen with 70 students attending.
Furthermore, Dr. Daniel Schubert also held the lecture "Bemannte Weltraumexploration und Habitate" at the Chair of Space Systems under the leadership of Prof. Dr. Martin Tajmar at the TU Dresden with over 120 students attending.

KEY FIGURES - 2021

JOURNALS

Maiwald, V., Schubert, D., Quantius, D., Zabel, P. (2021) From space back to Earth: supporting sustainable development with spaceflight technologies. Sustainable Earth, 4 (4). BioMed Central. doi: 10.1186/s42055-021-00042-9. ISSN 2520-8748.

Zeidler, C., Woeckner, G., Schöning, J., Vrakking, V.,Zabel, P., Dorn, M., Schubert, D., Steckelberg, B., Stakemann, J. (2021) Crew time and workload in the EDEN ISS greenhouse in Antarctica. Life Sciences in Space Research. Elsevier. doi: 10.1016/j.lssr.2021.06.003. ISSN 2214-5524.

Nesteruk, S., Shadrin, D., Pukalchik, M., Andrey, S., Conrad, Z., Zabel, P., Schubert, D. (2021) Image Compression and Plants Classification Using Machine Learning in Controlled-Environment Agriculture: Antarctic Station Use Case. IEEE Sensors Journal, 1 (1). IEEE - Institute of Electrical and Electronics Engineers. doi: 10.1109/JSEN.2021.3050084. ISSN 1530-437X.

Poulet, L. B., Zeidler, C., Bunchek, J., Zabel, P., Vrakking, V., Schubert, D., Massa, G. D., Wheeler, R. (2021) Crew time in a space greenhouse using data from analog missions and Veggie. Life Sciences in Space Research. Elsevier. https://doi.org/10.1016/j.lssr.2021.08.002. ISSN 2214-5524.

PEER-REVIEWED CONFERENCE PROCEEDINGS

Rettberg, P., Fahrion, J., Zabel, P., Schubert, D. (2021) The Microbiome of a Greenhouse for Ground Demonstration of Plant Cultivation Technologies in Space, COSPAR 2021, 28. Jan - 4. Feb 2021, Sydney, Australia and Virtual Event (Hybrid).

Fahrion, J., Fink, C., Zabel, P., Schubert, D., Houdt, R., Leys, N., Eikmanns, B., Beblo-Vranesevic, K., Rettberg, P. (2019) Microbial Monitoring in the EDEN ISS greenhouse, a mobile test facility in Antarctica. 4th Human Physiology Workshop 2019, 7. Dez. 2019, Cologne, Germany.

Fahrion, J., Fink, C., Zabel, P., Schubert, D., Beblo-Vranesevic, K., Hellweg, C.E., Eikmanns, B., Rettberg, P. (2019) Microbial Monitoring in the EDEN-ISS Greenhouse, a Mobile Test Facility in Antarctica. EANA 2019, 3 – 6 September 2019, Orléans, France.

Zeidler, C., Woeckner, G.(2021) Using Augmented Reality in a Planetary Surface Greenhouse for Crew Time Optimization. Space ACM CHI Conference on Human Factors in Computing Systems 2021: Workshop on Human-Computer Interaction for Space Exploration, 14.05.2021, Virtual Conference.

INVITED TALKS

Schubert, D.: „EDEN ISS – The Antarctic Space Greenhouse and its Terrestrial Spin-offs“, Space2Agriculture workshop, 17.05.2021, online

Schubert, D.: „MEPA - Mobile Deployable Plant Growing Device“, 31.03.2021, International Astronautical Federation, Aerospace Technologies in support of Humanitarian Aid, Online Workshop: https://youtu.be/wsYGwcfkbzE 31.03. IAF Vortrag

Schubert, D.: „EDEN ISS: Analogue Testing of Plant Cultivation Technologies for Space „, 20.04.2021, Institut für Luft- und Raumfahrttechnik, Online Seminar

Schubert, D.: „Bioregenerative Life Support & Greenhouse Modules I & II“, HSF 27, SpaceTech Master, Graz University of Technology, Online Lecture

Schubert, D.: „EDEN ISS: Analogue Testing of Plant Cultivation Technologies for Space“, 13.01.2021, University of Applied Sciences Dresden, Faculty for Agriculture/ Environment/ Chemistry, Online Lecture

Schubert, D.: „Assessment of extraterrestical greenhouses - Transferring space-related systems to terrestrial applications“, 26.04.2021, Department Chemical Process Engineering, Faculty of Production Engineering, University of Bremen, Online Workshop

Zeidler, C.: „EDEN ISS Lessons Learnt“, Agriculture and Agri-Food Canada; AAFC Internal Greenhouse Workshop, 06.05.2021, Online.

Zeidler, C.: „EDEN ISS Lessons Learnt“, National Research Council Canada, NRC Internal Greenhouse Workshop, 08.06.2021, Online.

Zeidler, C.: „Panel Discussion and Breakout Session. Food for the Next Frontier“: NASA & CSA Food for Space Workshop, 23.06.2021, Online.

Güne Lunge im Ewigen Eis; BNI, 16.09.2021; bremen,
Zabel, P.: „Gebäudeintegrierte Pflanzenanbausysteme - Beispiel EDEN ISS“, in Emerging Fields in Architecture, Technical University Vienna, 12.10.2021.

Zabel, P.: „Introduction to In-Situ Resource Utilization“, in Bemannte Weltraumexploration und Habitate, Technische Universität Dresden, 13.12.2021.

Schubert, D.: „EDEN ISS - Analogue Testing of Plant Cultivation Technologies for Space“, University of Kassel, H21 Tutorium Bodenfruchtbarkeit und Nährstoffkreisläufe, 21.06.2021, (invited talk)

Schubert, D.: „EDEN ISS - Analogue Testing of Plant Cultivation Technologies for Space“, Fakultät Kunst und Gestaltung, Bauhaus-Universität Weimar, 22.06.2021, (invited talk)

DIPLOM-/ MSC.-/ BSC.-THESIS

Volling, N.: „Entwicklung und Auslegung einer Saatgut-Matte mit der Nährstoff-Film-Technik als Bewässerungsmethode für eine mobile entfaltbare Pflanzenanbaueinheit“, Abteilung Maschinenbau; Fakultät 5 Natur und Technik, Hochschule Bremen; Bachelor Thesis; 2021.

Schroth, J.: „Development of the Atmosphere Managemnet System of the EDEN Next Gen Greenhosue Module for long-term space missions“, Institut f. Luft- und Raumfahrttechnik, Technische Universität Dresden, Diploma Thesis, 2021

Brück, K.: „Augmented Reality in Verbindung mit dem Einsatz von Einarmrobotern zur Unterstützung der Pflanzenkultivierung im EDEN ISS Gewächshaus“, Fachbereich 2, Umweltinformatik, Hochschule für Technik und Wirtschaft Berlin, Bachelor Thesis, Institute for Space Systems, 2021.

Steinert, S.: „Development of a digital twin of the DLR EDEN ISS greenhouse for data enabled analysis“, Technical University Darmstadt, March, 2021.

Guerrero, F.: „Analysis of an In-Situ Material Production Concept for Potential Thermal Applications in a Lunar Mission“, Technical University Munich, 2021.

Caesar, P.: „Design of the Nutrient Delivery System for the EDEN NextGen Greenhouse Module“, Delft University of Technology, December 2021

INTERNAL/ EXTERNAL RESEARCH REPORTS

Schubert, D., Bamsey, M., Zabel, P., Zeidler, C., Vrakking, V., Dong, C.(2017): „Yearly Report 2016- Yearly Status Report EDEN Initiative“, German Aerospace Center, Institute od Space Systems, Department of System Analysis Space Segment.

Schubert, D., Bamsey, M., Zabel, P., Zeidler, C., Vrakking, V. (2018): „Yearly Report 2017- Yearly Status Report EDEN Initiative“, German Aerospace Center, Institute od Space Systems, Department of System Analysis Space Segment.

Schubert, D., Zabel, P., Zeidler, C., Vrakking, V. (2019): „Yearly Report 2018- Yearly Status Report EDEN Initiative“, German Aerospace Center, Institute od Space Systems, Department of System Analysis Space Segment.

Schubert, D., Zabel, P., Zeidler, C., Vrakking, V. (2020): „Yearly Report 2019- Yearly Status Report EDEN Initiative“, German Aerospace Center, Institute od Space Systems, Department of System Analysis Space Segment.

Vrakking, V., Schubert, D., Zabel, P., Zeidler, C., Dorn, M., Ferl, R., Paul, A. (2021) EDEN ISS - Greenhouse in Antarctica. Chapter in Expeditions to Antarctica: ANT-Land 2020/21 Neumayer Station III, Kohnen Station, Flight Operations and Field Campaigns Reports on Polar and Marine Research, 758. Seiten 59-66. doi: 10.48433/BzPM_0758_2021. ISSN 1886-3192.

Schubert, D., Zabel, P., Zeidler, C., Vrakking, V. (2021): „Yearly Report 2020- Yearly Status Report EDEN Initiative“, German Aerospace Center, Institute od Space Systems, Department of System Analysis Space Segment.

SPECIAL

Zabel, P. ‚Member of the ICES International Committee and co-chair of session 204 ‚Bioregenerative Life Support‘

Schubert, D., Zabel, P.: „Human Space Exploration & Habitation“, lecture, Elective module, Space Master, SS2021, University of Bremen

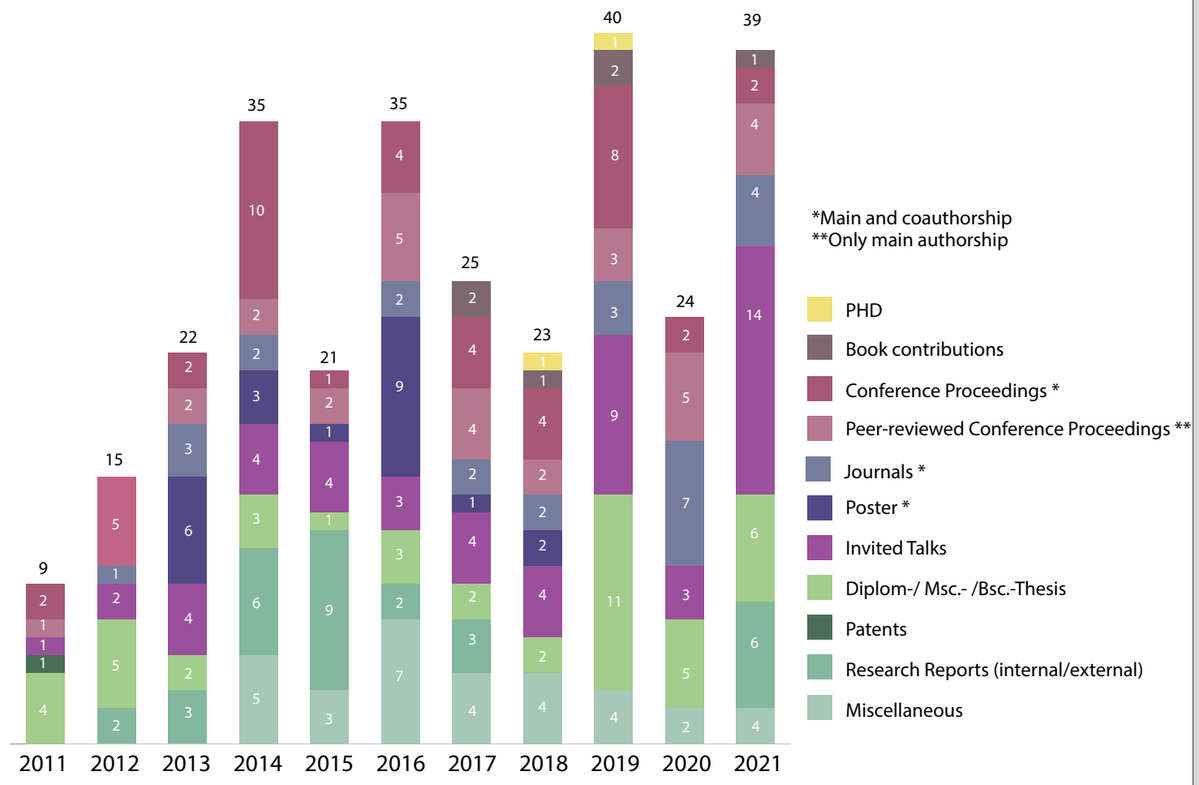
Schubert, D.: „Bemannte Weltraumexploration & Habitate“, lecture, Studium Generale, WiSe2021/22, Technical University of Dresden

BOOK CONTRIBUTION

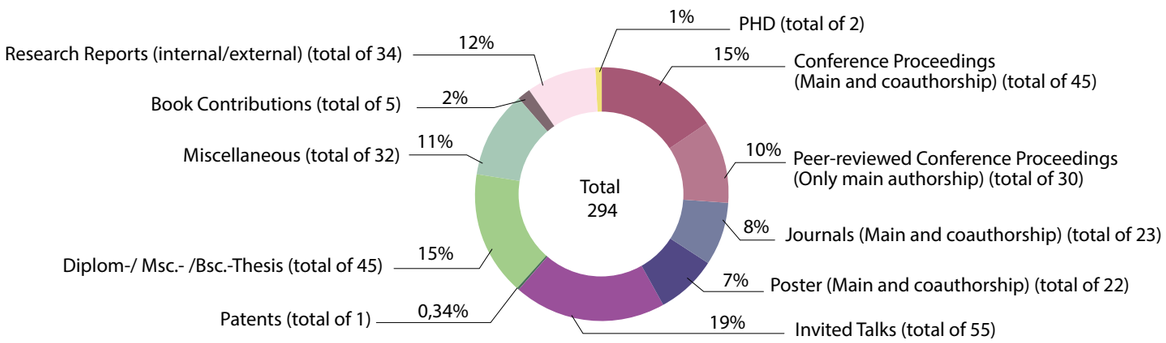
Schubert, D. (2021) Hydroponics. Greenhouses in the Extreme. In: Antarctic Resolution Lars Müller Publishers. Seiten 577-579. ISBN 978-3-03778-640-6.

SUMMARY KEY FIGURES (2011-2021)

PUBLICATIONS & KEY FIGURES 2011-2021



TOTAL PUBLICATIONS & KEY FIGURES 2011–2021



THE STUDENTS OF PLANETARY INFRASTRUCTURES

Without the assistance and help of highly-motivated students, the success of the EDEN Initiative would not have been possible! Therefore the entire EDEN team would like to say thank you. See below what the student's tasks were and what they are doing now:

CHRISTOPHER BRYSON was an intern within the EDEN ISS project as part of his SpaceMaster program, a dual-degree study in Space Science and Technology carried by Luleå University in Kiruna, Sweden and Paul Sabatier in Toulouse, France. His tasks included the setup of a new lab environment at the DLR institute, and the further testing and development of the MEPA project. Furthermore, he organized the control room visualization tool receiving images and live data from the EDEN ISS greenhouse in Antarctica.

KARLA BRÜCK studied Environmental Informatics at the University of Applied Sciences Berlin (Germany). During her work at the DLR Institute of Robotics and Mechatronics in Oberpfaffenhofen, she explored ways to use robotics in the scenario of planetary crop cultivation. In the course of her Bachelors thesis with the EDEN team, she incorporated those findings into the EDEN ISS greenhouse under the use of augmented reality.

DANIEL ZIMNOWODA studies Safety Engineering at the University of Wuppertal (Germany). He is currently working on the MEPA project and is writing his Bachelors thesis on the analysis and optimization of the Nutrient Delivery System. Furthermore, he is doing tasks in manufacturing and assembly of the MEPA-structure.

JULIUS SCHROTH studied Aerospace Engineering at the Technical University of Dresden. During the time as a graduating student in the EDEN team he wrote his Diploma thesis on the EDEN NEXT Gen greenhouse module. In particular he developed the first design of the new Atmosphere Management System.

FRANCISCO JAVIER GUERRERO GONZALEZ studied aerospace and mechanical engineering at the TU Munich. During his Master's thesis with the Synergetic Material Utilization group, he analyzed the overall In-Situ Resource Utilization (ISRU) chain to identify potential processes that would yield valuable metals and metalloids as co-products of the oxygen extraction from lunar regolith.

MICHEL FABIEN FRANKE is a student pursuing a Master's degree in space engineering at the University of Bremen. He joined the SMU team as a research assistant in June 2021 with the aim of completing his thesis about lunar regolith beneficiation. In this thesis, he developed a laboratory test stand that is capable of creating an ilmenite-rich feedstock for the in-situ oxygen production on the Moon.

MORITZ HANSONIS studies Aerospace Engineering at the University of Stuttgart. He joined the SMU group in June for an internship. Currently he is writing his Bachelors thesis on the feasibility of ISRU technologies for the extraction of nutrients necessary for plants and algae production in future life support systems. His work as an intern included research and development as part of system analyses of ISRU applications and construction and modification of laboratory equipment.and modification of laboratory equipment.

SVEN JULIUS STEINERT studies M.Sc. Aerospace Engineering at the Technical University of Darmstadt and did his Bachelor's thesis on machine learning-based time-series forecasting of the EDEN ISS system. He followed up his thesis with an internship as a member of the SMU group where he analysed possible ISRU applications to be implemented in future missions to the Moon and Mars. In particular, he worked on lunar mapping and resource processing.

PHILIPP CAESAR is an aerospace engineering student at the Technical University of Delft (The Netherlands). During his time at DLR he carried out a literature study on Bio-regenerative Life Support Systems and finished his Master's thesis on the design of the new Nutrient Delivery System for the EDEN NEXT Generation greenhouse module.

NORA VOLLING studies aerospace engineering at the Bremen University of Applied Science. After her internship in 2020, she stayed within the EDEN group to work on the MEPA project for her Bachelor's thesis with the title:"Entwicklung und Auslegung einer Saatgut-Matte mit der Nährstoff-Film-Technik als Bewässerungsmethode für eine mobile entfaltbare Pflanzenanbaueinheit".

IMPRESSIONS 2021

ANOTHER SUCCESSFUL YEAR DESPITE THE PANDEMIC...

Off-loading of materials and supplies for the 2022 isolation phase.

Polarstern at the 15 m high shelf ice during offloading

The Neumayer overwintering crew with a climate change statement

A screenshot of Jess Bunchek during the EDEN ISS press conference

The iced EDEN ISS greenhouse entrance after several storms in Antarctica

Neumayer Crew picture. Left to right: Markus Baden, Theresa Thoma, Timo Dornhöfer, Tanguy Doron, Jess Bunchek, Paul Ockenfuss, Linda Ort, Florian Koch, Peter Jonczyk, Lorenz Marten, Tim Heitland.

A screenshot of Jess Bunchek outside the EDEN ISS Container during the Press Conference. The Neumayer Station in the background.

EDEN ISS Basil harvest

Crew Buffet in the Neumayer Station III lounge area

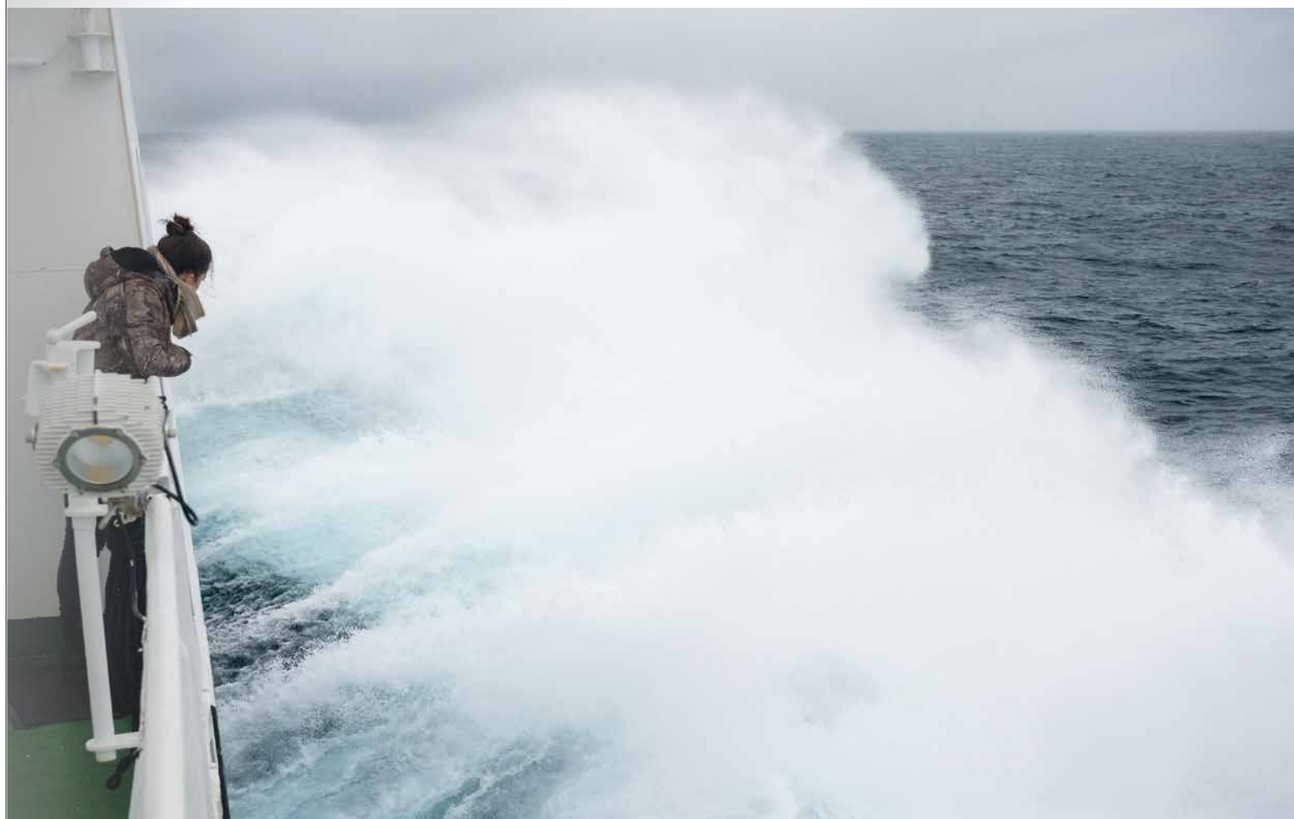
Jess Bunchek chatting with Neumayer Station overwintering veterans during the transit aboard Polarstern

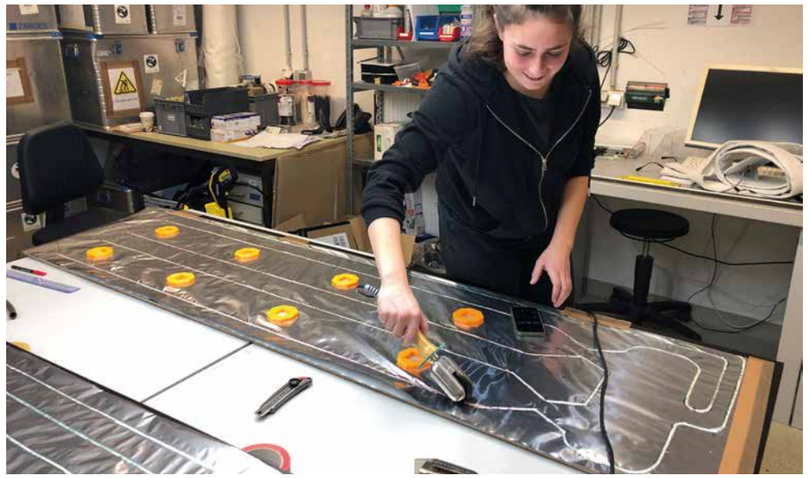
Jess Bunchek on her way from the Neumayer Station to the EDEN ISS greenhouse

Jess Bunchek working on the NDS (Nutrient Delivery System)

Jess Bunchek on the Polarstern on its way to Antarctica

Such big ´Frizzy Lizzy‘ leaves harvested by Jess Bunchek





Nora Volling working on the Seed Cultivation Mat

Karthi Savundararajan preparing the 3D printed plant holders for the Cube Circles project

Markus Dorn showing MEPA crops, which were harvested from the SCM

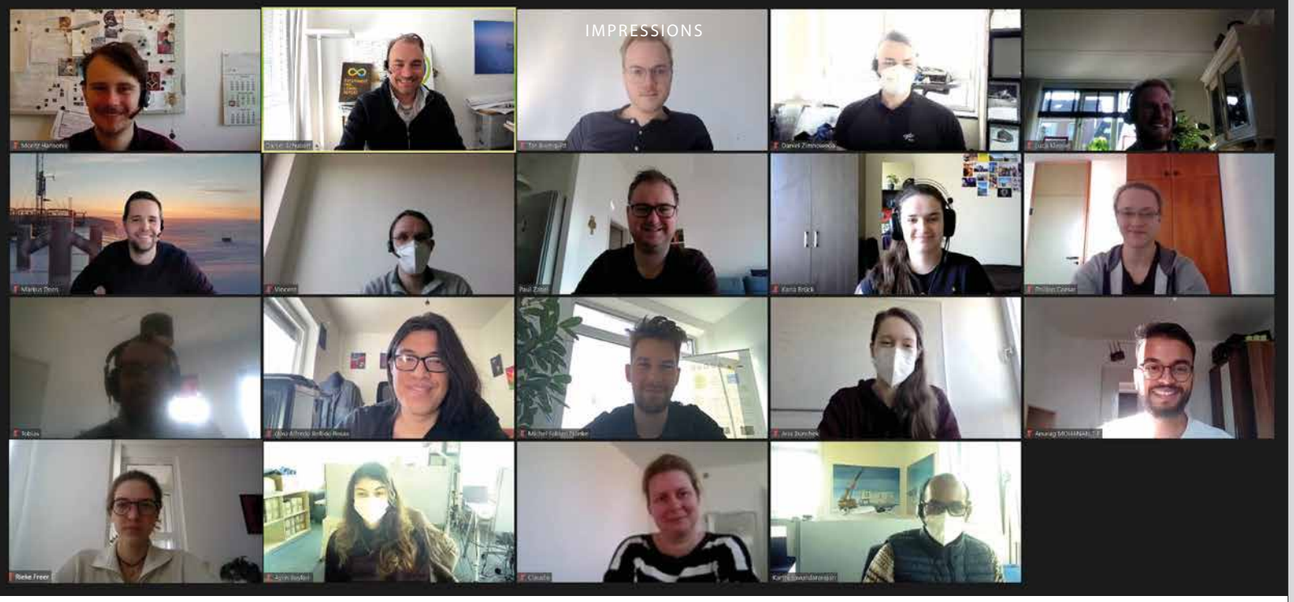
The Planetary Infrastructures Team during lab work

Aylin Baylan, Daniel Zimnowoda and Fran Guerrero having a chat at the team event

Paul Zabel, Luca Kiewiet and Michel Franke at the team event

Team is preparing the BBQ during the team event in summer

The Team around the campfire at the team event in summer



The team gathered online during a weekly Monday Meeting

Group picture of the students' camping trip

DLR at a glance

DLR is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation's largest project management agency.

DLR has approximately 8000 employees at 20 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Bremerhaven, Dresden, Goettingen, Hamburg, Jena, Juelich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Oldenburg, Stade, Stuttgart,Trauen, and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.

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