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Masterarbeit

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Entwicklung einer mobilen Arbeitsplattform für das Mond-Landwirtschaftsmodul

Mobile Working Platform Design for Lunar Agriculture Module

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Assignment

OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG MB FAKULTÄT FÜR MASCHINENBAU

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für Herrn Max Pohl Matr.-Nr.: 249042
<u>Thema:</u> **Entwicklung einer mobilen Arbeitsplattform für das Mond-Landwirtschaftsmodul**
engl. Mobile Working Platform Design for Lunar Agriculture Module

<u>Erläuterung zur Aufgabenstellung:</u>

Join the EDEN research group at the German Aerospace Center (DLR) in Bremen — an interdisciplinary team of engineers, biologists, and space architects developing an advanced closed-loop plant cultivation system for the Moon, known as the Lunar Agriculture Module (LAM). The goal is to maximize resource recycling and promote crew well-being during long-duration human missions through the implementation of bioregenerative life support systems. One sub-project involves the development of ground-based test demonstrators for future lunar applications.

The aim of the master's thesis is the conceptual development of a mobile work platform within the LAM and its implementation as a demonstrator.

Following points of the mission include:

- Conducting a user and task analysis to define the functional requirements for a mobile working platform within the LAM, considering crew activities, equipment handling, and operational efficiency
- Investigate and evaluate various technologies and approaches through a design trade-off analysis to determine optimal solutions for platform mobility, stability, and manipulation capabilities
- Develop conceptual and detailed designs for the platform, including its structural elements and system interfaces, based on research findings
- Participate in the prototyping and testing of the mobile working platform at the aluminum profiled mockup of DLR, validating key design choices and functionality

Beginn der Arbeit: 19. JAN. 2026 Abgabe der Arbeit:

Erstgutachter: Dr.-Ing. Ramona Träger, FMB-IEPS
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Verantwortlicher Hochschullehrender

Die Arbeit ist nach der Gestaltungsrichtlinie (FMB 03-01) und der Anleitung zur Bearbeitung von Abschlussarbeiten (FMB 03-02) auszuführen und in zweifacher Ausfertigung **fristgerecht im Prüfungsamt der FMB**, hilfsweise im Campus Service Center, einzureichen. Das Abgabedatum muss amtlich dokumentiert werden!
Die Arbeit kann einer Plagiats- und KI-prüfung unterzogen werden.

Kenntnisnahme
Student/Studentin

Max Pohl

Acknowledgement

I would like to take this opportunity to thank everyone who supported and guided me throughout the process of writing this master thesis.

Special thanks go to Kim Kyhunghwan. We originally connected through an internship posting, and fortunately, upon my request, a suitable master's thesis topic for my field of study was quickly identified. He provided me with deep insights into a subject area that I had previously had no connection to, but which deeply fascinated me during my time at DLR. Kyhunghwan was always there to assist me with guidance and information, shared valuable methodological approaches, and consistently provided constructive feedback on my methodology. I am also particularly grateful for being included in the team meetings regarding the LAM project, which allowed me to gain a tremendous amount of specialized knowledge.

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Finally, I would like to thank my parents. Without their support, my studies and career would not have been possible.

Abstract – German

Für eine dauerhafte Mondpräsenz im Rahmen zukünftiger Weltraummissionen ist die Nahrungsmittelproduktion, Sauerstofferzeugung, Kohlendioxid Recycling und Abwasseraufbereitung mithilfe von bioregenerativen Lebenserhaltungssystemen (BLSS) essenziell.

Die Evolution & Design of Environmentally-Closed Nutrition-Sources (EDEN) Initiative am Institut für Raumfahrtsysteme des Deutsche Zentrums für Luft- und Raumfahrt (DLR) in Bremen entwickelt hierfür das Lunar Agriculture Module - Ground Test Demonstrator (LAM-GTD). Die beengten Platzverhältnisse im Korridor dieses Gewächshausmoduls, erschwerte Zugänge zu den oberen Pflanzenschalen sowie das Fehlen einer Arbeitsplatzumgebung beinträchtigen jedoch die Arbeitsabläufe der Crew.

Ziel dieser Masterthesis ist daher die konzeptionelle Entwicklung einer mobilen Arbeitsplattform für das LAM-GTD. Basierend auf einer Analyse der Vorgängermission EDEN ISS und einer Ergonomie Untersuchung wurden nutzerzentrierte Gestaltungsrichtlinien abgeleitet. Da eine Markt- und Patentrecherche keine existierenden Lösungen für dieses spezifische Arbeitsumfeld aufzeigte, wurde eine Neuentwicklung eingeleitet. Die systematische Ideenfindung und deren Bewertung erfolgte mittels einer Nutzwertanalyse sowie durch DLR interne Umfragen und Experteninterviews.

Das resultierende Vorzugskonzept wurde in einem detaillierten CAD-Modell ausgearbeitet. Die finale mobile Arbeitsplattform zeichnet sich durch ein platzsparendes und klappbares Design aus, das über ein Schienensystem flexibel innerhalb des LAM-Korridors verschoben werden kann. Dadurch wird die Bewegungsfreiheit der Crew bei Nichtbenutzung nicht eingeschränkt, während im Betrieb eine Bereitstellung aller erforderlichen Werkzeuge und Hilfsmittel gewährleistet ist.

Das finale Modell der mobilen Arbeitsplattform ist so detailliert ausgearbeitet, dass eine physische Prototypenrealisierung direkt über den Kauf der Komponenten durch einen DLR-Partner erfolgen kann.

Abstract

Food production, oxygen generation, carbon dioxide recycling, and gray water treatment using bioregenerative life support systems are essential for a sustainable lunar presence as part of future space missions.

The Evolution & Design of Environmentally-Closed Nutrition-Sources Initiative at the Institute of Space Systems at the German Aerospace Center in Bremen is developing the Lunar Agriculture Module Ground Test Demonstrator for this purpose. However, the cramped conditions in the corridor of this plant cultivation module, difficult access to the upper plant trays, and the lack of a workstation environment hinder the crew's workflow.

The goal of this master's thesis is therefore the conceptual development of a mobile work platform for the LAM-GTD. Based on an analysis of the predecessor mission EDEN ISS and an ergonomic study, user-centered design guidelines were derived. Since a market and patent search revealed no existing solutions for this specific work environment, a new development was initiated. Systematic idea generation and evaluation were carried out using a utility analysis as well as through internal DLR surveys and expert interviews.

The resulting preferred concept was developed into a detailed CAD model. The final mobile work platform features a space-saving and foldable design that can be flexibly moved within the LAM corridor via a rail system. This ensures that the crew's freedom of movement is not restricted when the platform is not in use, while providing all necessary tools and equipment during operation.

The final design of the mobile work platform is so detailed that a physical prototype can be built immediately by purchasing the components through a DLR partner.

Declaration of independence - German

Hiermit erkläre ich, Max Pohl,

- dass ich die vorgelegte Arbeit selbstständig und ohne unerlaubte Hilfe angefertigt habe
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- dass meine Arbeit mittels Software auf Plagiate überprüft werden kann. Mir ist bekannt, dass es sich bei der Abgabe eines Plagiats um ein schweres akademisches Fehlverhalten handelt und dass Täuschungen nach der für mich gültigen Studien- und Prüfungsordnung geahndet werden.

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Meine eigene geistige Leistung stand immer im Vordergrund und ich habe jederzeit den Prozess steuernd gearbeitet.

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(Unterschrift)

Magdeburg, 02.06.2026

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List of Abbreviations

AMS	Atmosphere Management System
APH	Advanced Plant Habitat
BLSS	Bioregenerative life support systems
CSA	Canadian space agency
DLR	German aerospace center
EDEN	Evolution and Design of Environmentally Closed Nutrition Sources
EDEN LAB	Space Habitation Plant Laboratory
ESA	European Space Agency
EVE	EDEN Versatile End-Effector
FEG	Future exploration greenhouse
GTD	Ground Test Demonstrator
HabSIM	Habitat simulator
IPC	International Patent Classes
ISS	International space station
LAM	Lunar Agriculture Module
MELiSSA	Micro Ecological Life Support System Alternative
MTF	Mobile Test Facility
NASA	National Aeronautics and Space Administration
NDS	Nutrient delivery system
PP	Polypropylene
SES	Service section
Veggie	Vegetable Production System

1 Introduction and objective of the thesis

This chapter provides an overview of the topic and the objectives of this thesis. Plant cultivation modules, such as the DLR's Lunar Agriculture Module (LAM), are essential for future missions to the Moon and Mars.

The main objective of this thesis is to develop a conceptual mobile work platform that makes it easier for the crew to perform their daily tasks within the plant cultivation module in a small space.

In addition to the five key milestones of the thesis, this chapter presents a vision model. This model illustrates in a simple and clear way the objectives in the areas of function, design, and ergonomics.

1.1 Introduction

Since the beginning of space exploration, it has served as a driving force for innovation and international cooperation, advancing the progress of humanity. In the long term, nations aim to explore the lunar surface, which serves as a testing ground for new technologies and as preparation for crewed missions to Mars [1].

Due to its history, the Mars offers a wide range of research opportunities, such as the search for past signs of life and water, which makes the development of life support systems essential for long-term crewed space missions [1].

The Evolution and Design of Environmentally-Closed Nutrition Sources (EDEN) initiative of the DLR Institute of Space Systems in Bremen is focused on these long-term goals. The objective of the EDEN initiative is to develop bioregenerative life support systems (BLSS) with a particular focus on plant cultivation modules [2]. These systems are essential for supplying the crew with food, oxygen, and recycled water for future crewed space missions to the Moon and Mars.

The most well-known project of the EDEN initiative was the EDEN ISS mission, during which a mobile greenhouse was installed near the Neumayer III Station in Antarctica [2]. Antarctica served as an ideal location for this project, characterized by its isolation and cold climate.

The findings from the EDEN ISS mission serve as a direct basis for the development of future plant cultivation modules, such as the LAM for the Moon, through ongoing research and development.

The objective of this thesis is to develop a conceptual design for a mobile working platform for the LAM, with the aim of supporting and optimizing the crew's workflow in the greenhouse module. The focus is on enhancing human task performance while taking into account ergonomics and user-centered design within the spatially limited corridor of the greenhouse module. The solution to be developed should enable access to the upper plant trays and integrate safe and hygienic storage of tools and equipment. To ensure long-term usability, modularity is a central aspect, allowing the system to be adapted to potential changes in the mission objective.

This initiative is part of the LAM project, which seeks to maximize resource recycling and promote crew well-being during long-duration crewed space missions through the implementation of a BLSS.

The following milestones have been defined to achieve this goal:

- **System analysis**: Investigation of existing BLSS and Space Agriculture projects, as well as the LAM Ground Test Demonstrator (GTD).
- **User task analysis:** Examination of the workflows and equipment used in the EDEN ISS, as well as expert surveys and interviews to validate operational requirements.
- **Ergonomics analysis:** Application of human factors principles to enable a user-centered design for the platform.
- **Idea-, concept development and evaluation**: Generating ideas that are developed into fully-fledged concepts using a utility analysis.
- **Design:** Final development of a detailed CAD model with consideration for prototype implementation.

1.2 Objectives and vision model

In order to present the DLR's tasks and requirements for the thesis in a clear and concise manner, a vision model is being created as a guiding principle. This is a method that was developed in the Integrated Design Engineering program at Otto von Guericke University Magdeburg.

While traditional development goals in mechanical engineering and industrial design are often difficult to grasp, the vision model offers a simplified, three-stage alternative for defining tasks. The highest level consists of a vision that serves as a guiding principle and source of motivation, providing a framework for the project. This is followed by the fundamental goal, which translates the guiding principle into a concrete task consisting of a single sentence. The final level consists of the instrumental goals. While these provide concrete metrics for development, they are intentionally limited in scope and are not intended to replace the traditional list of requirements. They help to achieve the fundamental goal [3].

Figure 1 shows the vision model for the development of a mobile work platform in the LAM. The vision is: “Technology that opens up space – for efficient support, maintenance, and care of orbital cultivation systems.” This means that the work in the plant cultivation module of the future LAM crew will be supported by a mobile work platform in a confined space. The fundamental objective, “Development of a mobile work platform for flexible and safe operation and work on vertical farming systems in the LAM under cramped conditions,” explains in concrete terms how the vision will be achieved.

The instrumental objectives are divided into function, design, and comfort/ergonomics. The focus of functionality is on the integration of holding mechanisms for the crew and the tool to support work in lower gravity. In addition, it is intended that the platform will have a work surface that can be used for working while standing or sitting and that can also be used as storage space.

The design follows a space-saving concept that is adapted to the conditions of the LAM. A simple structure reduces complexity during assembly and susceptibility to potential errors. At the same time, a solution for the mobility of the platform ensures that users can access different workspaces within the LAM.

In the ergonomics category, the focus is on intuitive, body-centered operation. The platform is designed so that the operating height is adapted to natural working postures.

Folding and pivoting mechanisms enable flexible working and adaptation of the platform to current fields of activity.

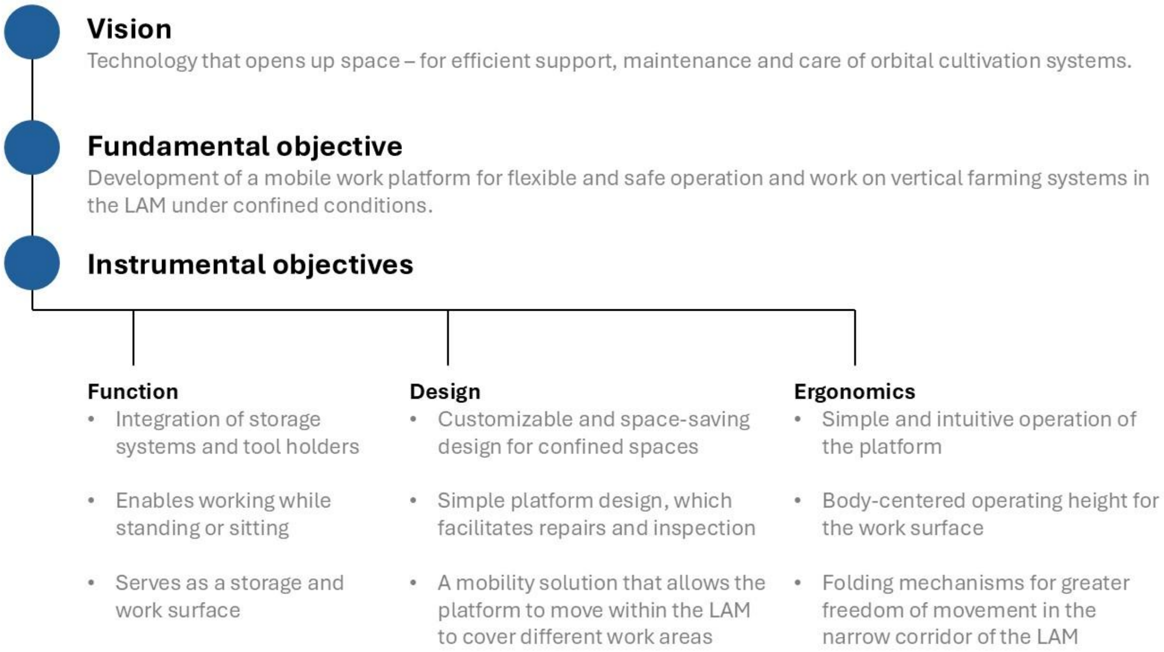


Figure 1: Vision model

2 Agricultural Projects for Long-Term Missions in Space

This section of the thesis serves as an introduction to the field of plant cultivation in space and the BLSS. It aims to make the technological insights and complex research more accessible.

Research into plant cultivation beyond Earth is not the endeavor of individual companies or nations. On the other hand, there are numerous research experiments taking place in a wide variety of environments, such as directly in space on the international space station (ISS), in isolated habitat simulators on Earth, or under extreme conditions in Antarctica.

Prominent pioneers include the European space agency (ESA) Micro Ecological Life Support System Alternative (MELiSSA) project, which began in the 1980s and has been conducting decades of research in the field of closed life support [4]. Another pioneering achievement from the 1960s and 1970s was the BIOS-3 BLSS research project of the former Soviet Union [5]. The goal was to create a closed environment for future manned space travel that does not require an external supply of resources.

To gain a deeper understanding of plant cultivation in space and the development of BLSS, three prestigious projects from different countries will be presented, spanning the period from the past to the present.

The completed Lunar Palace 1 project by Beihang University in China, which achieved one of the most advanced BLSS experiments combining plants, humans, and animals over a 370-day operation [6]. This is followed by the National Aeronautics and Space Administration (NASA) ongoing Vegetable Production System (Veggie) and Advanced Plant Habitat (APH) projects, which are researching food production under the direct influence of microgravity in space on the ISS [9], [10]. The LAM-GTD is presented last as a future project currently under development. It is a joint project between the German Aerospace Center (DLR), Canadian space agency (CSA) and multiple partners aimed at providing edible biomass from future manned lunar space stations [12].

The presentation of these three national and international projects illustrates the vision of self-sustaining systems in space and demonstrates the transition to practical models that are no longer based purely on theory.

2.1 Lunar Palace 1

The Lunar Palace project focuses on testing a BLSS and was launched by Beihang University in 2013. Its goal was to conduct basic research on the long-term presence of a crew on manned space stations on the Moon and Mars with as little as possible food supplies from Earth [6].

The central component of the system consists of two plant growth chambers (Figure 2) with a three-story growing area of 120 m². Connected to these is a module that serves as crew quarters, featuring a bathroom, living room, and bedrooms. A total of 35 different plant species were grown, including five types of grains, one type of fruit, and 29 types of vegetables [6].

Different light cycles were controlled in the two plant chambers, a 24-hour light cycle was simulated in one chamber and a 12-hour day-night cycle in the other, in order to study the effects on plant growth and yield [6].

Thanks to a highly efficient recycling system, the mission achieved a material closure rate of 98.2%. Water was recovered from wastewater and treated using UV disinfection and other purification processes [6].

The crew's waste was fermented with grain straw and bacteria, some of which was used for mushroom cultivation. Residues from the fermentation and mushroom cultivation served as feed for mealworms, which were essential as a key protein source for the crew [6].

Among all BLSS projects, Lunar Palace achieved a groundbreaking continuous mission lasting 370 days. The mission was divided into three phases and two teams. In the first phase, the first team (b) was isolated for 60 days, in the second phase, the second team (c) was isolated for 200 days, and in the third phase, the first team (b) was isolated again for 110 days. It is noteworthy that no crew members experienced psychological disturbances during the experiment. This was achieved through a high level of activity, such as four hours of plant care per day in the plant cabins, and the positive psychological effects of the plants on humans [7].

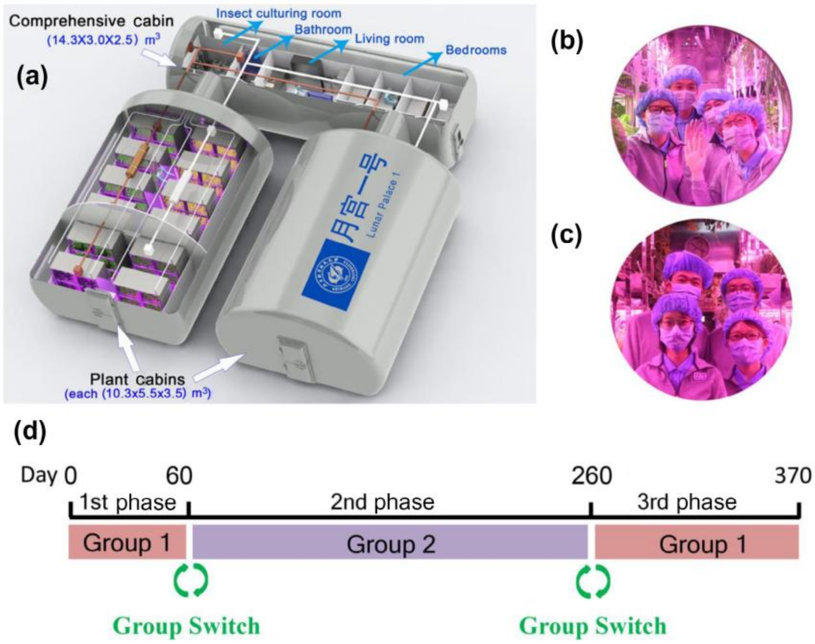


Figure 2: Lunar Palace [1]

2.2 Veggie and APH

The Veggie is a cost-effective and energy-efficient plant growth system for use in space, the mission began in 2014 and is still ongoing. Veggie is designed to produce fresh food for the astronauts on the ISS, thereby improving their mental well-being. Experiments conducted in the plant growth system support research into plant responses under microgravity. Veggie is equipped with a foldable, transparent plastic cover that folds back to access the plant tray (29.2 x 36.8 cm) inside [8].

The plant tray is designed to hold a total of six plant pillows. Each one consists of a Kevlar outer layer and a Nomex base coating to absorb heat. The inside of the plant pillows is made of fired clay mixed with fertilizer, ensuring optimal plant growth. The six units are watered via a wick system that passively delivers water to the plants. To ensure germination in every plant pillow, two to three seeds are placed in each unit. To keep the Veggie Unit and the edible biomass it produces free of contamination, both are disinfected with citric acid-based wipes [9].

There are two Veggie units on board the ISS: a growth chamber and the APH (Figure 3).

Unlike the Veggie system, which is operated primarily manually, the APH is a fully autonomous system [10], [11]. It provides the plants with a self-contained ecosystem through a hermetically sealed environment and climate control [11].

The system's autonomy allows researchers on earth to monitor and control the experiments in real time with minimal intervention from ISS crew members. On the technical side, the system includes 180 sensors that monitor and control temperature, air humidity, CO2 concentration, and light intensity [11].

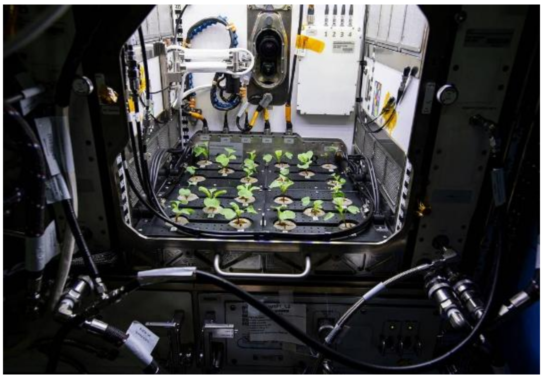


Figure 3: Veggie System (left) APH System (right) [2] [3]

2.3 LAM-GTD

The LAM GTD project involves a terrestrial test facility that will serve as a technological precursor to future plant cultivation module on the Moon. As outlined in this draft, the platform is primarily intended for testing BLSS and conducting scientific research. This includes, among other things, microbiome studies, the collection of validation data for plant growth models, and the evaluation of suitable crops [12].

Building on the experience gained from the EDEN-ISS prototype deployed in Antarctica, the project aims to demonstrate the feasibility of producing fresh food with a high degree of autonomy using a robotic arm. The specific objective is to meet at least ten percent of the caloric needs of a three-person crew. Following the planned launch in 2028, an operational phase of at least three years is to follow in order to establish the essential foundations for a real plant cultivation module for the Moon [12].

In terms of system architecture (Figure 4), the LAM-GTD is divided into three main components. These are the plant cultivation module itself, an airlock module that provides an integrated workstation, and habitat simulators (HabSim).

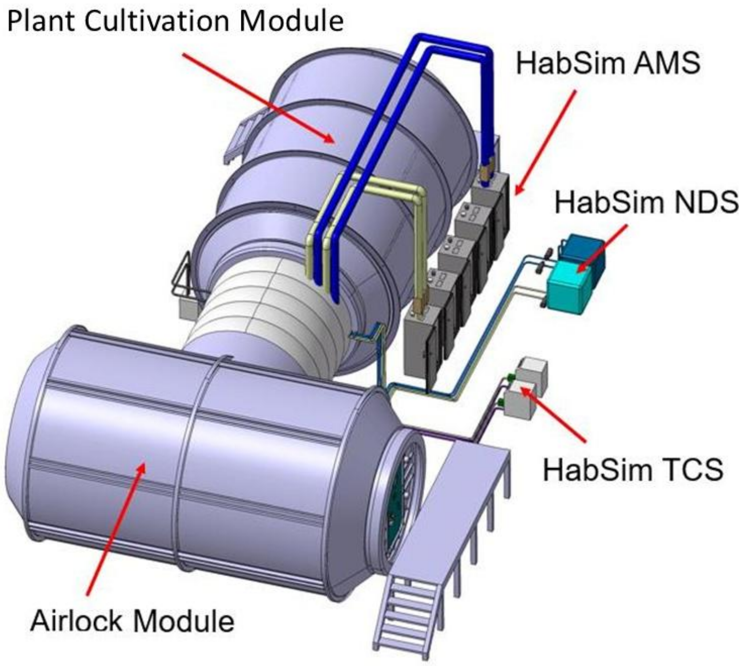


Figure 4: LAM-GTD configuration (edited by the author) [4]

In space research, HabSims are used to simulate realistic working and living conditions on Earth for extraterrestrial scenarios that would not be possible under normal conditions.

Plant Cultivation Module

The design of the plant cultivation module (Figure 5) is based on the mass and volume transport criteria of a Falcon 9 launch vehicle. The usable growing area within the module has been increased to around 24 m² through optimal use of space [12].

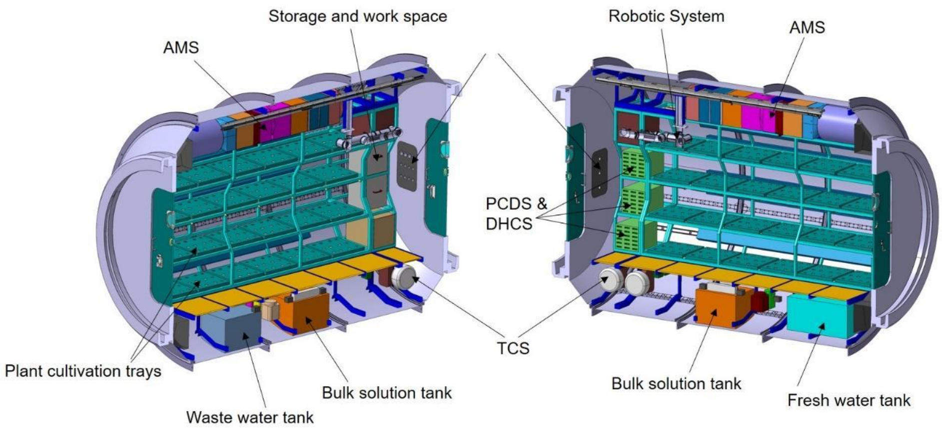


Figure 5: Cross-section of the Plant Cultivation Module [4]

The plant racks are mounted along the corridor in the center of the module, with the plant trays positioned inside them. These are integrated into a rail system so that the crew can pull the plant trays out toward the corridor, which facilitates efficient work. The supply systems are integrated into the floor and ceiling of the plant cultivation module to make optimal use of the cylindrical space [12].

To bridge the period before the crew's arrival, a robotic arm mounted on the ceiling of the agricultural module is designed for autonomous operations. This saves the crew time and allows the module to be used for non-continuous missions involving human participants [12].

For a more in-depth and detailed description of the individual subsystems, a comprehensive overview with explanations is provided in appendix A.

2.4 Findings for space agriculture and its workplace

The projects presented served as an introduction to provide an overview of past, current, and future projects involving the cultivation of plants in space. The insights gained from these projects make an important contribution to food production for future long-term missions, such as a permanent presence on the Moon or Mars.

Among all BLSS projects, the Lunar Palace 1 project achieved a groundbreaking, continuous mission duration of 370 days. This impressively demonstrates that the technology is already advanced enough to enable the long-term self-sufficient supply of edible biomass to an isolated crew. In addition to the nutritional supply itself, the psychological benefits are of immense value, as actively working with the plants has a positive effect on the crew's well-being.

The ongoing Veggie and APH projects on the ISS confirm these findings through their continuous operation. Veggie also demonstrate how important hygiene measures are in space. Regular disinfection of the agricultural unit and the edible biomass using citric acid-based disinfectant wipes is essential to prevent critical contamination within the closed habitat.

Despite extensive research, however, there remains a research gap regarding the specific design of workstations and the precise handling of plants in terms of aids and tools. From Figure 2, Figure 3 and Figure 5, it can only be inferred that there is no separate workstation system for the agricultural systems in Lunar Palace 1, Veggie, and APH, as well as the LAM-GTD, rather, the necessary work is carried out directly on the agricultural systems themselves.

3 Lunar Agriculture Module - Working Scenario

In order to better understand the needs of a worker in a plant cultivation module for the development of a mobile working platform for the LAM, it is first necessary to examine the working methods and tasks involved in a plant cultivation module. The EDEN ISS mission, with its Mobile Test Facility (MTF) and the EDEN-LUNA mission serve as references. By analyzing the operational procedures of these two greenhouse facilities, a persona is developed, along with a corresponding work scenario, to evaluate challenges.

3.1 EDEN ISS

The EDEN ISS project was carried out by DLR in Antarctica in 2018 with funding from the EU. A greenhouse was moved near the German Neumayer III research station to test the technologies for a future BLSS in operation. Due to the characteristics of Antarctica, such as remoteness, isolation, and dependence on technical systems, it serves as an ideal location for studying the technology and behavior of the crew. The successful test showed that, in the first growing season, the harvest yield of edible biomass amounted to 268 kg, which significantly improved the food supply at the Neumayer III Station. The findings will contribute significantly to the development of the LAM [13].

The structure of the MTF can be seen in Figure 6. It consists of two 6 Meter long shipping containers, each divided into a service section (SES) and the future exploration greenhouse (FEG) [13].

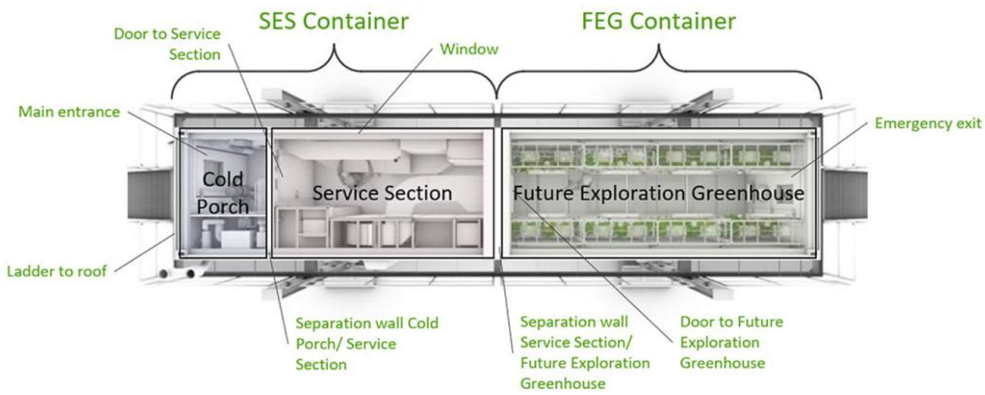


Figure 6: MTF configuration [5]

Before EDEN ISS became operational, the operational tasks were originally divided into seven activities. As the project was refined and expanded, the number of operational tasks was reduced to four and subsequently increased to five task groups in order to track the crew's working time [14]. The major operational tasks can be divided into four groups [15]:

- Crop cultivation
- Maintenance
- Repairs
- Science

These are all tasks that also arise in LAM-GTD. Plant cultivation is divided into sowing, where the seeds are placed in rock wool cubes. This is followed by transferring the plants from the propagation station to the propagation tray, pruning and thinning, where wilted leaves and side shoots are removed, and harvesting. During harvesting, the edible biomass is separated from the non-edible biomass [15].

The edible biomass is divided into five plant groups, such as lettuces and leafy greens, which are further subdivided into 23 plant types [16].

The tasks performed, such as routine cultivation tasks in the MTF, lasted from 30 minutes to several hours.

For a more detailed overview, appendix B includes a list of all plant groups and plant types, appendix C provides six different workdays with the daily routine and tasks for the MTF and appendix D shows pictures of the inside and outside of the MTF.

3.2 EDEN-LUNA

Following the successful completion of the EDEN ISS mission (2018–2022), the MTF containers were transported back to Germany from Antarctica. The insights gained from the mission led to a partnership between the DLR and the European Space Agency (ESA), which resulted in the transformation of EDEN ISS into EDEN LUNA [17].

Building on the knowledge gained during the five-year mission, the system underwent technical modifications while retaining the identical system architecture and functional areas and was integrated into the LUNA-Analog-Facility in Cologne for continued operation. This facility hosts realistic operations in a simulated lunar environment. EDEN-Luna complements the simulation environment with its greenhouse and modernized systems [17].

The main upgrades to the EDEN LUNA are:

- EDEN Versatile End-Effector (EVE)
- C.R.O.P Biofilter

The main upgrades involve EVE using its robotic arm with an integrated hand to reduce the crew's workload by taking over unscheduled tasks such as cleaning or plant handling. To convert the crew's urine into a usable nutrient solution for the greenhouse, the C.R.O.P. biofilter is integrated and connected to the nutrient delivery system (NDS) [17].

A comparison of the structural design of EDEN LUNA with that of EDEN ISS, as shown in Figure 7, reveals that it has not changed significantly. However, accessibility for maintenance, repair, and cleaning has been improved [17].

The structure consists of an FEG container, which houses the plants and an SES container. While the SES container contains the subsystems and a workbench for performing tasks.

Given the nearly identical system architecture, it is assumed that the operational scenario will differ little from that of EDEN ISS. However, it must be noted that the working procedure is still under development at the time of this thesis.

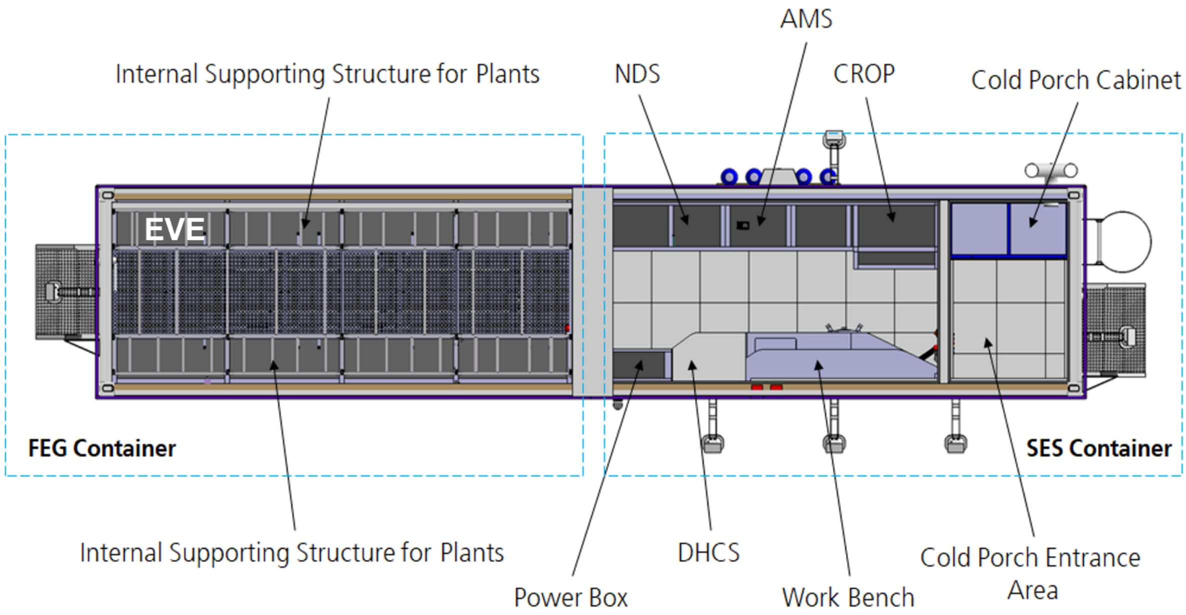


Figure 7: EDEN LUNA configuration [6]

3.3 Potential workflow in the LAM-GTD

The work scenario is designed to help users put themselves in the shoes of someone working in the plant cultivation module and to introduce them to all stages of plant cultivation, along with the associated tools and work methods. While it does not reflect reality, since the LAM-GTD is not yet operational, it is intended to closely approximate reality.

In addition, the student's experience in plant care and harvesting gained at the space Habitation Plant Laboratory (EDEN LAB) is incorporated into the scenario. A detailed report on this can be found in appendix E.

3.3.1 Persona for a working person for the LAM

Personas are used in the product development to represent the target group in order to design a product that is as user-centered as possible. These are fictional but realistic visualizations of the target group, which allow the developer to avoid relying on specific individuals. By presenting demographic data, behavioral patterns, career histories, and physical characteristics, it is possible to create a profile that helps presenting the target group [18].

The persona created is Benjamin, an aerospace engineer who represents the target group of a worker within the LAM-GTD. His background, goals, physical properties, and strength and coordination are illustrated in Figure 8.

Figure 8: Benjamin persona for the LAM user scenario [7]

3.3.2 Scenario

To provide an overview of the tasks performed within the LAM-GTD, the created persona, Benjamin, goes through the work steps of a worker within the plant cultivation module, covering the areas of sowing and germination, transplantation, pollination, pruning, plant care and monitoring, as well as a final inspection.

Sowing and germination

Benjamin enters the plant cultivation module and starts with the lowest plant trays as seen in Figure 9. These are still empty and are being prepared for sowing and germination. To work at the bottom of the rack, he has to sit or kneel on the floor. He then soaks rock wool blocks in a nutrient solution and places them in the trays. He presses holes into the rock wool blocks and carefully and loosely inserts the seeds (Figure 9 (1)) with tweezers so that they are not damaged.

Transplantation

Benjamin takes it a step further and focuses on plants that are already 14 days into their growth process. In doing so, he notices that the roots have already grown through the rockwool blocks at this stage, a sign that it’s time to transplant, and transfers the matured plants into plant trays. He is annoyed that there is no nearby surface to temporarily place the trays for the transplant.

Therefore, he temporarily sets the trays down on the floor of the LAM, which forces him to assume a crouching and unnatural posture. There is no seating option, such as a stool, which would help him in this situation while working on the lower plant trays.

Pollination

For the next step, Benjamin can finally stand up, as he is working on the plant trays at medium height. The plant species he is working on needs to be pollinated, which he does using a cotton swab. There is no trash can or similar storage place nearby for the cotton swabs. Out of necessity, he places the used cotton swabs on the plant tray surface for the time being. He will pick them up later and throw them in the trash can on the service rack.

Pruning, plant care and monitoring

For the next step, Benjamin has to go to the cabinet at the service rack to get a bag and a pair of scissors so that he can prune the plants on the neighboring trays. To improve the yield of the plants, he uses the scissors to cut away excess side shoots and wilted leaves (Figure 9 (2)). He collects the side shoots and leaves in a plastic container and places it on the floor for now, to be cleared away later.

During this step, Benjamin also checks on the plants well-being. He inspects them for any changes in appearance, such as unusual patches on the leaves. For now, however, he can only do this on the lower, accessible levels, as he needs a stool or something similar to reach the top plant trays. He isn't tall enough to reach them on his own.

The monitoring helps him detect plant diseases early on and allows him to take prompt action to prevent the plant from being lost.

Benjamin records the monitoring results on a tablet, which he stores in the cabinet of the service rack after documenting them.

The constant back-and-forth inside the plant cultivation module is starting to get on his nerves, since he can't work effectively that way. The idea of a central storage place for his tools near his workspace is taking root in his mind.

For his final task in plant cultivation, he has to go to the top plant trays. This is where the plants ready for harvest are located. But even at 1.80 m tall, he has to take a stretched posture and still can't reach the ripe plants. To make the task easier and more efficient, Benjamin brings a box (Figure 9 (3)) to stand on so he can more quickly separate the edible biomass from the non-edible biomass.

Unfortunately, there is no surface at a central, waist-high level where he can set the plant tray down to work more comfortably. At that moment, he wishes he could set the plant trays down for this step to avoid having to work overhead. He places the harvested edible biomass into a bowl he has taken from the storage cabinet on the service rack.

Final inspection

To finish up, Benjamin walks through the module, checks that the system is functioning properly, and inspects all the plants once more to make sure there are no issues. Before gathering his work materials and waste, he records his working hours on a clipboard, which he then returns to the cabinet at the service rack.

As he leaves the plant cultivation module, he's a bit annoyed and thoughtful, since he hasn't figured out how to better store his tools and supplies while working or how to arrange the plant trays more efficiently. After all, constantly walking back and forth to the cabinet in the service rack and then having to adopt an uncomfortable posture isn't a long-term solution for working effectively.

He has come to feel a growing desire and need for a platform that supports him in his work at LAM and that he can easily move to wherever he needs to perform his tasks.

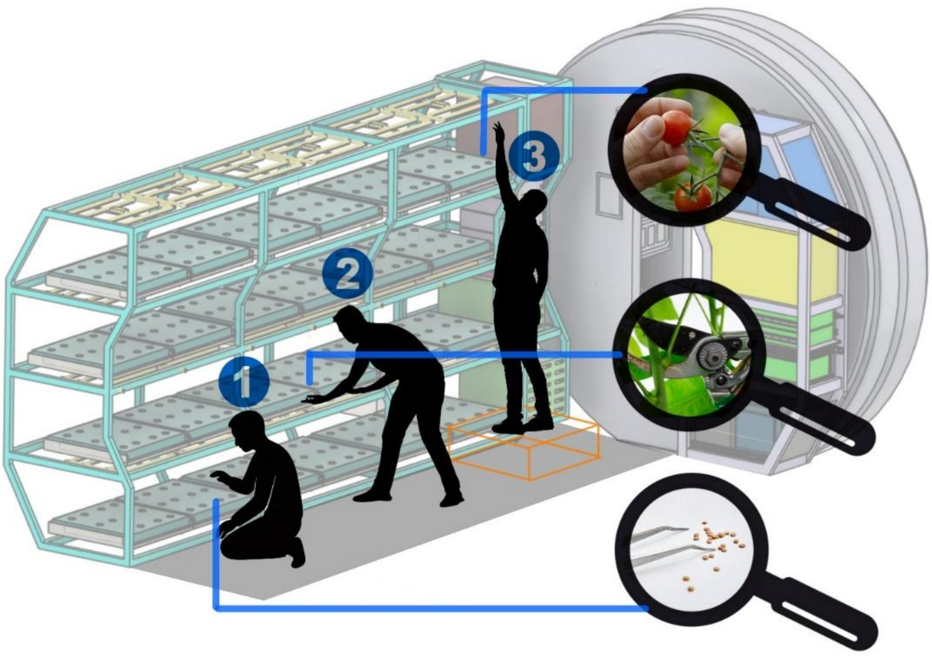


Figure 9: LAM Workflow Steps [8] [9] [10] [11] [12] [13] [14]

To clearly and concisely highlight the observations and the resulting design problems and design needs from the created work scenario, these can be viewed in Table 1.

Table 1: Scenario observation, including the resulting design problems and design needs

Scenario observation	Design problem	The resulting design need
• User works on lower trays while kneeling or crouching.	• Forced posture and discomfort.	• Provide a seated or posture-changing work option.
• User places trays temporarily on the floor.	• Lack of intermediate work surface.	• Provide a stable work surface near the tray level.
• Tools and equipment are stored at the service rack.	• Frequent walking and workflow interruption.	• Integrate task-specific tool storage on the platform.
• User cannot reach upper trays safely.	• Limited reach hight.	• Provide a secure step function.
• Consumer goods, edible and non-edible biomass do not have a nearby collection point.	• Waste and biomass handling is inefficient.	• Provide a solution that allows for the separate storage of waste and edible and non-edible biomass.

4 User-centered product design based on ergonomics

This chapter focuses on a comprehensive ergonomic approach that ranges from human cognitive and physical capabilities to the effects of reduced gravity, and extends to the optimal design of workstations to ensure maximum usability and an optimal gripping zone, while avoiding forced postures that pose a health risk. In a space module, the physical and mental strain on humans is particularly high due to the extreme conditions, limited space, and reduced gravity. Ergonomics is therefore crucial to enable efficient, safe, and healthy working. When developing a mobile work platform for the LAM, it is important that the design is adapted to human needs and physical capabilities.

Taking ergonomics into account in the design helps to make interaction with the platform as intuitive as possible and enables efficient working.

Ergonomics is an interdisciplinary science that deals with the analysis and design of interactions between humans and technical systems. The aim is to optimize both human performance and well-being in work processes. Ergonomic principles are therefore systematically taken into account in the development of work systems and products in order to create technical solutions that are efficient, safe, and tailored to human physical and cognitive abilities. The central goal of ergonomics is to adapt technical systems to human needs and abilities [19].

4.1 Usability

Usability results from the development of products based on ergonomic principles. According to the DIN EN ISO 9241-11:2018 norm, usability can be defined as the extent to which users achieve defined goals in a specific context of use with the help of a given system. The evaluation criteria for this are the effectiveness and efficiency of achieving the goals and the perceived satisfaction in doing so [19].

Effectiveness refers to the extent to which a user can correctly and completely achieve their goals with a product. A product is considered effective if it is fundamentally suitable for performing the intended tasks [19].

Efficiency, on the other hand, describes the relationship between the result achieved (effectiveness) and the effort required to achieve it. A product is efficient if it enables the achievement of goals with minimal expenditure of resources or time [19].

Effectiveness, efficiency, and satisfaction are the key criteria for evaluating usability. Their interdependence is clearly illustrated in the target pyramid (Figure 10). The lower levels serve as fundamental conditions for the upper target level [19].

Figure 10: Target pyramid (translated by the author) [15]

4.2 Height requirements

In addition to psychological and academic requirements, an analysis of the physical requirements of the crew is essential in order to validate the ergonomic design of a mobile working platform. The ESA defines a permissible body height range of 150 cm to 190 cm, while the NASA specify a body height range of 157.48 cm to 190.5 cm [20], [21].

These specifications result primarily from technical requirements. This is because astronauts and crew members must comply with physical compatibility requirements based on standardized space suits, the launch vehicle, and the controls located therein.

4.3 Forced postures

One of the main causes of physical discomfort is performing repetitive work tasks and maintaining static, forced postures. These arise when the muscles remain under constant tension for an extended period of time while almost motionless. The resulting reduced blood flow to the tissues contributes to the development of physical discomfort. Such a strain situation can manifest in nearly all parts of the body. The spinal region and the extremities are particularly affected [22].

Typical situations involving such strain include activities performed in a bent or twisted posture, working overhead, and remaining in a kneeling, crouching, or rigid standing position for extended periods (Figure 11) [22].

Figure 11: Forced postures of the upper body and head [16] [17]

4.4 Gravity on the moon

To ensure safe and ergonomic working conditions, the strain caused by lifting and carrying loads during work activities and when moving the mobile working platform must be taken into account. On the Moon, the gravitational acceleration is approximately 1.6 m/s², compared to 9.8 m/s² on Earth, which means that an object on the Moon weighs only about one-sixth of what it does on Earth [23].

While weight is reduced under lunar gravity, the mass and inertia of objects remain unchanged. Consequently, the mobile work platform must still provide secure stability and anchoring to prevent unintended shifting or movement.

4.5 Cognitive ergonomics

Since diverse tasks generally predominate in LAM, it is essential to take cognitive ergonomics into account when planning and designing a mobile work platform in order to keep the mental demands on the user as low as possible.

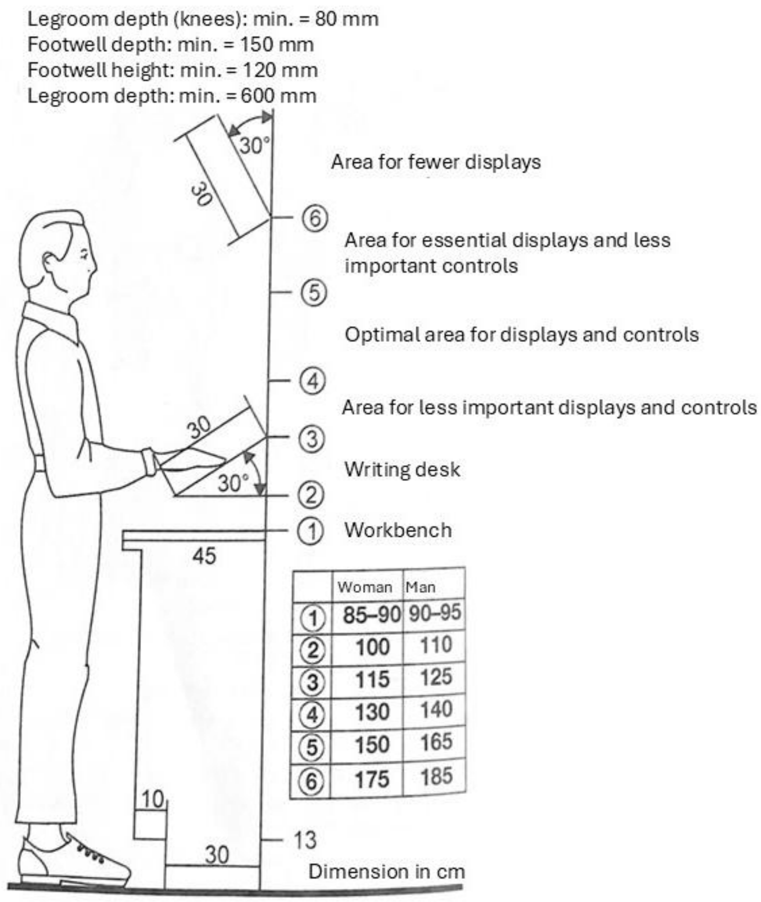
This is where cognitive ergonomics comes in, with the aim of adapting working conditions, processes and systems to human mental needs. The focus is on supporting cognitive functions such as perception and decision-making, rather than overburdening them with unfavorable design. A cognitively ergonomic work design is characterized, among other things, by a high degree of comprehensibility and user-friendliness of systems. Implementation includes the targeted use of visual aids such as graphics and symbols to make information quick and easy to understand [24].

4.6 Workplace design

In order to cover the entire spectrum of workplace design, both standing and sitting working postures are taken into account with the corresponding workplace. The aim is to ensure an ergonomically optimized working environment that is adapted to the individual needs of the user.

Standing workstation

For activities that are performed exclusively while standing, the recommended working height for women is between 85-90 cm and for men between 90-95 cm, as shown in Figure 12. In order to ensure an ergonomically suitable working height for both sexes when standing, an average value of 90 cm is recommended. In addition, a legroom depth of at least 8 cm and a legroom width of at least 60 cm are suggested [25].



	Woman	Man
1	85–90	90–95
2	100	110
3	115	125
4	130	140
5	150	165
6	175	185

Figure 12: Workplace design for standing work (translated by the author) [18]

If the workplace is primarily designed for a seated working posture and is height-adjustable, a work surface height of 62-85 cm is recommended for sitting. If activities are carried out standing up at such a workplace, it is recommended to select a working height between 95-125 cm.

Seated workstation

For workstations that are primarily designed for seated activities and do not have a height-adjustable work surface, a work surface height of 74 cm is recommended for both genders

(Figure 13). If activities are nevertheless carried out standing up at such a workstation, a work surface height of 105 cm is recommended.

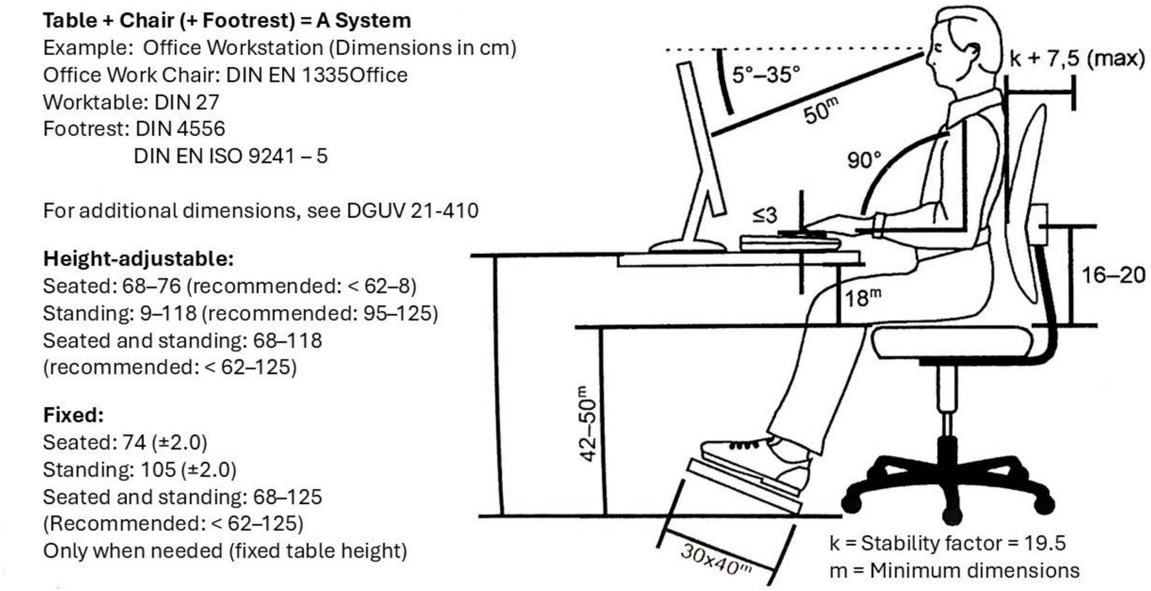


Figure 13: Workplace design for hybrid work - standing and sitting (translated by the author) [19]

If the workplace is primarily designed for a seated working posture and is height-adjustable, a work surface height of 62-85 cm is recommended for sitting. If activities are carried out standing up at such a workplace, it is recommended to select a working height between 95-125 cm.

However, if a hybrid working model with alternating sitting and standing working positions is implemented, it is recommended that the work surface height be set flexibly within a range of 62-125 cm. For the ergonomic design of the lower body area at a seated workstation, a legroom depth of at least 80 cm and a recommended legroom width of 120 cm (at least 85 cm) are provided [26].

4.7 Reaching range

To analyze the optimal arrangement of tools and aids for static working postures, Figure 14 visualizes the relevant reaching ranges of a worker. The two-handed zone (1) defines the central working area that is within the worker's direct field of vision and in which the main task of the work process is performed with both hands. The one-hand zone (2) comprises the gripping space in which all tools and aids that are used regularly and can be reached with one hand are located. The extended one-hand zone is intended for aids and tools that are only used sporadically in the work process but are nevertheless used [27]. To cover the entire gripping surface, a length of approximately 140 cm and a depth of approximately 41 cm are recommended.

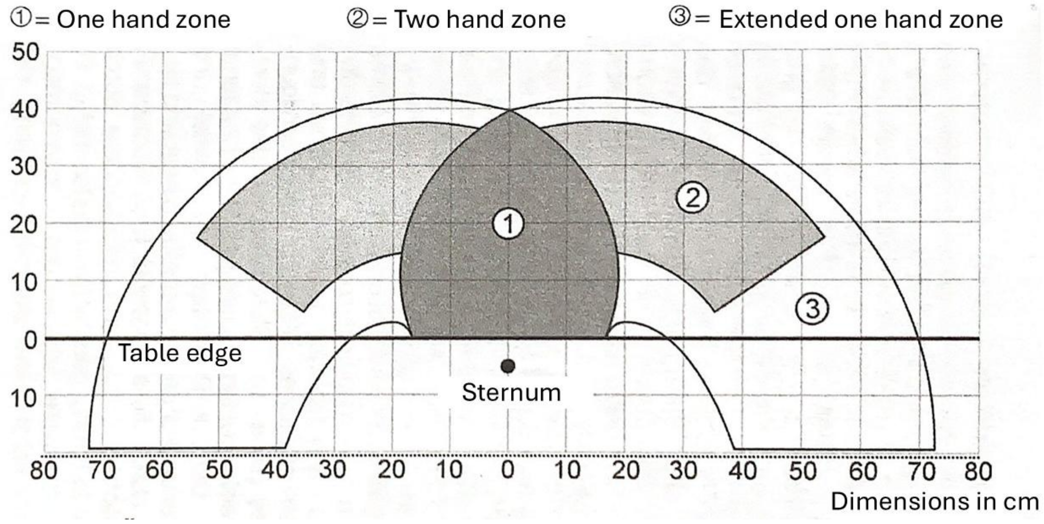


Figure 14: Grip zone layout (translated by the author) [20]

4.8 Summary and Findings of the Ergonomic Analysis

The ergonomic analysis provides the theoretical foundation for a user-centered design of the mobile work platform for the LAM. The research makes it clear that the platform's usability extends far beyond its pure functionality. It is defined by the interplay of effectiveness and efficiency, which forms the basis for user satisfaction. The goal of the design must be to make the interaction between the LAM crew and the platform as intuitive as possible.

Cognitive ergonomics is particularly crucial in the high-tech and confined environment of a space module. The investigation shows that a simple and intuitive design is essential for reducing mental workload and thereby preventing errors.

The analysis of standing and seated workstations provides specific measurements for the technical implementation of the platform:

- **Standing workstations:** recommended work surface height between 95 and 125 cm
- **Hybrid model:** recommended work surface height of 62 to 125 cm

The study of the reaching range provides insights into the design of work surface dimensions, taking all reaching zones into account. A length of approximately 140 cm and a depth of approximately 41 cm are recommended as the optimal dimensions for the entire work surface to cover all reach zones.

The results demonstrate that the platform must function not only as a storage surface, but as an active support element for the work areas within the LAM.

5 Systematic analysis of existing technologies

To develop a solution for a mobile work platform for the LAM, it is essential to conduct market research on existing mobile and modular workstations. This chapter of the thesis focuses on a systematic analysis of various industrial sectors, such as logistics and manufacturing. In addition to commercially available solutions, it examines specific patents and technologies related to mobility concepts in order to facilitate a potential technology transfer.

5.1 Market research

Conducting market research on existing products is an essential step in the development of new products. It enables for a systematically assess the current state of the market and develop a comprehensive understanding of existing solutions and customer needs. This forms the basis for the development of mobile working platform. In addition, market research helps to make informed strategic decisions and significantly increases the chances of success for the new product. In this sense, it serves as an indispensable tool within the development process.

5.1.1 Mobile workstations

Mobile workstations (Figure 15) are specifically designed for dynamic applications such as logistics and manufacturing [28]. Their primary unique selling point is their exceptional flexibility and functionality. An integrated, off-grid power supply enables the system to perform decentralized data collection (e.g., via integrated laptops or scanners) directly in the work environment without relying on a stationary power source [29].

Among other things, this facilitates seamless documentation of goods movements directly at the system's point of use, particularly in logistics. Given the different requirements across various industries, mobile workstations stand out for their high adaptability to their working environment. Consequently, the mobility of these systems is a key factor in ensuring efficient operational processes [28].

Figure 15: Mobile Workstation [21]

Mobile workstations, which are typically equipped with casters, not only enable the safe transport of tools but also provide an ergonomic and functional workspace [30]. This is achieved by customizing the setup and adding work accessories such as laptops, mounts, or storage systems. Thanks to their independent power supply, they can be used for several hours or even entire shifts without needing to be recharged, making them particularly efficient and versatile in daily workflows [30], [31].

In addition to sectors such as logistics, these systems are also used in hospitals and office environments.

5.1.2 Tool trolley

A tool trolley (Figure 16) is a mobile storage unit with drawers that allows for the organized and clearly arranged storage of tools while offering maximum flexibility in the workplace thanks to its mobility [32]. Instead of traditional tool cabinets, tool trolleys are increasingly being used because they offer significantly more flexibility in day-to-day work [33]. Thanks to their mobility, all necessary supplies and tools are always available exactly where they are needed [32]. At the same time, a tool trolley makes it easier to organize work materials and keeps the workplace tidier [33]. One of its greatest strengths, however, lies in its versatility. Thanks to its extensive storage system, the trolley can be individually customized to meet different requirements and equipped precisely to suit the needs of the target group [32], [33].

With models featuring an integrated worktop, the cart can also serve as a workbench, allowing tasks to be performed on it, which eliminates the need for a full-sized workbench. This is ideal for work environments with limited space.

Figure 16: Tool trolley [22]

5.1.3 Modular, adaptable workstations

Modular workstations (Figure 17) are flexibly configurable workstation systems that can be individually adapted to different requirements. These systems are based on rails and tube profiles, which serve as a stable foundation. Thanks to the standardized modular design, the type of workstation, its location, and its equipment elements can be easily and quickly changed or expanded. This modularity enables efficient design of the work environment, tailored to specific needs and workflows. This facilitates quick and easy process optimization [34].

For ergonomic working, the workstation can be adjusted to suit the individual user like adjusting the height of the work area. This modularity enables efficient design of the working environment, tailored to specific needs and workflows. This allows for quick and easy process optimization. Examples of add-ons for the profile base include accessories such as clipboards, lamps, screens, storage surfaces, and storage containers for components or tools [35].

In industry, these modular workstations are used in assembly, workshops, logistics and also in test and inspection stations [36], [37].

Figure 17: Modular and adaptable workstation [23]

Since there is currently no permanent base on the Moon, there is a lack of direct reference models for mobile workstation solutions in a lunar context. While existing table designs, storage surfaces, and mounting systems have been examined, this was done in the context of space stations such as the ISS. These provided no relevant insights into the specific requirements of this thesis. The tables and storage surfaces identified can be viewed as images in the appendix F.

5.2 Mobility Concepts

The development of a mobile work platform requires a solution that equips the work platform with a mobility concept. Since the platform must move reliably within the LAM corridor, it is essential to examine various means of transport. The choice of a suitable system not only influences mobility, but also aspects such as load capacity and the integrability of the existing system.

This section analyzes and compares different mobility solutions. The focus is on industrial casters, linear rails, parking rails, running rails, and a circular rail transport system. Each of these mobility solutions has characteristics that bring advantages or disadvantages.

The aim of the study is to illustrate the respective strengths and weaknesses of the individual systems and to evaluate their suitability for use in a mobile work platform. Finally, the advantages and disadvantages are clearly listed in a table so that they can be taken into account in a later phase of this work during the idea generation process.

5.2.1 Industrial casters

Industrial casters (Figure 18) are a fundamental component of modern production and logistics processes [38]. They are used on a wide variety of work equipment, such as transport carts and rollable platforms, which facilitate the easy transport of materials. This includes the transport of everything from entire machines to individual parts [39].

Figure 18: Industrial casters [24]

By minimizing physical rolling resistance and the force required to move large objects or products, integrated caster systems contribute to improved workplace ergonomics and increase efficiency in the required application processes [38], [39]. Depending on process and maneuvering requirements, fixed or swivel casters are used. These feature a wide range of materials, such as plastics and rubber [39].

In addition to load-bearing requirements, the various materials ensure the protection of sensitive floor coverings and contribute significantly to noise reduction in the work area [40].

However, despite their numerous advantages, industrial casters also have some drawbacks. Even when parking brakes are used, the platform is generally not completely immobilized, which can compromise safety. In addition, each castor must be secured individually via its integrated braking mechanism, which increases the effort required to operate them. Furthermore, the directional stability of industrial castors is limited. During movement, lateral offset or unintended rotation of the wheels can occur, particularly when changing direction or when the load is unevenly distributed.

5.2.2 Linear rails with guide carriages

A linear rail is a guidance system designed for precise positioning and for guiding components along horizontal and vertical axes. The system consists of a fixed guide rail and a carriage integrated into it, which ensures stable and precise positioning of the components [41].

There are two different types of guide carriages, which differ only in whether they have integrated ball bearings or roller bearings (Figure 19) [41].

Figure 19: Rail carriages with ball bearings (left) and roller bearings (right) [25] [26]

Guide carriages equipped with ball bearings are characterized by smooth running and also offer low-friction movement. They are frequently used in fields such as manufacturing technology, which require precise positioning of components [41].

In addition to ball-bearing-equipped guide carriages, there is an alternative that replaces the ball bearings with roller bearings. This structural change increases the load-bearing capacity and enables smooth operation, particularly when covering longer distances. As a result, roller-based guide carriages offer greater stability and durability, making them the preferred choice in work areas involving heavy components [41].

Despite its advantages, this system also has some negative aspects. Linear rails with guide carriages have limited freedom of movement, as the movement is strictly bound to the rail guide and is therefore exclusively linear. Lateral evasive movements or the circumvention of obstacles is not possible, which significantly limits the system's possible applications. In addition, linear rail systems offer little flexibility when it comes to layout changes. After installation, adjustments to the route or the working area can usually only be made with considerable effort, as this usually requires mechanical modifications.

5.2.3 Running and parking rails

Based on the same design principle, running rails and parking rails provide a space-saving solution for guiding and positioning carts. While running rails serve as a modular and flexible guide for carts, the floor-mounted parking rails ensure that the carts are precisely positioned and secured at predefined locations.

Running rails

Running rails (Figure 20) are a modular logistics system that can be scaled, adapted, and expanded to meet the user’s requirements. The basic structure of the system consists of two parallel rails, with the track width defined by spacers. Each rail has a groove that serves as a guide for the trolleys and ensures exclusively linear guidance [42].

To make it easier to insert and position the trolleys, guide caps are attached to the ends of the rails. A key advantage of the system is that the trolleys can be moved and positioned freely outside the running rails and are not restricted to linear movement [42].

Furthermore, the rails don’t require permanent floor mounting, as the weight of the loaded and unloaded trolleys is enough to keep them stable in position. Depending on the specific configuration of the system, often only one running rail per track is enough to position trolleys safely at the desired location [43].

Overall, the structural design of the system not only increases operational flexibility but also offers a cost-effective alternative to other transport systems due to its low price.

Figure 20: Running rails [27]

Parking rails

Parking rails (Figure 21) are constructed according to the same principle as running rails but are permanently mounted on the floor. They are used for the precise positioning of trolleys by engaging two wheels in the existing groove and securely fixing the trolley in place [44], [45].

In this way, defined positions can be set up, and for example, several stations can be implemented along a process.

Figure 21: Parking rails [28]

Running and parking rails have several limiting similarities in terms of disadvantages. The movement options of the trolleys used are limited exclusively to a linear layout if they are to be integrated into the rails. In addition, rails that are integrated into the floor or laid on top of it pose a potential tripping hazard, especially in areas with limited space, which can have a negative impact on occupational safety. Furthermore, parking rails in particular can only be moved to predefined positions, which limits positioning accuracy. In addition, running and parking rails require a system with wheels.

5.2.4 Circular rail transport system

The circular rail transport system (Figure 22) consists of a network of rails embedded flush with the floor, along which transport vehicles can be moved either manually or automatically. It is particularly suitable for heavy loads of up to 200 tons, thereby ensuring an efficient flow of products and materials. Even lighter loads can be moved effortlessly by a single person. For example, it is possible to push a load of up to 5 tons without much effort [46].

However, the circular rail transport system offers even more advantages that combine cost-effectiveness, functionality, and ergonomics. Thanks to durable rails and wheels, as well as minimal energy consumption when moving heavy loads, it is particularly cost-effective. The floor-level installation prevents tripping hazards, can be quickly integrated into existing or new hall floors, and can be easily driven over by vehicles [47].

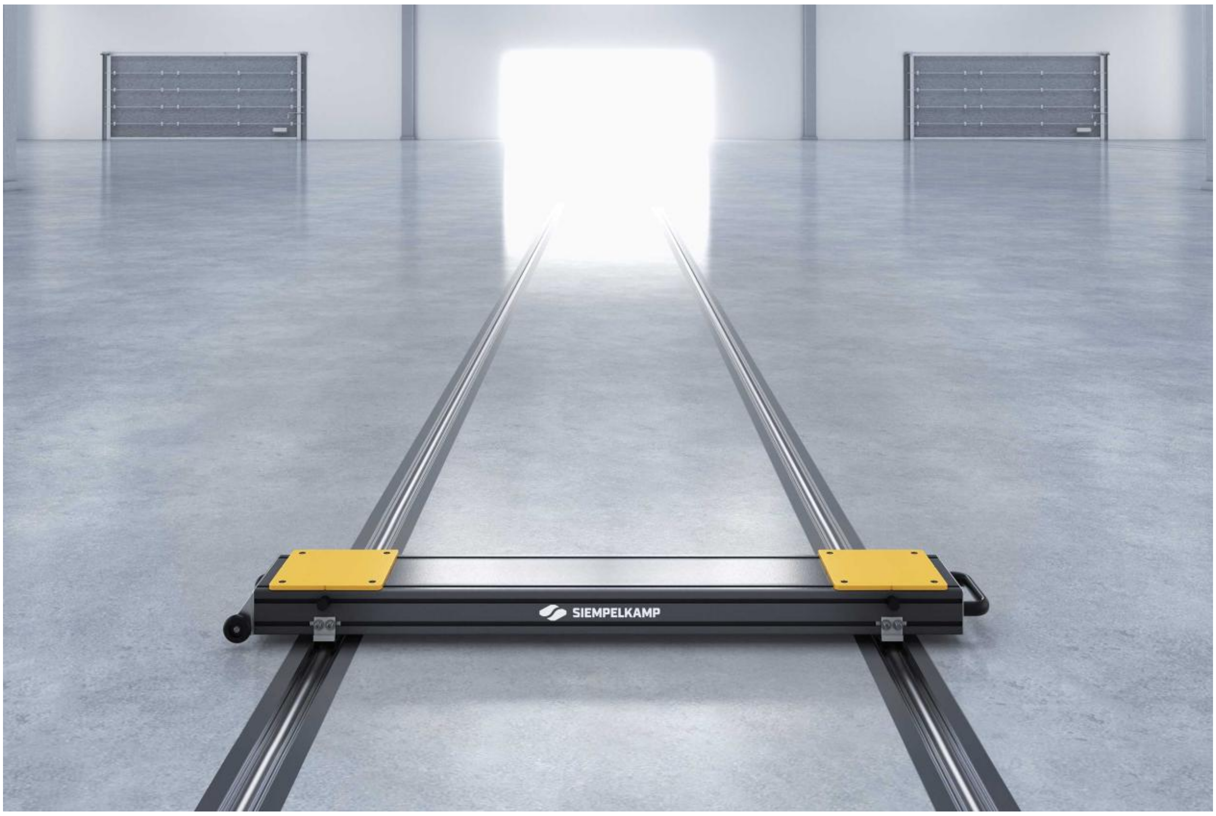


Figure 22: Circular rail transport system [29]

The system stands out for its exceptional positioning and repeatability, accuracy, quiet operation, and seamless integration. It can also be customized to meet the specific needs and requirements of the user. Last but not least, the system offers clear ergonomic benefits. In addition to requiring minimal effort, its low profile, starting at just 100 millimeters and quiet, smooth movement contribute to a comfortable and safe working environment [47].

For a more compact overview, Table 2 lists the advantages and disadvantages of the mobility concepts.

Table 2: Advantages and Disadvantages of Mobility Concepts

Mobility solution	**Advantages**	**Disadvantages**
Industrial casters	• Wide variety of models • Wide range of sizes • Wide range of materials • Protects delicate floor coverings	• Limited lane-keeping capability • Individual control for each brake on the wheel

Table 3: Advantages and Disadvantages of Mobility Concepts - Continuation of Table 2

Linear rails with guide carriages	• High accuracy • Good positioning repeatability • High reliability • High stability • High load capacity • Long service life	• Only possible in a linear configuration • Limited flexibility for layout changes
Running rail	• Easy to expand or reduce the size of the system • No need for permanent fastening to the floor • A single running rail is sufficient for linear guidance • The carriages can leave the rail at any time and be positioned freely in the room	• Can only be used in a linear layout • Risk of tripping • Requires a system with wheels as an add-on
Parking rail	• Cost-effective • The trolleys can leave the track at any time and be positioned freely in the room • High layout flexibility when mounted on the floor	• Must be screwed to the floor • Risk of tripping • Can only be placed in pre-set positions • Requires a system with wheels as an add-on
Circular rail transport system	• Very heavy loads can be moved with ease • Durable system • Even floor surface (no tripping hazard) • High positioning accuracy • High repeatability • Quiet operation	• Designed primarily for heavy loads • The rail system must be embedded in the floor • Intended primarily for industrial buildings

Since there is currently no permanent base on the Moon, there is a lack of direct reference models for mobile workstation solutions in a lunar context. While existing table designs, storage surfaces, and mounting systems have been examined, this was done in the context of space stations such as the ISS. These did not provide much relevant insights into the specific requirements of this thesis. The tables and storage surfaces identified can be viewed as images in appendix F.

5.3 Patent research

The following section presents the patent research that was conducted. The aim of this research is to gain additional inspiration for generating new ideas, particularly in areas that were not fully covered by the previous market research. By analyzing existing patents, innovative approaches and technical solutions were identified that can serve as impetus for the further development of our own concepts.

The patent search utilized the European Patent Office's freely accessible Espacenet database, whose online library provides access to over 150 million patents. The database is used to analyze the current state of technological development and to identify the owners of the registered patent. Thanks to its intuitive user interface, Espacenet is particularly suitable for people who are not familiar with the field [48].

During the research, a conscious decision was made not to subdivide the results according to International Patent Classes (IPC). The IPC is used to classify patents into a multi-level structure. This structure is divided into several sections, each of which is further subdivided into subgroups. This allows users conducting a patent search to filter very precisely the specific area in which an analysis should be performed [49].

Not using the IPC in search allows for the broadest and most open search possible in all directions and does not limit the search thematically from the outset. Subsequently, specific search criteria were defined, which served as the basis for systematic research. These criteria are clearly listed in Table 4.

Table 4: German and English search criteria for patent searches

German	English
mobil	mobile
faltbar	foldable
modular	modular
anpassbar	customizable
Laufende schienen	Continuous
Ausklappbar	fold-out / foldable
Werkbank	workbench
Arbeitsplatz	workstation
Schrank	cabinet
Werkstattwagen	Workshop trolley

The search criteria established were then combined and entered into the Espacenet database in order to search specifically for relevant patent documents. The respective search query, the number of hits, and the number of patents rated as relevant are summarized in Table 5.

Table 5: German search queries, along with the number of hits and the number of relevant patents

Search query in german	**Hits**	**Relevant**
Modulare Werkbank	95	3
Werkbank ausklappbar	15	1
Ausklappbarer Arbeitsplatz	26	none
Laufende Schienen Schrank	124	3
Mobiler Arbeitsplatz	612	7
Mobile Werkbank	339	3
Werkstattwagen	381	3
Anpassbar Arbeitsplatz	770	9
Faltbarer Arbeitsplatz	21	none

A total of 2,383 patents were examined, of which 29 were classified as particularly relevant. It is striking that a very large number of hits were obtained, especially when synonyms such as mobile or adaptable were used in combination with other terms. This led to a search space that was difficult to manage, mainly because no deliberate restrictions were imposed in terms of IPC classes or specific product categories. This open approach was chosen because the research takes place at a very early stage in the development process and serves primarily to gain as broad an overview as possible of existing solutions and conceptual approaches.

The research identified both complete overall concepts and individual technical solutions. The focus was clearly on the overall concepts, as these offer a holistic representation of an idea and its intention. Exactly what is needed at this early stage. Individual solutions, on the other hand, show how specific functions or technical details were implemented, but were not the main focus of interest. The patents that were found to be very interesting can be divided into storage systems and mobile compact workstations.

5.3.1 Storage system for tools

The Patent EP3790679A1 (Figure 23), from the year 2021, describes a device for storing tools, as in this example for a press brake. As such complex machines are used in a wide variety of applications, a large number of additional tools are required. These are kept close at hand in external storage solutions, such as cabinets at the workstation [50].

The aim of the patent is to facilitate work processes by positioning the tool as close as possible to the machine and to improve workplace safety through proper storage [50].

The patent comprises a guide rail (140) mounted on the press brake, to which a movable carriage is attached. This sled carries a module carrier in which the necessary tools are safely stored. The mobility of the carriage along the guide rail allows the storage system to be flexibly positioned on the machine and adapted to the respective requirements [50].

In addition, the module carrier has a foldable storage surface that can be folded out as needed without disrupting the production process. This surface is used to store drawings and other work utensils, thus contributing to the creation of a variable and functional workplace directly at the machine. In addition, the system provides the option of attaching additional storage boxes for tools on both sides of the device [50].

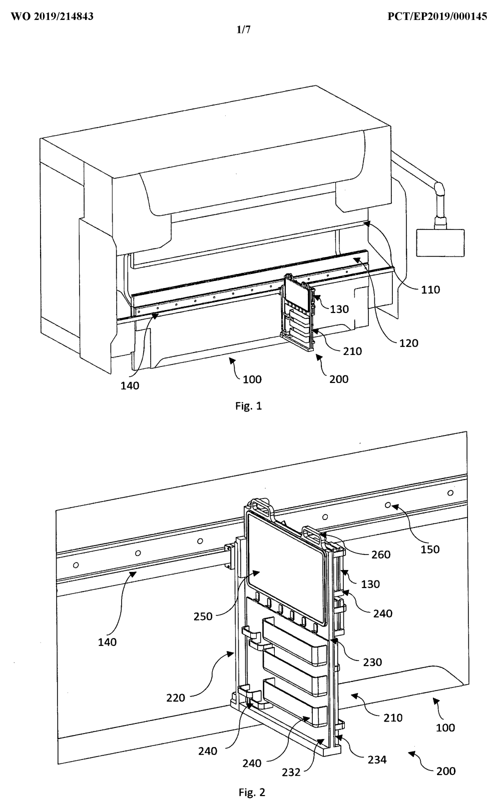


Figure 23: Patent EP3790679A1 tool storage system [30]

5.3.2 Compact workstation

The Patent DE10252537A1 (Figure 24) from 2004, describes a mobile workstation for work areas where the location changes frequently. The patent clearly focuses on providing a compact and portable system that can be deployed regardless of the work location and without the need for additional equipment. Unlike the workstations identified in the market research, this system already integrates all the necessary equipment and items required to function as a complete compact computer workstation that can be flexibly deployed at various work locations. The system does not require any additional customization beforehand [51].

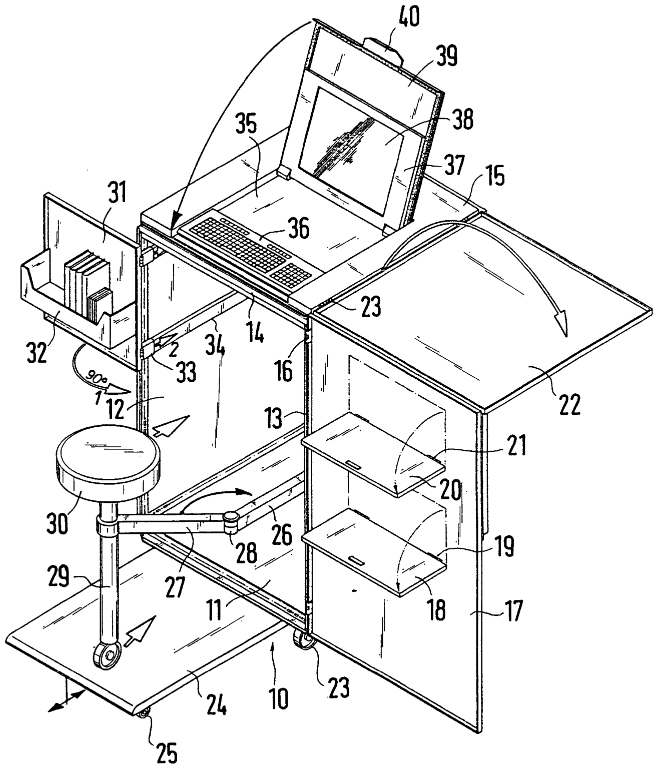


Figure 24: Patent DE10252537A1 compact workstation [31]

The system consists of a cube that can be unfolded using folding mechanisms, thereby significantly increasing the usable work surface. On the top is a flap that houses the screen and keyboard. When closed, this flap serves as a full-fledged work surface. The front of the cube (17) can be folded out to provide two additional fold-out storage surfaces (18 & 20) [51].

A retractable seat connected to the workstation via a swivel arm is provided for use while seated (30). An extendable base plate ensures the necessary stability (24). To ensure the mobility of the system, the underside is equipped with casters (23) so that the entire workstation can be easily moved to different locations [51].

Another patent that serves as a compact and mobile workstation is the patent DE202006000333U1 (Figure 25) from 2006 and describes a mobile workstation that takes a fundamentally different approach to previous solutions [52].

Instead of a folding cube system, the design is based on the shape and functionality of a pull-along trolley with a seat element placed on top (10). This design makes it particularly easy to use and highly mobile [52].

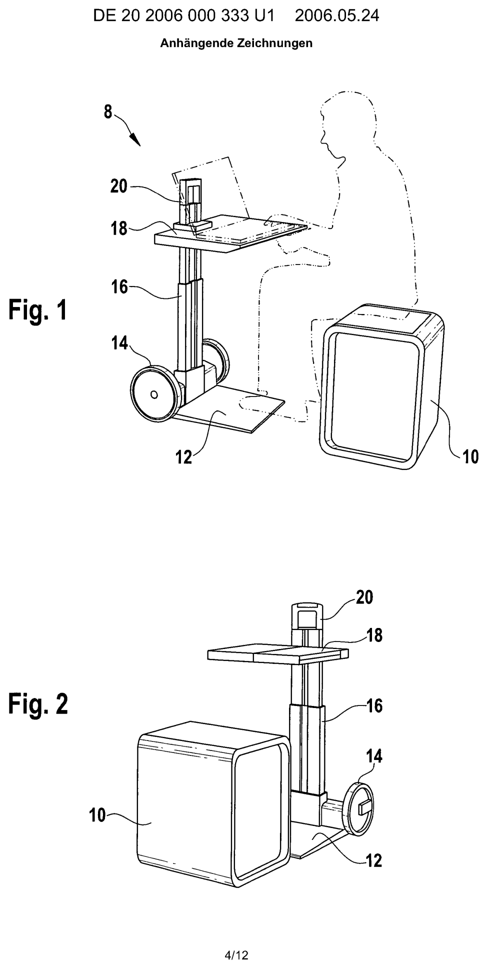


Figure 25: Patent DE202006000333U1 compact workstation [32]

The workstation has a height-adjustable shelf (18), which also has an extendable extension to increase the usable area if required. A stable base (12) ensures stability by supporting the user's feet, it also serves to position and hold the seat. The seat element itself (10) is multifunctional and includes an integrated drawer that serves as storage space. Two wheels on the underside and a handle on the top make the entire unit easy to transport. If the worker wants to work in one place, the trolley is simply parked, and the seat element is moved into position. If the workstation is needed in another location, the system can be quickly assembled and pulled along [52].

5.3.3 Summary and Findings of existing technologies

In conclusion, the current market offers a wide range of mobile workstation solutions for industrial applications. The market analysis shows that mobile and modular workstations, in particular, provide valuable inspiration for further development. The patents investigated also demonstrate innovative approaches to space optimization through folding and seating combinations as an integrated system. However, the research highlights a critical problem. As of the current status of this thesis, there are no bases on planets other than Earth and, consequently, no workstations that can be examined, except on space stations such as the ISS. Nevertheless, this does not offer a viable solution, as no conventional workstation systems are available. Instead, they take the form of kitchen tables, storage surfaces, or laptop mounts designed for zero gravity. The systems examined are primarily designed for industrial floors and large-scale warehouses. This highlights the urgent need for a new development to address the work and space limitations in the LAM.

A complete list of all patents found can be found in appendix M.

6 Needs analysis of potential users

The design and development of new systems in highly specialized environments such as the LAM requires a deep understanding of operational requirements. To implement a solution that goes beyond theoretical or subjective assumptions, empirical data collection is essential.

The goal of this chapter is to conduct a comprehensive needs analysis that will serve as the foundation for the subsequent development process of the mobile working platform. To create a requirements profile, a methodological mix of an expert survey and expert interviews was chosen.

The synergy of these two methods provides detailed insights that are directly integrated into the list of requirements. This ensures that the final platform fulfills the actual needs of future LAM users.

6.1 Survey

In order to develop a solution that goes beyond the theoretical and subjective assumptions of the student, empirical data collection in the form of an expert survey is essential.

The use of a mobile working platform takes place under limited spatial conditions and an existing installation space structure. The survey serves to ensure user-centered design by obtaining direct feedback from experts at DLR Bremen. The survey defines specific functional requirements such as determining the tools and aids, identifying the main tasks of the platform, and the most promising mobility concept. The evaluated data is incorporated into the development of a mobile working platform.

In order to obtain a holistic picture of the requirements, the survey was structured around the following main points:

- **Background profile of survey participants:**
  Determination of participants' professional experience and expertise
- **Identification of the main tasks of the mobile working platform:**
  Prioritization and determination of the task areas to be covered
- **Tools required for the tasks:**
  Analysis of the tools and aids required in their respective areas of responsibility
- **Platform functions:**
  Evaluation of functions such as storage options or seating options
- **Evaluation of design options:**
  Evaluation of examples from market and patent research
- **Final feedback:**
  The opportunity to leave individual wishes, ideas or comments

6.1.1 Background profile of participants

This survey is based on the participation of ten employees from the DLR site in Bremen who have a highly specialized professional background. The participants are familiar with the relevant projects EDEN-ISS and LAM. The evaluation shows a clear dominance in the field of aerospace engineering, followed by expertise in biology, space sciences, and "other" fields, as shown in Figure 26. In terms of professional experience, the picture is mixed, ranging from entry-level employees to experts with over 15 years of professional experience.

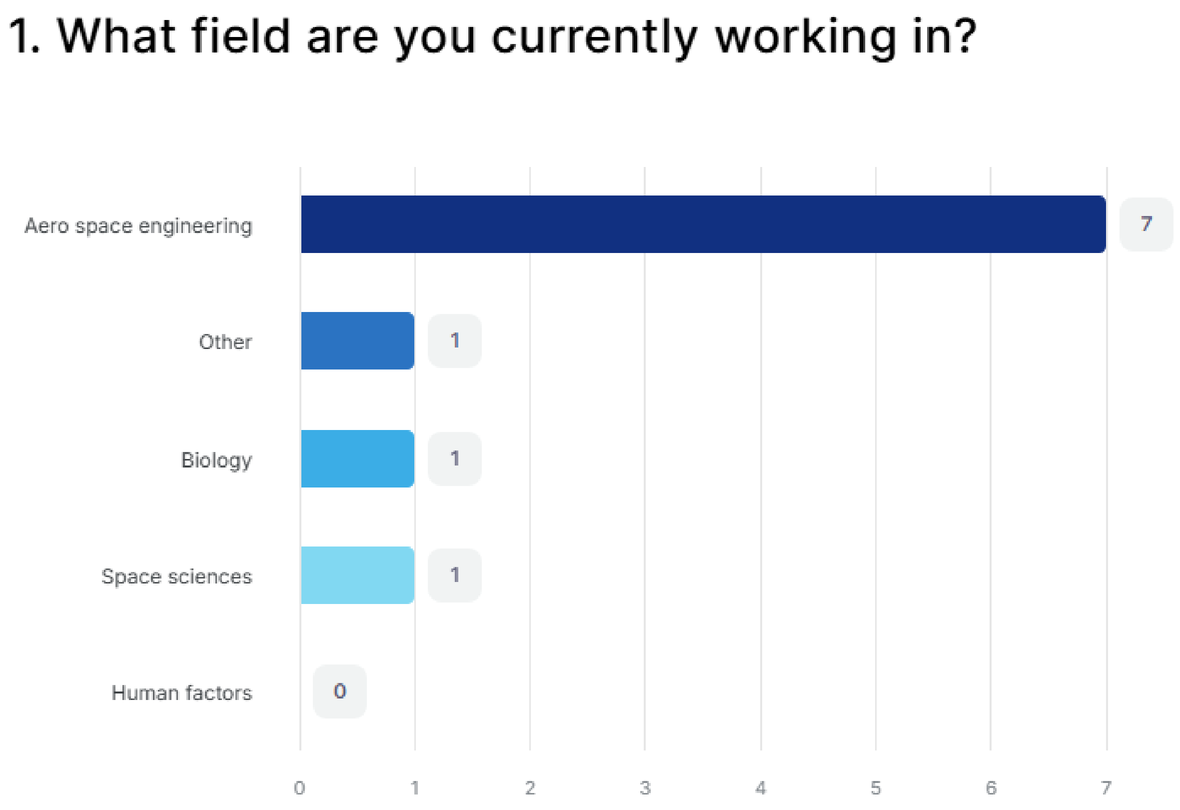


Figure 26: First question from the DLR internal expert survey

Identification of the main tasks of the mobile working platform

A key objective of the survey was to identify the primary tasks that the mobile working platform needs to support. Respondents identified "sowing and germination" and "plant care" as the highest priority tasks, followed by 'pruning' and "harvesting." Maintenance tasks were considered relevant, while transport and observation tasks play a secondary role. In the feedback section, it was emphasized that cleaning and disinfection tasks must be considered essential components of plant-based work.

Tools required for the tasks

In addition to the tasks, specific tools and equipment were identified. Containers for edible and non-edible biomass and cutting tools such as shears and knives are essential for harvesting and plant care. Placing sticks are primarily needed for sowing processes. In the feedback section, an important detail was mentioned: cutting the rockwool in which the plants are located as a soil substitute should ideally be done outside the plant cultivation module. In addition, equipment for documentation and cleaning is also required.

Platform functions

When designing the platform, participants prioritized tool storage and accessibility to the upper plant levels. In terms of storage options, drawers were clearly preferred over open solutions.

There was a high degree of agreement regarding modularity and expandability to suit individual user needs. A multifunctional concept combining a seat with a step to enable working in a seated position while still reaching the top plant trays was rated particularly positively. In addition, participants indicated that precise positioning of the platform was very important to them, but no clear conclusion was reached regarding mobility options such as casters or a rail-guided system. With a two-thirds majority, participants preferred a freely positionable solution such as a tool trolley, while one-third opted for a linear solution.

Evaluation of design options

When evaluating visually presented mobility solutions, there was a clear contradiction regarding the free positioning of the platform. Although two-thirds of respondents preferred free positioning, concrete visual representations painted a different picture. Here, the rail-guided design option, which is mounted directly on the plant rack, received the highest rating. In contrast, a freely movable workstation was rated significantly lower. This contradicts the two-thirds majority from the previous section who were in favor of free positioning.

Final feedback

Lastly, the free text section highlights the spatial limitations within the plant cultivation module. Previous solutions, such as the tool trolley used in the EDEN ISS project, were found to be cumbersome and completely blocked the narrow corridor. The future design solution must therefore be more compact and must not completely block the corridor. In addition, the desire for a step stool was mentioned once again in order to use it as a substitute for a chair when working in a seated position and, at the same time, as a solution for reaching the top plant trays in the LAM.

A complete analysis and evaluation of all questions in the survey can be found in written form in appendix G, where all 31 questions in the survey are also included as an illustration.

6.2 Expert Interview

Developing a work platform for the LAM requires not only theoretical knowledge but also a deep understanding of the challenges encountered in real-world conditions. For this reason, the survey results were supplemented by qualitative expert interviews. The aim of these interviews was to bridge the gap between theoretical assumptions, participant expectations, and actual reality.

The experts interviewed work at DLR Bremen and are:

- Jess Bunchek – Ph.D. Candidate
- Markus Dorn – Research Assistant

Not only do they possess in-depth expertise in working with plants, but also bring 14 months of experience from the time at the MTF of the EDEN ISS Project, like Jess. Through their work in the greenhouse and laboratory in Bremen, they have gained solid practical knowledge of which equipment and tools are truly necessary. They are familiar with the space limitations involved in performing botanical tasks, documentation, and maintenance work. Their practical insights are essential for designing the mobile work platform in a way that meets the actual needs of future workers on the Moon in the LAM.

Although the previous internal survey was already highly informative and provided a clear foundation of necessary tools and requirements, the expert interviews added further details to the data, even though the level of agreement was very high.

Sowing and germination

In the area of sowing and germination, the survey revealed a clear preference for tweezers and sticks for working with rockwool. The experts confirmed this and provided further details on the practical requirements. Jess emphasized that, due to the varying seed sizes and the small openings in the rockwool cubes, a set of two to three different types of plant tweezers is necessary. Markus added that the rockwool cubes should be prepared in advance with a knife or scalpel and that a weighing pan should be used to hold the seeds during the sowing process.

Pollination

Regarding pollination, the survey indicated a preference for tools such as brushes and cotton sticks. Markus explained, however, that active pollination in the plant cultivation module should generally be avoided. If tools are nevertheless necessary for certain varieties, he recommends brushes over cotton sticks, as brushes tend to stick together when wet. Jess prefers to use only her hands for pollination.

Pruning and plant care

According to the survey, the main tools needed for plant care and regular pruning are shears, cords, storage containers, and disinfectant. In practice, Jess uses three different pairs of shears for this: a very fine pair for detailed work, a medium-sized pair, and a large pair for plants with thick stems. Markus confirms this need and always carries a small magnifying glass to inspect plants for pests and fungi. He uses a pocket knife for quick interventions.

Harvesting

When it came to harvesting and managing the biomass, practical experience differed slightly from the theoretical expectations of the survey, which prioritized storage containers, shears, and knives. While large trays are used for major harvests, Jess noted that a set of small, stackable boxes is sufficient for daily, regular harvests. Markus confirmed that small storage containers are adequate for daily harvesting.

Observation and Monitoring

In the field of documentation and observation, the survey revealed a desire for clipboards, pens, and a holder for documentation equipment. Here, the experts demonstrate different, highly personal preferences. Jess pointed out that electronic data collection is the global scientific standard and therefore recommends using tablets or laptops. Markus, on the other hand, prefers pens and a notepad for quick routine checks. A scale and a folding ruler were also mentioned as essential for documenting harvests and growth.

Maintenance and system maintenance

System maintenance and cleaning are also part of the day-to-day work in the plant cultivation module. Jess explained that only hydrogen peroxide should be used for disinfection near plants, as alcohol-based products are toxic to them. She prefers to use paper towels for wiping, while Markus, on the other hand, first uses cotton cloths for larger amounts of liquid and then dries them off with paper towels. For standard maintenance and leaks, common household tools such as a tool set and Teflon tape are sufficient.

Additional questions

The insights gathered are directly fed into the general requirements for the platform design. Jess once again emphasized that a self build tool trolley at the MTF was too bulky and blocked the entire corridor, and this must not be the case with the platform. Her guiding principle for the design is therefore “keep it simple” to avoid over-engineering. Finally, both experts confirmed that, due to the height of the top plant trays, a raised platform is necessary to reach them. Without this raised platform, workers cannot see into the back corners of the racks, where condensation and, consequently, fungal infections can often form.

The findings of the research have resulted in a list of requirements, which can be found in appendix H. In addition, appendix M contains the transcripts of the interviews as well as the audio recordings.

7 Idea development for a mobile working platform

The development of ideas is an essential first step in generating a visually visible solution for the development of a mobile working platform related to the LAM corridor and the plant racks. The ideas serve as the first step between the vision and the implementable product idea. The aim of idea generation is to consciously think “outside the box” and not to be overly constrained by technical or other restrictions at this stage. This makes it possible to generate partial ideas that can be implemented in the development of concepts, taking into account feasibility, usability, and the fulfillment of requirements.

The Morphological Box is used as a creativity technique to provide a largely objective and self-guided method for systematically generating ideas, drawing inspiration from market and patent research.

7.1 Systematic idea generation using morphological box

The first step is to define the task: the development of a mobile working platform. Next, the parameters representing different aspects of the overall task are defined in the left column of a table. The parameters are assigned different characteristics in the right columns, which represent possible partial solutions. In the final step, combinations are formed based on the top row of the table by selecting exactly one characteristic for each parameter. Each complete combination of characteristics results in an independent concept idea for a mobile work platform [53]. The morphological box used with the defined parameters, partial solutions, and combinations is shown in Figure 27.

Idea	Skate-Hub	Modu-Hub	Comp-Cube	The Rig	Tool Cruiser	Pro-Bench	Slide Bench	Sit and Slide	Bench 2 Go
System position	Corridor	ISPR							
System basis inspiration	Mobile work station	Tool trolley	Modular, adaptable work station	Patent: pull-along trolley	Patent: rail storage system				
Mobility concept	Linear ground. Circular rail transport system	Linear ground. Parking rails	Linear ground. Bunnings rails	Freely ground. Casters	Linear wall. rails				
Work surface	Static surface	Foldable without support element to the floor	Foldable with support element to the floor	Fold-out, divided into three sections	Pull-out work surface				
Height adjustment	None	telescopic mechanism	lift table/scissor mechanism	height-adjustable table leg					
Seating/stepping option	None	Rolling stool	Office stool	Leaning stool	Folding step stool	Folding step ladder			
Main storage options	Drawers	Stackable toolboxes							
Secondary storage options	None	Tool click mount	Nets						
Expansion options	None	Tool hole wall	Swivel arm with storage option	Grooves with the option to attach items in them	Poles with the option of mounting objects				
Biomass management	Bags	Container							
Trash management	fold-out trash can	pull-out trash can	hanging trash bags	Container / trash can					

- Skate-Hub
- Modu-Hub
- Comp-Cube
- The-Rig
- Tool Cruiser
- Pro-Bench
- Slide Bench
- Sit and Slide
- Bench 2 Go

Figure 27: Morphological box containing connections between platform ideas

A total of nine variants were combined, each of which was developed into a separate basic idea. The following section presents the developed basic ideas in detail. The focus is on describing their characteristic features and how they work.

7.1.1 Skate-Hub

The linearly movable platform idea Skate-Hub offers an extendable work surface that functions as a compact and space-saving system when folded.

The sketch of the idea can be seen in Figure 28. The basic principle is based on the main body resting like a kind of sliding carriage on a linear movement system (rails, parking rails, etc.). This makes it possible to push the idea along the corridor of the LAM and place it at the desired work location. To reach the top level of the plant trays, the folded main body serves as a stepping panel onto which the worker can climb. The worker then places the plant tray on the work surface and can extend it to the desired working height for standing work. A scissor mechanism or extendable rods are provided for this function. When extended, there is a recess in the base plate of the main body in which fold-out containers for biomass and waste can be placed. There are recesses on the side of the work surface that can be used to attach the tools that the worker needs. A drawer is integrated into the work surface, in which materials that are important but not used as often as the tools attached to the platform side can be stored.

However, there are challenges with the basic idea of the Skate-Hub, such as the risk of tripping when the rails are mounted on the floor and the subsequent adjustment of the work surface height.

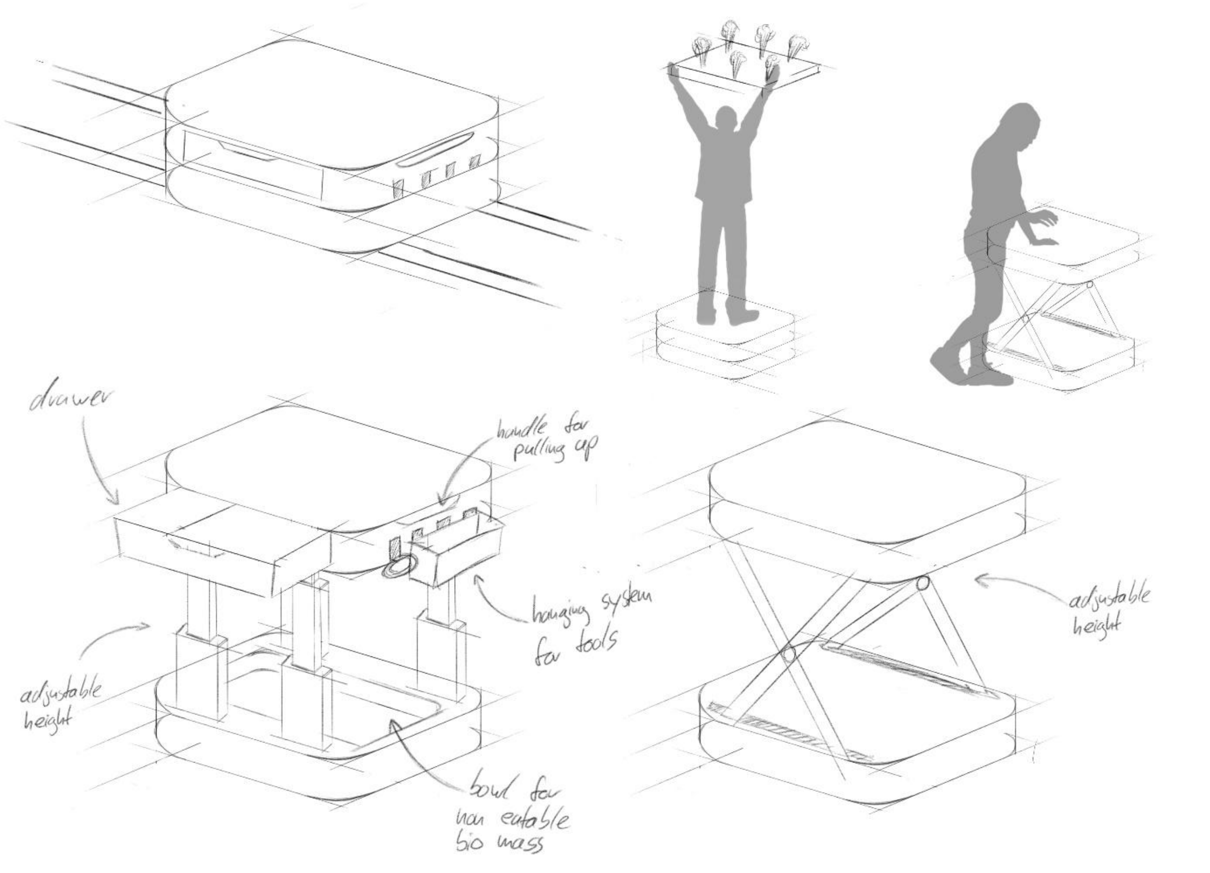


Figure 28: Sketch of the mobile working platform idea Skate-Hub [33] [34]

7.1.2 Modu-Hub

The Modu-Hub platform idea is a work platform mounted on plant racks that can be moved linearly to the desired location. A sketch of the concept can be seen in Figure 29. The main body is a narrow platform with containers mounted at its end for biomass and waste management. The boxes for biomass can be stacked and removed. The base plate between the containers is free and provides a storage area for tools. Above this is a storage system consisting of several drawers in which all tools and materials for the intended work areas can be stored. For mobility, rails are mounted on the plant racks, on which sleds are mounted to carry the platform. A hybrid seating option is provided for working in a seated or standing position, as well as for removing the plant tray from the top level. This is a fold-out ladder that can be hung on hooks on a suspension system below the platform. A fold-out panel serves as a work surface and has a supporting element on its underside so that it can bear the required load of the plant trays and tools. The support element can be folded into the underside of the worktop when not in use.

Despite the promising approach of the idea, there are still challenges to be addressed, such as securing the ladder, since it is suspended from only two hooks and ensuring the stability of the system, since it is mounted on only one rail.

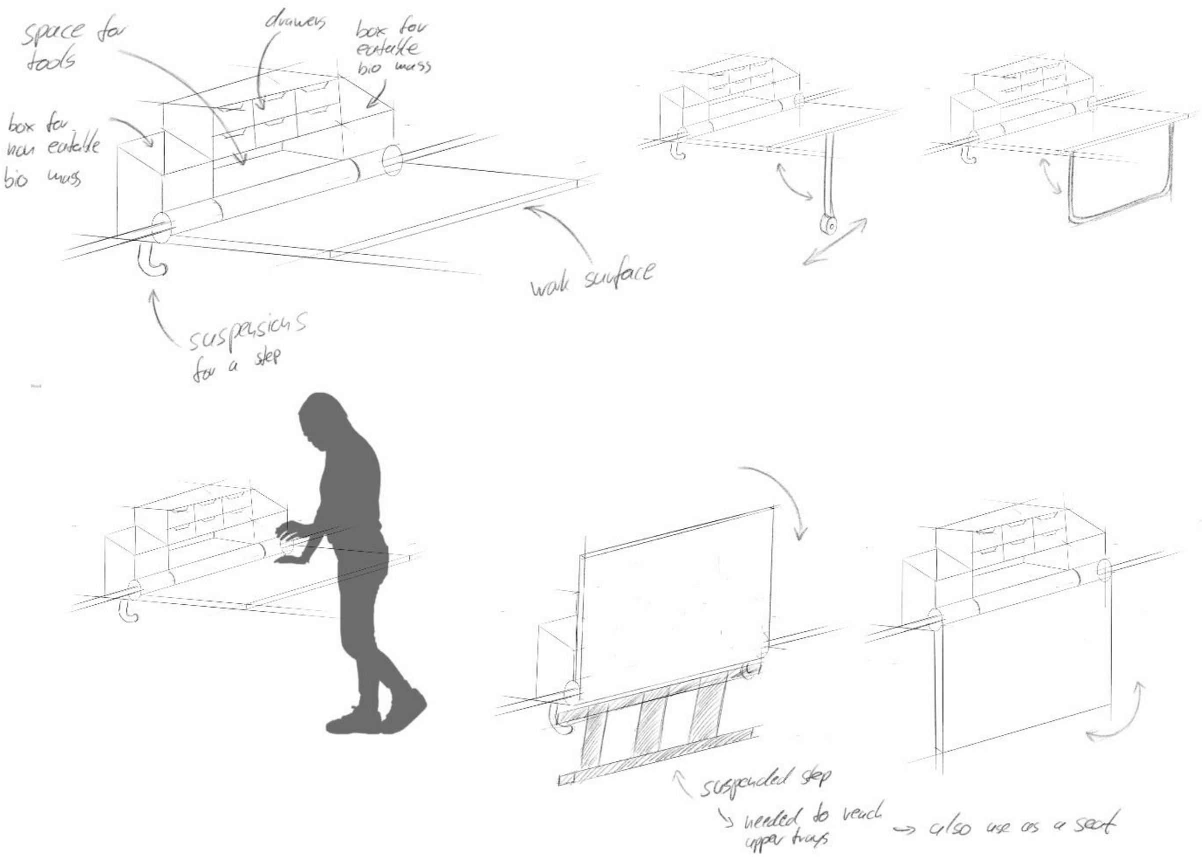


Figure 29: Sketch of the mobile working platform idea Modu-Hub [34]

7.1.3 Comp-Cube

The name Comp-Cube refers to the special feature of the platform design. It is a compact cube as the main body with a handle at the top so that the user can pull it behind them like a trolley when folded (Figure 30). Trolley mode allows users to freely position the platform in the LAM corridor and set up a workstation at any location. Once the workstation location has been selected, the handle can be pulled out to serve as a supporting element for the work surface. This is divided into three segments: the main work surface and two fold-out panels that extend the main work surface. When folded out, this provides space for a plant tray and tools can be placed next to it. The pull-out handle allows the work surface to be individually adjusted to the worker's height and enables a working position that allows both standing and sitting. To enable working in a seated position, a fold-out seat is integrated into the main body. This also serves as a stepping panel, allowing the worker to reach and remove the plant trays on the top level. A drawer for storing the necessary tools is integrated under the work surface in the main body of the cube. This is located in front of the worker and allows tools to be quickly accessed and changed. A large pull-out element is integrated into the side of the main body for biomass and trash management. A storage net is attached to the side of the Comp-Cube for easy storage of items such as a notebook with pens. In summary, the idea is a very compact, and mobile all-in-one solution for tackling tasks in LAM.

To reach the upper plant trays, it is necessary to redesign the seating arrangement to allow access to them or to implement a new solution.

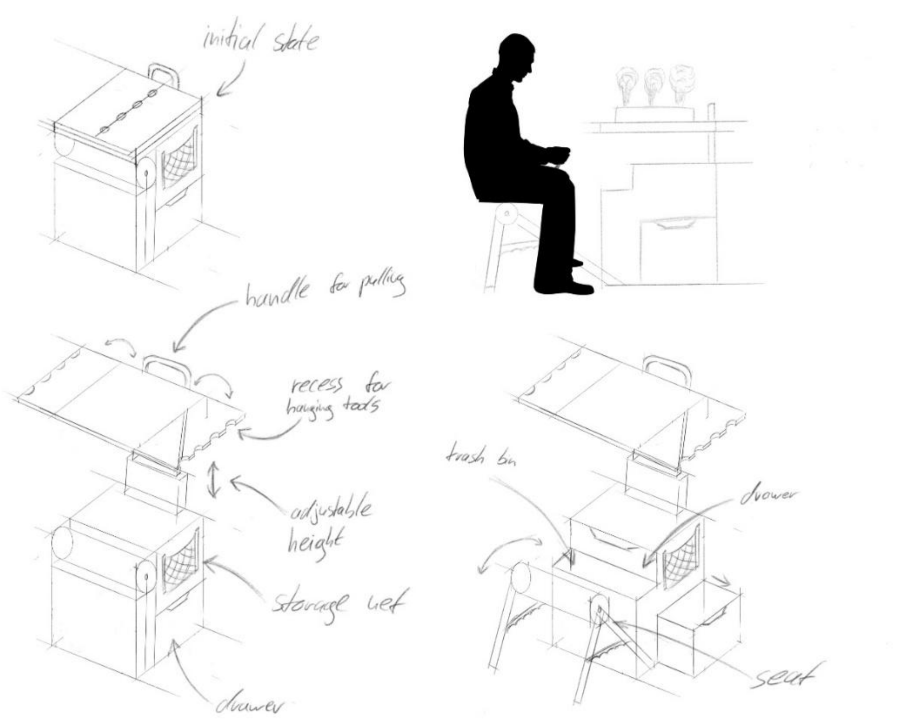


Figure 30: Sketch of the mobile working platform idea Comp-Cube [35]

7.1.4 The Rig

The idea presented here, The Rig, shown in Figure 31, consists of a long base plate with vertically mounted side panels. On the base plate, next to the side panels on the left and right outer sides, there are containers for biomass and trash management. Next to the containers, two storage systems with drawers are installed, providing sufficient space for the tools required for plant-based and cleaning tasks. A striking feature of the idea is its narrow appearance. This is because the work surface is divided into two parts. When folded, one half is located above the storage systems and the container. However, when unfolded, two narrow surfaces create one large work surface. The space between the storage systems allows the worker to place the plant tray and carry out the necessary tasks. The system is mounted on ball bearing slides on rails located on the plant racks, which allow the platform to be moved and positioned linearly. However, there is a challenge with the basic idea, as no hybrid sitting and stepping solution is integrated. A stool solution is planned, which allows the worker to work while sitting and to stand on it. However, this option is placed freely in the corridor. The Rig impresses with its simple basic structure and slim design, which does not block the corridor when folded and allows the worker to simply walk past it when not in use. In addition, the tools are easy to reach while working, as they are located in front of the worker and within easy reach. The overall solution provides a well-organized work environment but requires further development of a mounting bracket for the seating option.

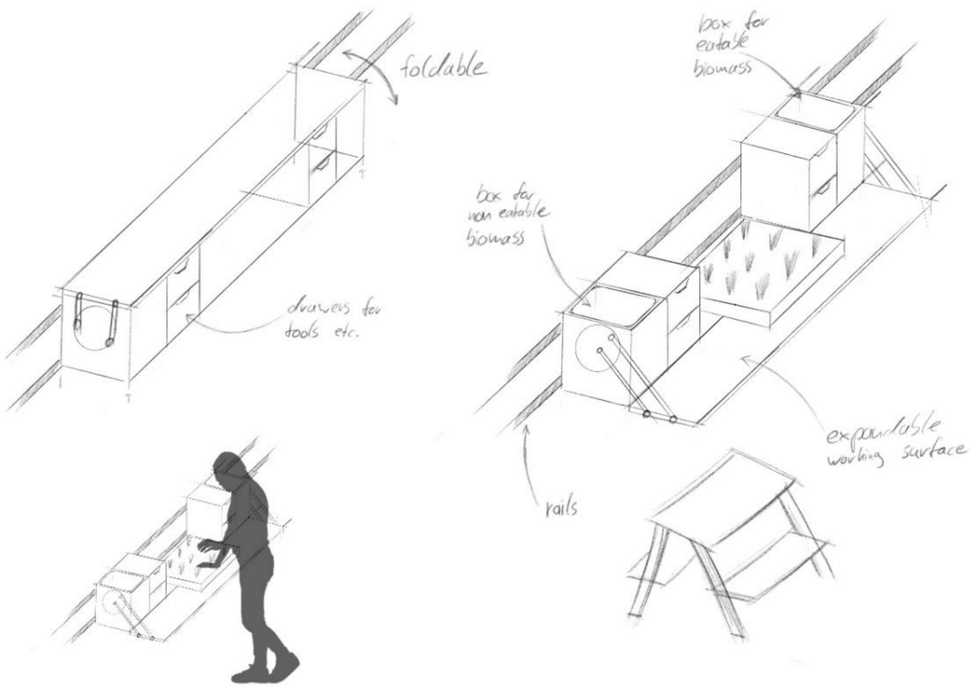


Figure 31: Sketch of the mobile working platform idea The Rig [34]

7.1.5 Tool Cruiser

The Tool Cruiser idea (Figure 32) is based on the basic principle of a classic workbench. Its most outstanding feature is the size of the work surface, which can accommodate a plant tray while also offering enough space to store tools or items such as for documentation. In addition, recesses are integrated at both ends of the Tool Cruiser, into which removable containers can be integrated for biomass and trash management. The work surface is supported by two storage systems consisting of drawers that provide very generous storage space. Next to the right-hand storage system, there is an integrated recess in which a hybrid sitting and stepping panel solution can be stowed away. When not in use, the user can fold it up and slide it into the recess. Casters or rails are provided for mobility, both of which are options in this design. Casters allow the design to be freely positioned in the LAM corridor, but the same goal can be achieved with rails integrated into the floor. To move the system, two large handles are attached to the ends of the work surface, allowing it to be pulled or pushed. The advantage of the Tool-Cruiser is that it is a very spacious and large workstation, and the worker has plenty of legroom in a seated position, just like at a desk.

However, in addition to the advantages, there are challenges that must be considered, such as the overall size of the system and the need to minimize its dimensions as much as possible to avoid blocking the LAM corridor.

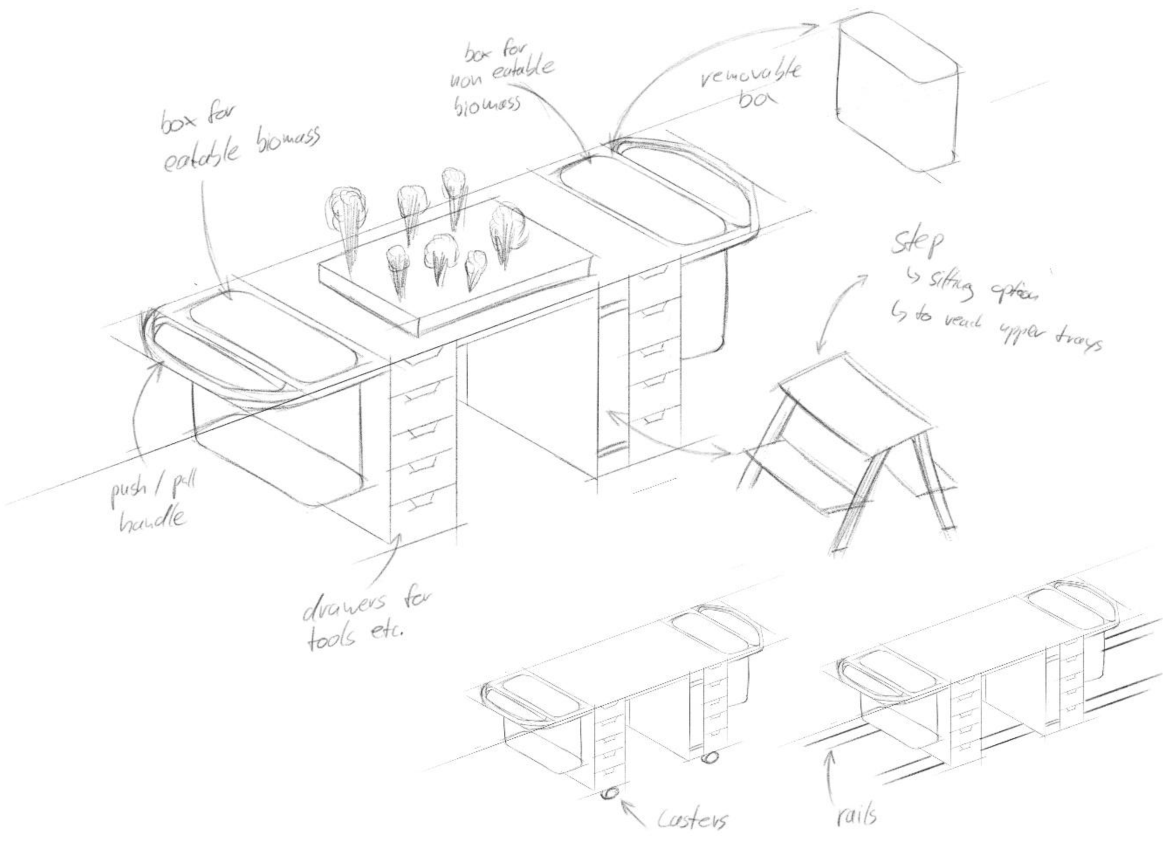


Figure 32: Sketch of the mobile working platform idea Tool Cruiser

7.1.6 Pro-Bench

Pro-Bench is a narrow rectangular system that is mounted on the plant racks and has a linear mobility concept thanks to rails, as shown in Figure 33. In the upper half of the system, six drawers are integrated into the main body, providing sufficient storage space for all necessary tools and tasks. Below this is a flip-up element for biomass and trash management. Containers can be placed side by side and removed from this element. Grooves are embedded in the upper half of the left and right outer sides of the main body. These allow the user to insert various attachments into the grooves, such as tool holders or open containers in which cleaning utensils such as disinfectant spray or cotton cloths can be placed. Alternatively, containers for biomass management can be attached to the side of the Pro-Bench instead of using the folding mechanism on the underside. This offers the user an option to adapt to individual tasks. Nets are attached under the grooves for storing items that do not require special protection, such as a notebook with pens. A stool is included with the system as a seat and stepping panel, which is placed in the corridor. A special feature of the Pro-Bench is the work surface, which can be pulled out from the rear of the system. This creates a system that hardly hinders the worker when not in use. Despite the space-saving design, challenges such as integrating the seating solution into the work platform and reaching the drawers when the work surface is folded out must be taken into account.

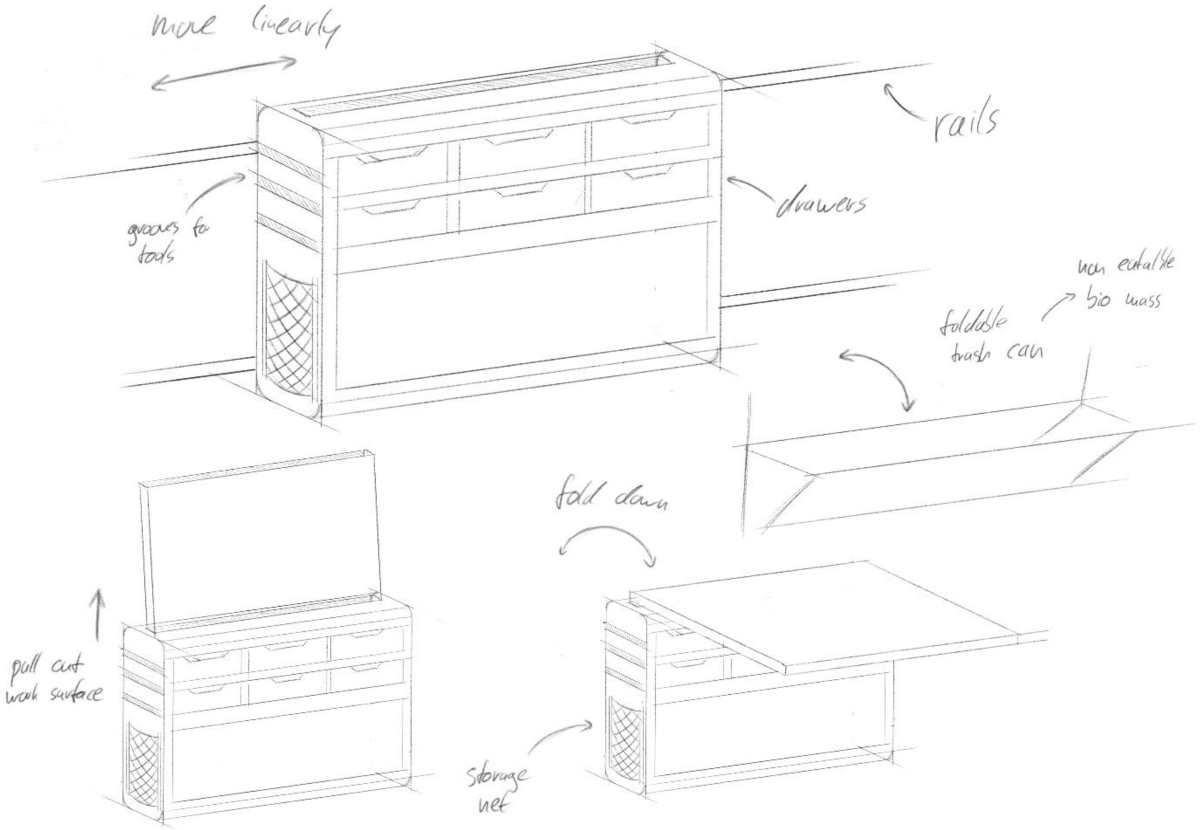


Figure 33: Sketch of the mobile working platform idea Pro-Bench

7.1.7 Slide Bench

After the Tool Cruiser, the Slide Bench is the most comprehensive system in terms of storage volume and system size (Figure 34). A striking feature is the rear of the system, which extends above the main body. The rear is a plate with holes that allows brackets with hooks to be placed in it. This means that tool holders or other add-ons can be placed across the entire surface in front of the worker. This is a customizable option that allows the selected tools to be placed within easy reach of the worker. The main body of the slide bench is divided into three different levels, with the two upper compartments intended for tools and other items such as containers for biomass. The lowest level serves as a storage space for a foldable ladder that can be used as a seat or as a stepping panel to reach the top level of the plant racks. The two levels above serve as storage space for plants and cleaning-related tools. The top area of the main body has recesses that allow kitchen roll, bags, or trash bags to be stored. This keeps the workspace tidy and allows quick access to cleaning supplies. Directly below this is a square element on which a trash bag can be hung. Since the base area of the main body would be too small to use as a work surface, a fold-out work surface is attached. To stabilize it when folded, swivel hooks are integrated to secure the work surface. To give the system mobility, four ball bearing slides are attached to the back of the Slide-bench. These form a symbiosis with the rails and enable the system to be moved linearly. Thanks to its size, versatility, and adaptability, the slide bench offers the potential to adapt to potential mission changes. However, despite its advantages, there are also challenges such as the large installation space and the resulting lack of space in the LAM, especially when the work surface is folded out.

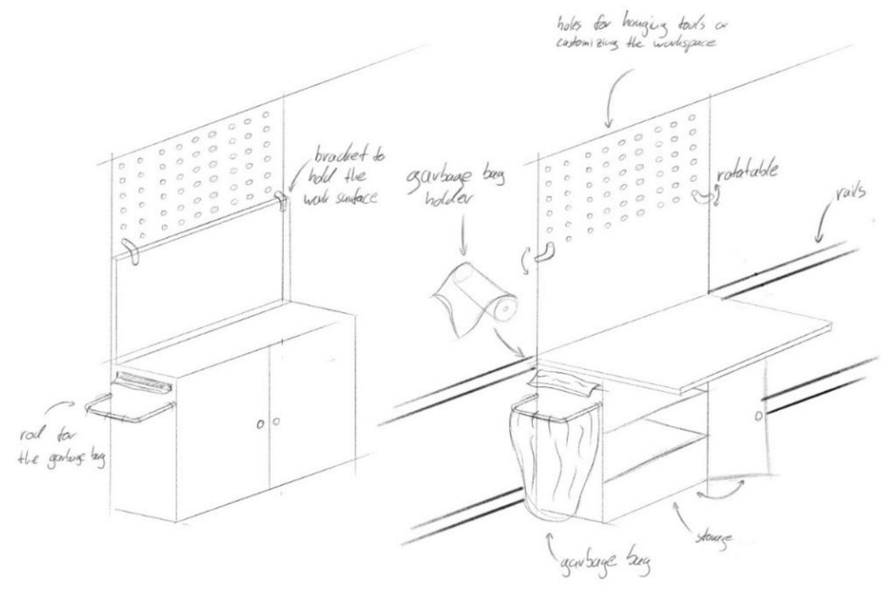


Figure 34: Sketch of the mobile working platform idea Slide Bench

7.1.8 Sit and Slide

Sit and Slide is a sliding working platform with an integrated seat, folding mechanisms, and storage systems. The idea is shown in Figure 35 as a sketch. The main body is a cube with two drawers in the upper third, which provide storage space for smaller tools such as scissors, knives, or tweezers. Below this is a drawer that takes up the entire base of the cube, thus offering twice as much storage space. This drawer can be used to store larger tools and items such as packs of nitrile gloves, cleaning materials, or documentation. In the bottom third of the main body, there is a large pull-out element that is used for biomass and waste management. Above it is a fold-out work surface that serves as an extension of the main work surface. At the rear of Sit and Slide is a rod system that serves to hold and extend tools. At the same time, it serves as handles for moving and positioning the system within the LAM. A bar system with a groove in the middle is attached to the underside of the main body. The groove is used to move a seat forward and backward. This allows the user to adjust their workstation to their height and place their feet on the floor to the left and right of the bar with the groove. The seat is also height-adjustable. To ensure mobility, four wheels with a braking mechanism are attached, similar to those on a shopping cart. One challenge with Sit and Slide is the space requirement, as the idea is to place it in the corridor of the LAM, which means it cannot be too wide. Another challenge is reaching the top level of the plant rack, it is questionable whether the stability and base area of the seat are sufficient to climb onto it. In addition, changing from a sitting to a standing position is made difficult by the seat system, which is an obstacle when standing. In addition, when working while seated, the work surface is not aligned with the user's upper body, which presents challenges that need to be addressed in further development.

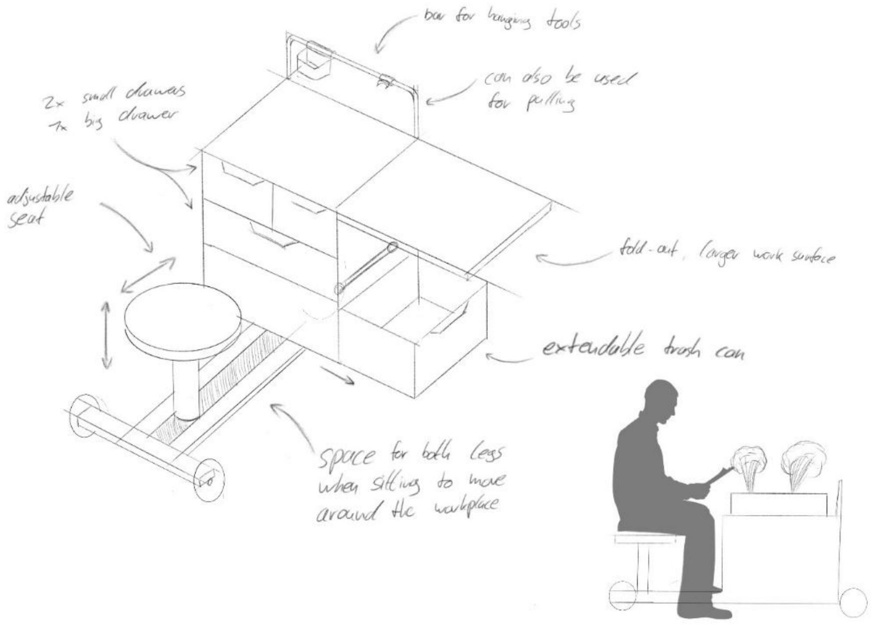


Figure 35: Sketch of the mobile working platform idea Sit and Slide [35]

7.1.9 Bench2Go

Bench2Go is based on the fundamental idea of compactness while still fulfilling its function (Figure 36). In compact mode, the main body is a space-saving workstation that can be placed in the corridor of the LAM when not in use. If the user wants to use the workstation, they can push or pull it in front of them using the handle. Two wheels on the underside of the Bench2Go ensure mobility. After placing and selecting the work location, a work surface can be folded out at the front and a plant tray placed on it. A tray is embedded in the top, which serves as a storage place for tools or other equipment. Underneath, in the upper half of the main body, there are three drawers in which all the tools required for the tasks at hand in the LAM-GTD can be stored. In the lower half of the main body, there is an element that the user can pull out and which functions as biomass and trash management. A ladder connected to the main body can be folded out from the back of the Bench2Go. This allows the user to reach the top levels of the plant racks. Challenges with this idea include stability, as there is a risk that the system could tip over to one side if too much weight is placed on one side of the work surface. A fold-out support element must be added to the underside of the work surface. Furthermore, a solution must be found to make the ladder removable rather than fixed to the main body, so that the user can also use it as a seat option for working in a seated position. This allows for more flexible working and different working postures.

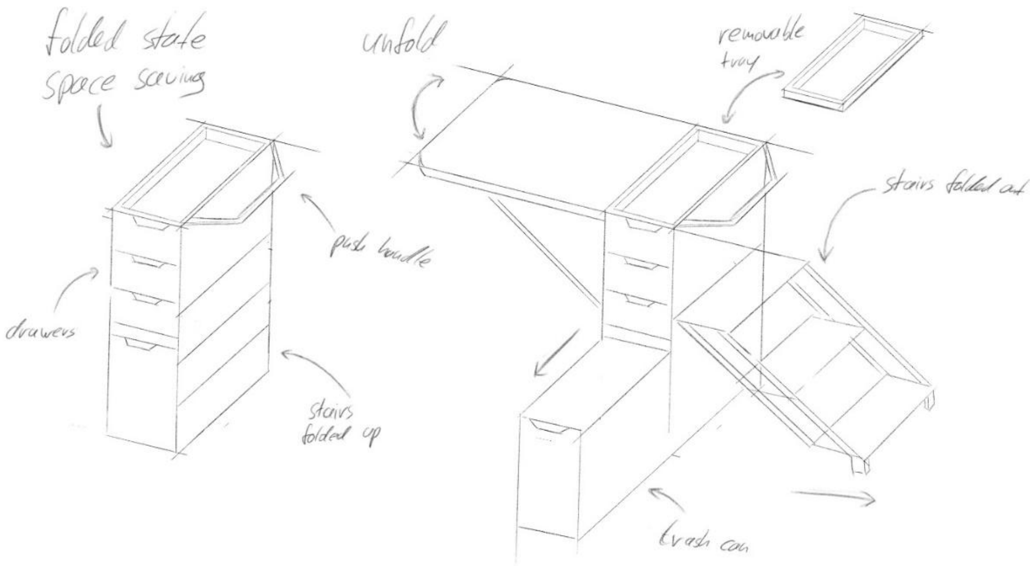


Figure 36: Sketch of the mobile working platform idea Bench2Go

Additional sketches and ideas that were not systematically developed using the morphological box and are too similar to the ideas presented can be found in appendix I.

7.2 Utility analysis

A utility analysis is performed to compare the ideas that have been developed. Selected evaluation criteria are listed in a table, each of which is divided into several sub-criteria for a more detailed comparison. The individual criteria are then evaluated using a points scale and their total is multiplied by a weighting factor. This enables the most promising ideas to be systematically identified.

7.2.1 Evaluation and subcriteria

The basic research, survey, and interviews resulted in four evaluation criteria and 14 subcriteria, with the subcriteria listed in Table 6. The first evaluation criterion is functionality and task coverage, which serves as the foundation for the mobile working platform and, at the same time, provides its key added value. The second evaluation criterion is ergonomics and user-friendliness, which concerns user-centered adaptation and use. Technical implementation deals with the implementation of the mobile working platform based on the given basis of the LAM. The final evaluation criterion is safety, material design, and hygiene, which concerns safety of use, surface design, and hygiene aspects.

Table 6: Evaluation criteria with descriptions

No.	Criteria	Description
1.1	Tool, waste and biomass management	Can all desired tools (scissors, tweezers, brushes, etc.) be stored sensibily and hygienically? Is separate storage for waste, edible and non-edible biomass integrated?
1.2	Mobility concept	The existing mobility concept is based on the responses of participants in the survey, ranging from rail-based systems to casters/wheels.
2.1	Cognitive ergonomics	Are all controls like handles or drawers logically placed, intuitive to use and easy to understand?
2.2	Hybrid seating and stepping solution	Is an integrated solution offered that serves as both a comfortable seat and a secure step, or can this be integrated into the Idea development?
2.3	Posture and reach	Does the design support natural movement and work processes (e.g., at waist height)? Are forced postures (bending over excessively, working above head height) avoided?
2.4	Effort required	Is the platform easy to move and lock in place? Is the effort required to push, pull and adjust minimal?
2.5	Compactness	How much space does the idea take up? Does it block the corridor when not in use? Can the worker simply past it?
2.6	Extensibility and modularity	Does the Idea offer potential for adaptility and modular design? Can it be adapted to that?
3.1	Integration into the LAM-GTD	How does the idea firit into the existing LAM-GTD structure and ISPR?

Table 7: Evaluation criteria with descriptions – Continuation of Table 6

3.2	Mechanical complexity	How simple is the design? A small number of moving parts minimizes sources of error and increase reliability.
3.3	Maintainability	Can the wear parts and mechanical components be easily accessed for inspection, replacement or repair?
4.1	Cleanability and hygienic design	Do the surfaces have a high surface quality (smooth, non-porous)? Are joints, crevices and cavities where biomass or germs can accumulate avoided?
4.2	Operational safety	Can safety risks such as pinch or shear points in folding mechanisms and sharp edges be minimized, e.g. with padding?
4.3	Safety	(Load capacity, stability, and tipping resistance) If the design provides a secure base, is there a possibility of tipping if loaded on one side? Can all tools be removed and placed on the panel with the plant tray without tipping?

7.2.2 Weighting of the criteria

Four key evaluation criteria (functionality and task coverage, ergonomics and user-friendlyness, technical implementation, and safety, material design and hygiene from the section 7.2.1) were established for the systematic and comprehensible evaluation of the ideas developed. Each criterion was assigned a different weighting, as shown in Figure 37. The weighting reflects the importance and objective of each evaluation criterion.

At 40%, functionality and task coverage is the criterion with the highest weighting. Functionality is the fundamental reason for the platform's existence, as its added value is measured by its coverage when all tasks can be performed reliably. It is essential here that the application scenarios are covered and that a corresponding solution for mobility and tool, waste, and biomass management prevails. This gives the criterion the highest priority.

The evaluation criterion of ergonomics and user-friendliness is weighted at 30% and thus represents the second central evaluation level. While functionality must first be ensured, ergonomic adaptation to the user is a decisive factor in usability in the application context. A mobile working platform that is functional but difficult, uncomfortable, or unintuitive to use fails to fulfill its practical purpose. Therefore, ergonomics and user-friendliness are weighted highly but deliberately chosen as the second most important criterion.

The evaluation criterion of technical implementation accounts for 20% of the overall evaluation. Although technical feasibility is essential for implementation, it is given less weight in this early idea phase. The reason for this is the assumption that suitable technical solutions can usually be found for ideas that are functionally and ergonomically convincing. Technical implementation is therefore primarily considered in terms of plausibility and basic realizability and is ranked below functionality and task coverage and ergonomics and user-friendliness.

The fourth evaluation criterion, safety, material design, and hygiene, is weighted at 10%. Although safety and hygiene are fundamentally critical aspects, they can only be evaluated to a limited extent within the current scope of this work. The ideas are at an early stage of development and are not sufficiently detailed, as is the case with concepts. Accordingly, this criterion serves primarily as an initial assessment of the potential in terms of safety during use, surface design, and basic hygiene suitability, without claiming to be a complete evaluation.

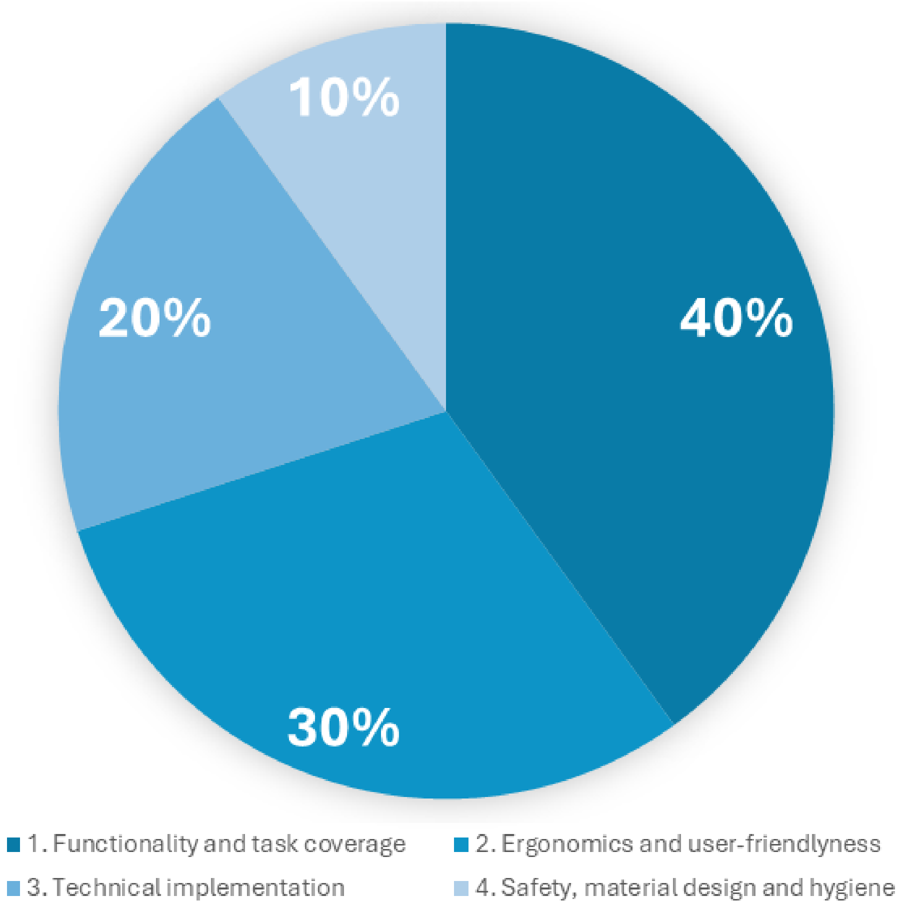


Figure 37: Evaluation criteria chart showing the percentage weighting

The weighting allows for a balanced but targeted evaluation of ideas, focusing on functionality and user-centred design, while technical and security-related aspects are taken into account in a context-appropriate way.

7.2.3 Evaluation of the point scale

After presenting the evaluation criteria and their respective weightings, the points are allocated within the individual subcriteria. Each subcriterion is evaluated on a criteria-specific point scale from one to four, with four points representing the maximum achievable score and one point representing the minimum score. Table 8 shows an example of how the individual points are awarded for the subcriterion “mobility concept”. A complete overview and Table of all point scales used can be found in the utility analysis in appendix M.

Table 8: Scoring breakdown for the sub-criterion "Mobility Concept"

Points	Description
4	Wall-mounted rails. According to the survey, this is the preferred mobility concept among participants, with an average rating of 3.6 out of 5 points.
3	Casters / rolls like a tool trolley. According to the survey, this is the second most popular mobility concept among participants, with an average rating of 2.8 out of 5 points.
2	Casters / rolls like a mobile workstation or modular, adaptable workstation. According to the survey, this is the second lowest rated mobility concept among participants, with an average rating of 2.3 (mobile workstation) and 1.9 (modular, adaptable workstation) out of 5 points.
1	Floor mounted rails. According to the survey, this is the lowest-rated mobility concept among participants, with an average rating of 0 out of 5 points.

7.3 Evaluation of idea assessment

In order to identify the ideas that stood out in the evaluation process and distinguished themselves from the alternatives, the individual concepts are systematically compared with each other in tabular form. Each idea can receive a maximum score of 10. First, the subcriteria assigned to the respective evaluation criteria are added up, resulting in the total value of each individual evaluation criterion. The total values determined for the four evaluation criteria are then multiplied by the previously defined weightings and combined to form a total value for each idea. The complete evaluation matrix is shown in the appendix, and Figure 38 shows the resulting ranking of the ideas as a supplementary visual illustration of the results.

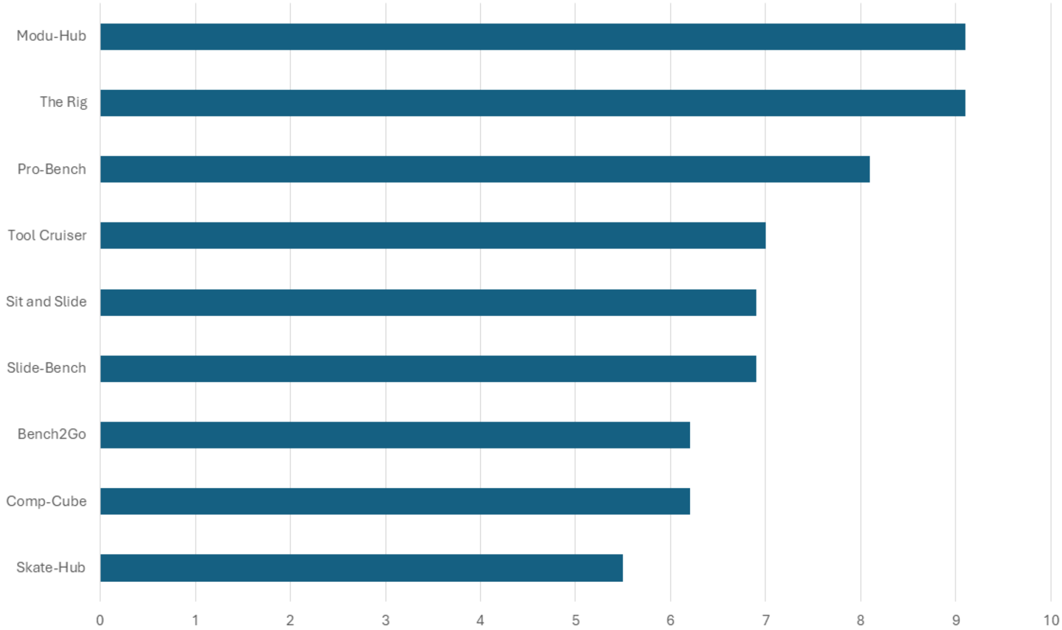


Figure 38: Bar Chart of the Idea Evaluation with Weighting

Modu-Hub and The Rig achieved identical overall scores of 9.1 points, placing them at the top of the ideas ranking alongside the Pro-Bench concept, which scored 8.1 points overall. The bar charts show that these three concepts clearly stand out from the other alternatives. It is striking that all three ideas are based on a common principle, namely a rail-based mobile working platform mounted on plant tracks.

Furthermore, it can be seen that these concepts are significantly different from the other ideas even without taking the defined weighting factors (maximum possible score of 56 points without weighting), as can be seen in Figure 39. This underlines the quality of the ideas and justifies their further development into concepts in the course of this work.

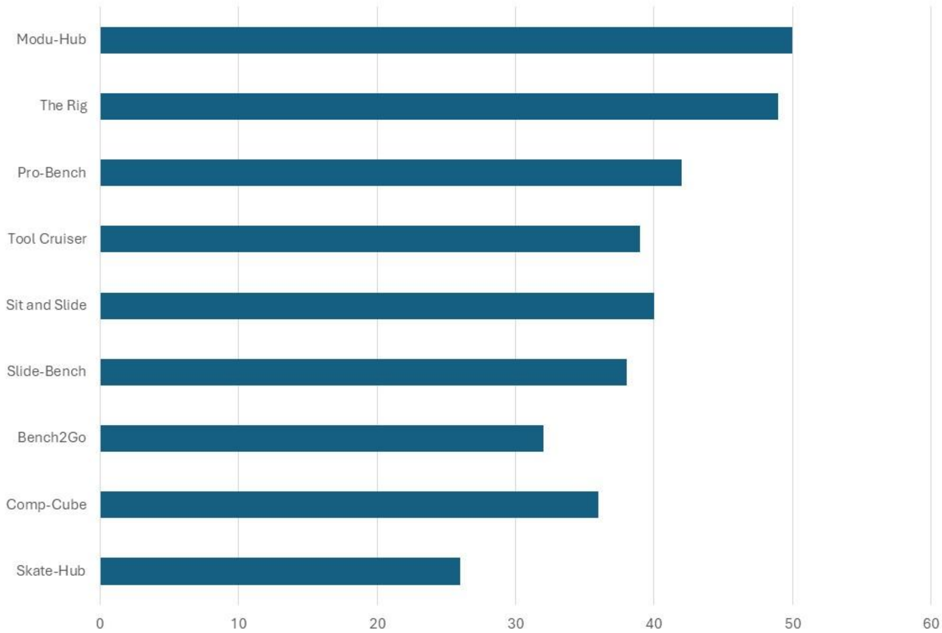


Figure 39: Bar Chart of the Idea Evaluation without Weighting

8 Concept creation based on the generated ideas

Building on the results of the idea evaluation, the three highest-rated concepts are further developed into complete designs. The goal is to concretize the selected ideas both functionally and visually and to refine their visual presentation to a significantly higher level of detail. By specifically highlighting details relevant to the concept, the visual comprehensibility of the functionalities and application scenarios is also improved.

A key focus of the design process is ensuring that the systems can be expanded as needed. In this context, a hybrid seating and stepping solution is integrated to enable users to work while standing or sitting, as well as to reach the top level of the plant racks. Furthermore, concepts are systematically adapted to meet the criteria defined in the requirements list whenever ideas do not fully address them. This ensures that the developed concepts fully meet the functional, ergonomic, and design objectives of the work.

8.1 The-Rig

The The-Rig concept (Figure 40) retains its fundamental conceptual structure as it transitions from the idea phase to a fully developed concept and continues to show clear visual similarities to the original idea. The main design adjustments relate in particular to the reorganization of the storage systems and containers, as well as the integration of a bar system for expanding tool and accessory storage and a mounting system for the hybrid seating and stepping solution.

The-Rig is designed as a mobile work platform and is characterized by its compact design and highly intuitive functionality. The system’s open structure also allows for flexible, retroactive adjustments to the layout to accommodate changing mission objectives or task requirements. At the same time, it ensures easy and direct access to all tools and equipment, thereby enhancing efficiency in the work process.

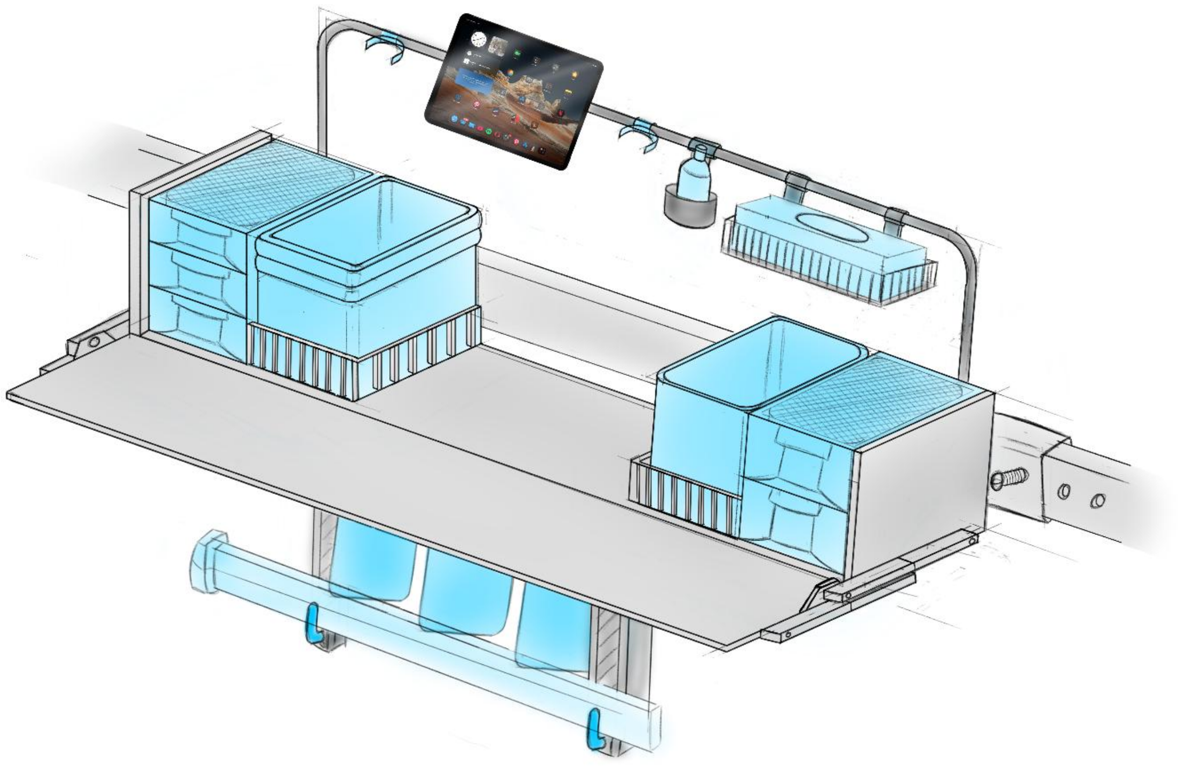


Figure 40: Mobile working platform concept The-Rig in the unfolded position

The storage systems are divided into two separate sections, each located on the outer sides of the concept. The storage system on the left is designed for plant-related tools and equipment and is divided into three drawers. Because these plant-related tools are relatively smaller in size, the storage system on the left has one more drawer.

The storage system located on the right-hand side, consists of only two drawers, as it for cleaning, documentation, and repair and maintenance tools, which require more space. The flat top surface of both storage systems also serves as additional storage space, thereby expanding the functional possibilities of the overall design.

On the inner sides of the concept, directly next to the storage systems, the components for waste and biomass management are arranged. On the left inner side are stackable plastic containers for the separate storage of edible and non-edible biomass. On the right inner side is a waste bin intended for non-biomass-related waste.

Both the waste bin and the biomass containers are secured by a surrounding barrier that prevents them from shifting uncontrollably while the platform is in motion, thereby ensuring they remain in place. Between these two areas, there is sufficient space in the central work area to position a plant tray and efficiently carry out the associated tasks.

A horizontal bar is integrated into the back of the design, allowing users to attach modular add-ons and customize them to suit their specific work style. Figure 41 shows examples of click-on holders that securely hold frequently used tools, preventing them from lying in the work area or falling off the work platform. In addition, a holder for disinfectant and a compartment for a pack of nitrile gloves are provided. These items are relatively voluminous, are needed regularly, and would unnecessarily disrupt the workflow if stored in drawers.

To support the necessary documentation processes, a tablet holder including a tablet is also mounted on the bar, ensuring that documentation is always accessible while working.

When the platform is not in use, the work surface can be folded up. This is achieved via an integrated folding mechanism consisting of two bars and supporting spring elements, which allows the work surface to be raised in a controlled manner with minimal effort.

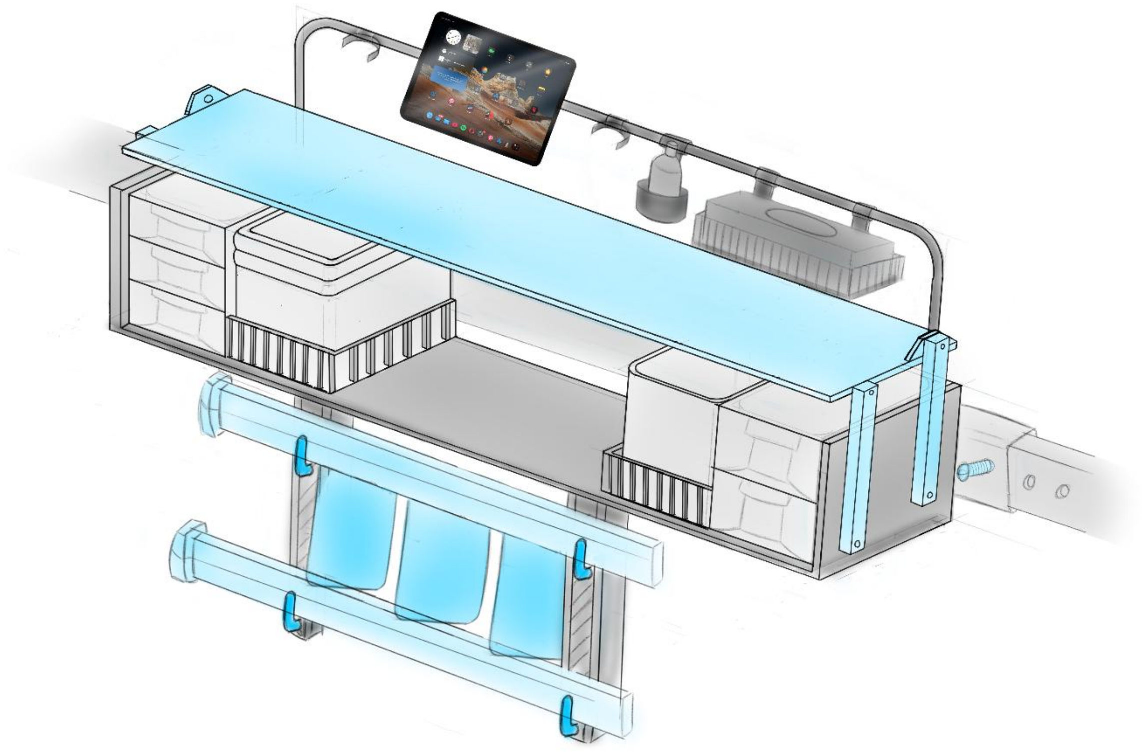


Figure 41: Mobile working platform concept The-Rig in the folded up position

Two rail carriages are attached to the back side of the concept, from which the main body of the concept is suspended. The carriages are mounted on a rail attached to the side of the plant rack, which is equipped with a series of holes for precise positioning. Each carriage has a bar with a knob at the upper end, held in position by spring force.

To secure the platform, the bar is inserted into the corresponding hole in the rail and held in place by the spring. If the user wishes to move the system, the knob is pulled, causing the bar to exit the rail so that the platform can be moved manually. Once the desired position is reached, the knob is released, allowing the bar to snap back into a hole thanks to the spring force, thereby securely locking the platform in place.

A suspension system is installed below the main body, consisting of two hooks that are height-adjustable. The height adjustment allows for flexible positioning, for example, when modifying the hybrid solution or using an alternative model. The hybrid seating and stepping solution is suspended from this suspension system.

If necessary, the user can remove the solution and position it according to their individual needs. The system supports both standing and sitting work positions and also allows access to the top level of the plant racks, so that even the highest plant trays can be easily removed, as shown in Figure 42.

The conceptual dimensions of The-Rig’s main body when not in use are 160 cm in length, 35 cm in depth (70 cm with the work surface folded out) and 60 cm in height, including the bar at the back. Plastic is intended as the material for the main body’s surface to ensure both durability and ease of maintenance.

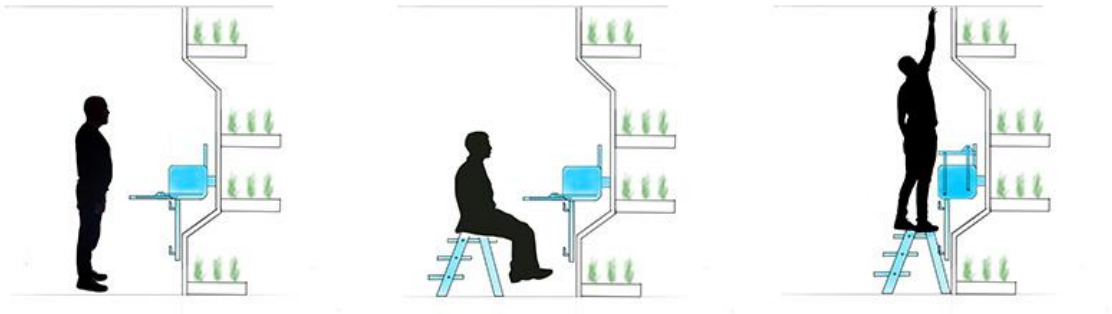


Figure 42: Working positions of the concept The-Rig [36] [37] [10]

8.2 Pro Bench

The Pro-Bench concept is a mobile work platform and, among the concepts developed, bears the greatest resemblance to a traditional workbench with a linear rail system. The concept remains particularly compact and is adapted to the physical conditions of the LAM-GTD. Similar to the The-Rig concept, the original basic idea behind the Pro-Bench remains clearly recognizable.

In terms of the visual adaptation of the basic idea into a finished concept, as shown in Figure 43, a hybrid step-and-seating solution and a rail system are specifically integrated into the back of the concept. These elements allow for both flexible adaptation to different work situations and the system’s expandability to additional usage scenarios.

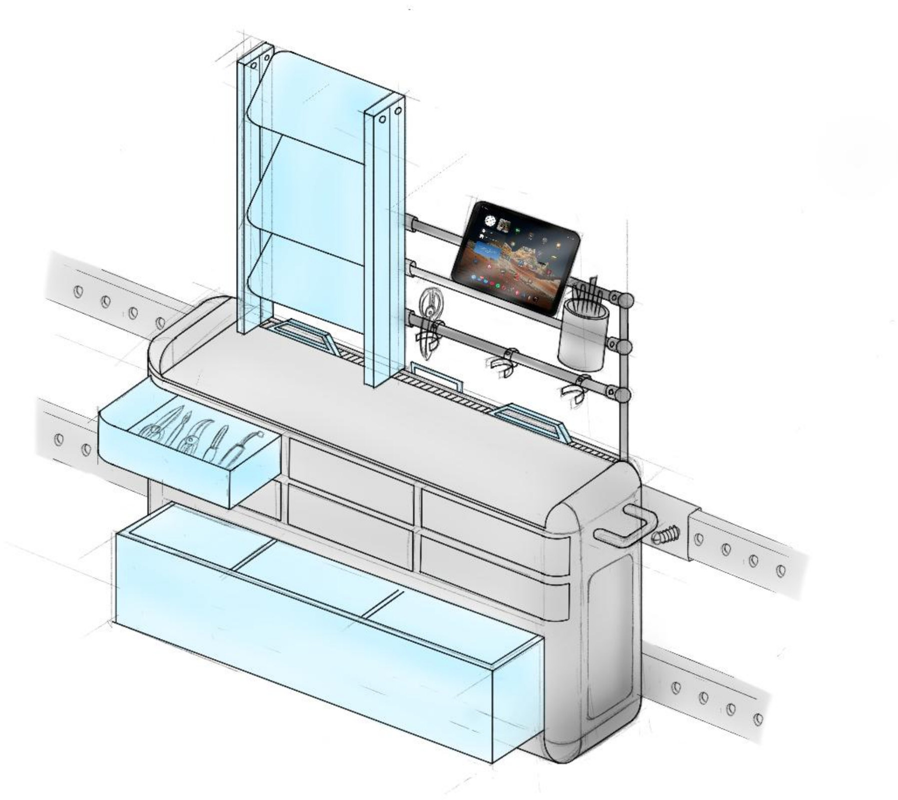


Figure 43: Pro Bench mobile working platform concept in the folded position

The storage system consists of a total of six drawers, arranged in two stacked rows, each containing three drawers. To ensure clear separation and structured organization of work materials, the upper drawers are designated for plant-related tools, while the lower drawers are used for supplies and tools for cleaning, documentation, repairs, and maintenance.

A large, pull-out system divided into three segments is integrated into the lower half of the main body. In the original concept, this system was designed to be tiltable, however, the decision was made to use a pull-out solution to maximize space efficiency. The left and middle segments hold containers for storing edible and non-edible biomass, while the right segment is intended for non-biomass-related waste.

To ensure the system's flexibility in terms of expansion and adaptability, a bar system is installed on the back, to which various click-in mechanisms can be attached for mounting tools, storage containers, a tablet holder (including a tablet) for documentation work, and a hook-mounted suspension system for the hybrid seating and stepping solution (Figure 44).

The rail system not only allows for expansion but also supports work preparation. Since the extended work surface restricts direct access to the drawers, the system enables the user to arrange all necessary tools and supplies in advance, thereby ensuring a seamless workflow.

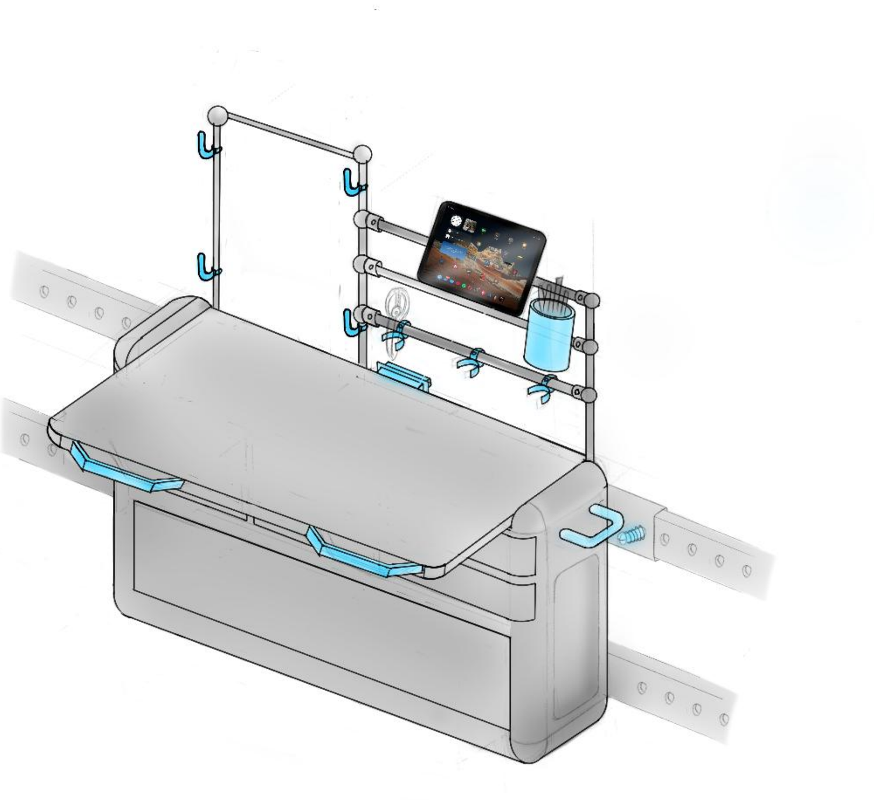


Figure 44: Pro Bench mobile working platform concept in the folded up position

The Pro-Bench work surface can be pulled out from the back by the user and securely locked into place using a recessed slot on the back. To assist with this process, two handles are attached to the front of the work surface, which improve handling and make it easier to safely pull out and lock the work surface into place.

To move the Pro-bench to the desired position, the system is mounted via a suspension system on four rail carriages, with two carriages per rail. The use of four carriages ensures that the system can still be moved even if one carriage fails.

The platform is secured by a bar with a knob at one end. A spring keeps the bar under constant tension, ensuring that it locks securely into a slot in the rail. If the user wishes to move the platform, they pull on the knob, causing the bar to disengage from the rail so that the platform can be moved manually by the handle. Once the desired position is reached, the knob is re-leased, allowing the rod to snap back into a slot in the rail.

For each usage scenario, a hybrid sitting and standing solution is mounted on the bar system and secured to a hook suspension. This solution allows the user to perform all work steps while either sitting or standing (Figure 45). In addition, the hybrid solution serves as a step to reach the top level of the plant trays so they can be taken out.

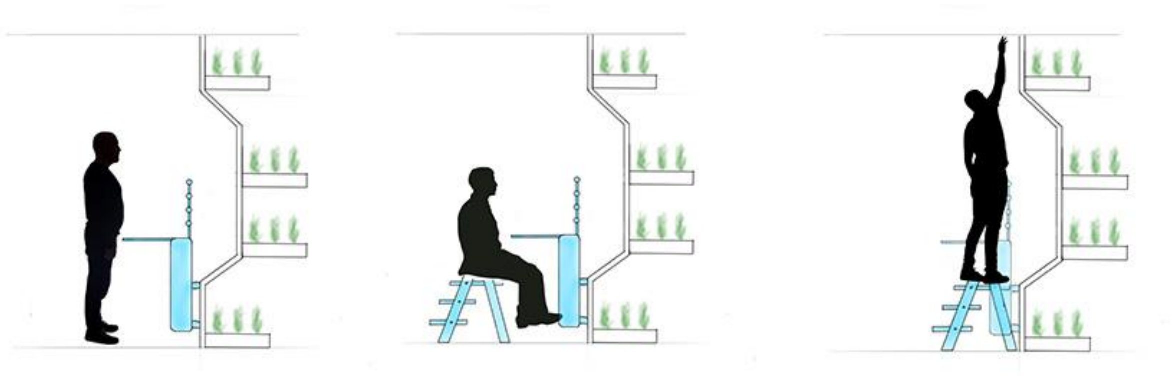


Figure 45: Working positions of the concept Pro Bench [36] [37] [10]

The design is based on an internal aluminum frame, which reduces weight, and on a plastic cladding that is also intended to serve as the surface material for the worktop.

For the main body of the concept, excluding the Aluminium frame system, the planned dimensions are 100 cm in length, 80 cm in height without the bar system (main body), 140 cm with the bar system, and 40 cm in depth (70 cm when the work surface is extended).

8.3 Modu-Hub

Modu-Hub (Figure 46) is a mobile working platform that can be moved linearly along rails and, from the outside, resembles a fold-out cabinet that can be transformed into a fully functional workstation by unfolding a work surface when needed.

Compared to the concepts introduced previously, Modu-Hub demonstrates the most significant visual evolution from the original idea to the final concept. The basic idea of the foldable work surface and the mount for the hybrid sitting and stepping solution remains clearly recognizable, but has been expanded with a newly added housing that preserves functionality while giving the design a more professional and appealing look.

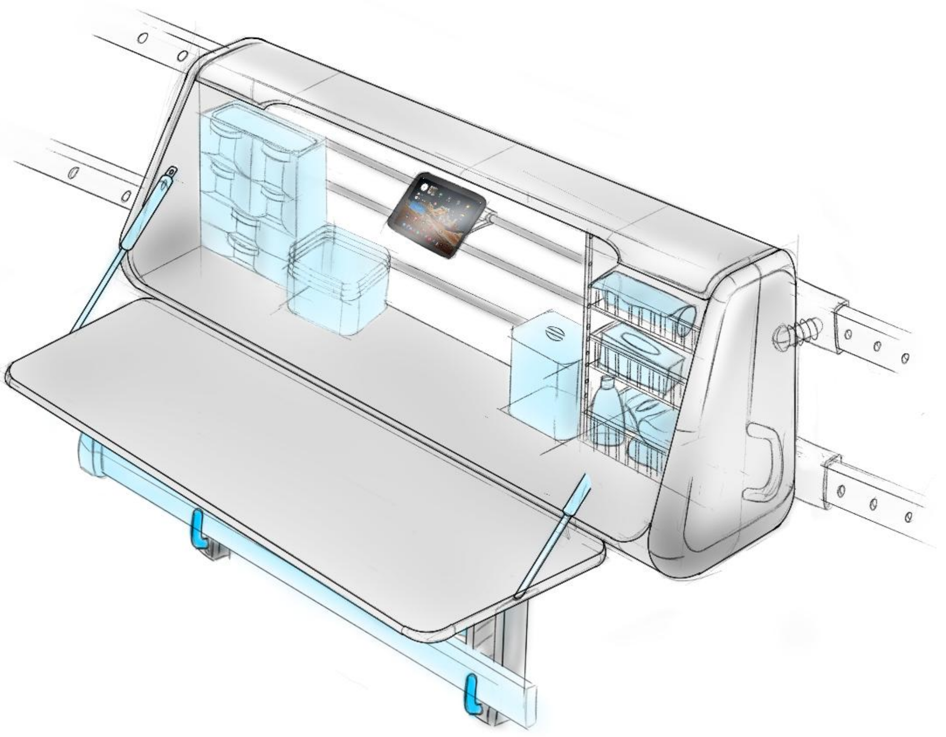


Figure 46: Modu-Hub mobile working platform concept in the unfolded position

The storage system for waste as well as edible and non-edible biomass has changed significantly during the concept development process. On the left side of the Modu-Hub, a storage system with a total of six drawers is integrated, four of which are small and two are large. All drawers are designed to hold plant-related tools. The four smaller drawers are used to store small tools such as scissors and knifes, while the two larger drawers are used for bigger tools like pruning shears.

On the right-hand side is an open storage system for cleaning, maintenance, and repair equipment, including items such as nitrile gloves and disinfectant. Directly next to the drawer system is a stack of plastic containers used for the separate collection of edible and non-edible biomass. A trash can is mounted on the right side for all non-biomass waste. This system ensures a clear separation of work areas and the associated tools, as well as efficient accessibility during work processes.

Behind the work area, three bars are installed in a regular arrangement one above the other, these serve as mounting points for add-ons, such as tool holders, and allow the user to customize their work area. Additionally, a tablet mount can be attached to these bars to support the documentation of plant-based work.

The work surface of the concept folds out toward the front. To prevent accidental folding or a tilted work surface, hydraulic hinges are mounted on both inner sides to ensure controlled movement. The work surface itself is connected to the base plate of the main body via hinges. The upper cover of the design also features a cut-out that allows the user to grasp the work surface at the outer end and fold it out and in (Figure 47).

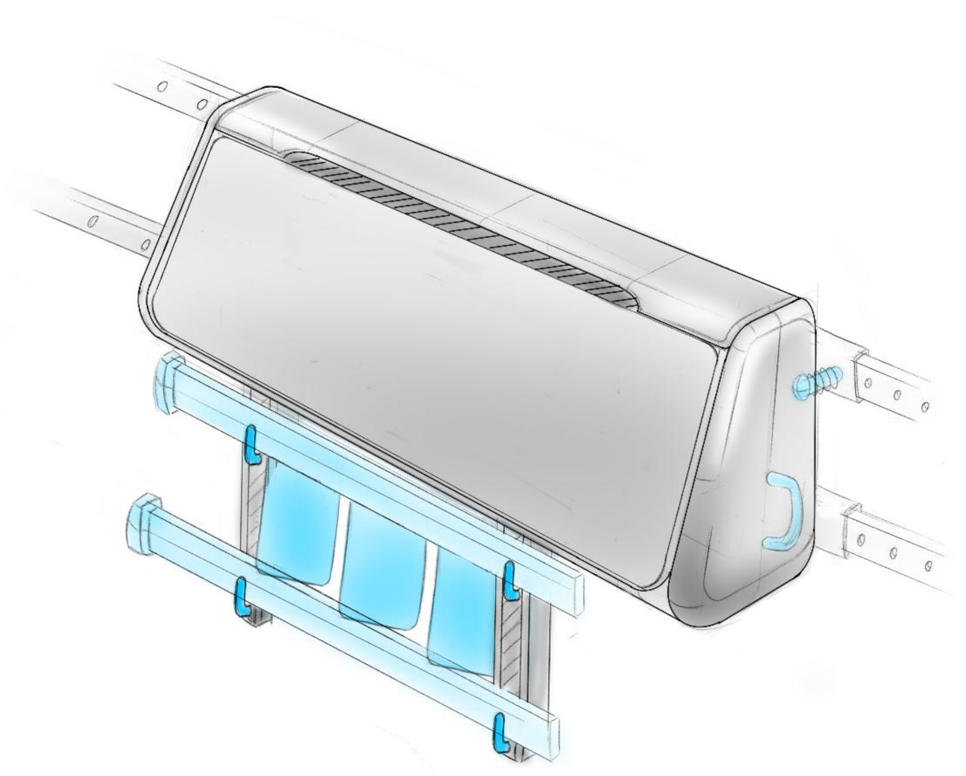


Figure 47: Modu-Hub mobile working platform concept in the folded up position

The platform’s mobility is ensured by four rail carriages mounted on two parallel rails. The rails themselves are permanently installed on the plant rack. The system is connected to the rail carriages via a suspension system, enabling precise linear movement of the platform along the rails.

The platform is secured by a bar fitted with a knob at its upper end and kept under constant tension by a spring. This design ensures that the bar reliably locks into the designated holes in the rail. To reposition the platform, the user pulls the knob, releasing the bar from the rail, and moves the platform to the desired working position using a handle. Once the target position is reached, the knob is released, allowing the bar to snap back into the rail with spring assistance and securely lock the platform in place.

A suspension system is integrated beneath the platform, to which the hybrid seating and stepping solution is attached when not in use. When needed, the user can detach this solution and position it as required. This allows for both standing and sitting while working, while also ensuring access to the upper level of the plant rack so that even the highest plant trays can be taken out (Figure 48).

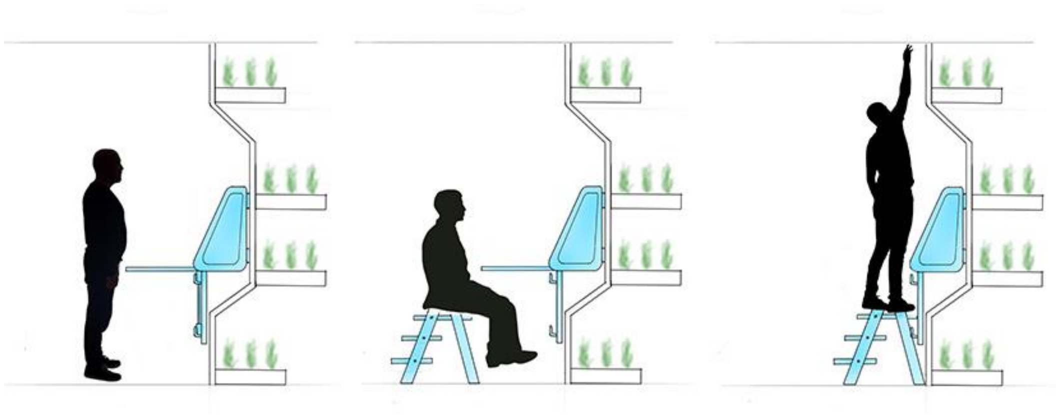


Figure 48: Working positions of the concept Modu-Hub [36] [37] [10]

The platform is structurally based on an aluminum frame covered with a plastic cladding. This combination of materials provides a smooth, hygienic, and easy-to-clean surface that meets the functional requirements of the application. The platform's intended dimensions are 160 cm in length, 60 cm in height, and 40 cm in depth. This provides a generous work surface when unfolded to place a 70 x 70 cm plant tray.

8.4 Comparison of the Concepts

The initial utility analysis of the idea phase identified three winning ideas, two of which had identical scores. Given this narrow range of results, no single preferred option was selected instead the top three ideas were developed into fully-fledged concepts.

Due to the fact that the three concepts are so closely aligned in the utility analysis and that the gap between them narrows even further as a result of the development process, the three concepts are compared in a side-by-side analysis in which a maximum score of 30 points can be achieved. This comparison is conducted from the user's perspective, as the use of a concrete scenario necessitates adopting the user's viewpoint. This ensures that the evaluated concept not only stands out in specific areas but also forms a convincing overall concept across all work steps and the user needs. The user scenario can be found in Table 9, and the complete comparison of the concepts is included in appendix M.

Table 9: User scenario for concept comparison

No.	Desicription
1	**User friendliness**
1.1	**Work preparation:** To prepare for the upcoming work with the plant trays, the user first wants to fold out the work surface, then pick up a plant tray and place it on the work surface. To reach the top trays, the user must use the hybrid seat and stepping option. However, this is not necessary when removing a tray from the lower three levels. For short tasks, it is not necessary to set up the seat for longer periods of work. If tasks arise that take up a lot of time, it is necessary to set up the seat option.

Table 10: User scenario for concept comparison – Continuation of Table 9

1.2	**Accessibility of plant-related tools and biomass management:** Once the user has prepared their workspace, they can begin the upcoming plant-related tasks, such as removing wilted leaves, harvesting edible biomass, and separating inedible biomass. Having the tools within easy reach, intuitive to use, and accessible without detours makes the work easier. Which concept offers the shortest route from tools to workers and biomass to waste containers?
1.3	**Availability of cleaning-related tools and waste management:** After completing the plant-related tasks, the worker should clean and disinfect the tools they have used. They should also dry the work platform if any liquid has leaked from the trays. Any waste, such as disinfectant wipes or kitchen roll, is disposed of in a trash can on the work platform. Which concept offers the shortest route from tools to workers and biomass to waste containers?
1.4	**Changing work positions:** The tasks require a significant amount of time, and the worker would like to change the work position. The worker ensures that the hybrid seating solution can be easily and quickly removed and repositioned.
2	**Hygiene of the platform and work surface**
2.1	**Surfaces:** After completing the plant-related tasks, the worker wants to clean the work surface. In doing so, the user checks for any slits into which liquid, biomass remnants, or pieces of wipes could have entered. It is important for the user that the cleaning can be carried out without too much hassle or effort.
2.2	**Corners:** In addition to checking for slits, the worker pays attention to corners where dirt residue can collect during cleaning.
3	**Failure of the support mechanisms of the rail carriages and work surface**
3.1	As all platforms are rail-based, the worker pays attention to what happens when a carriage to which the platform is attached fails. What can the user do if this happens?
3.2	What can the worker do if the mechanism used to fold out the work surface fails? How easy is it to find a replacement or repair solution?

Table 11: User scenario for concept comparison – Continuation of Table 10

4	**Adjustment options should the mission objectives change**
4.1	How easily can the structure of the concept be adapted from the worker's perspective when mission objectives change?
5	**Compactness**
5.1	How compact is the concept? Is it an obstacle for the worker to walk around it when not in use? When the mobile working platform is in use, can a second worker walk past it while work is being done on the platform?

The user-based comparison of the three concepts showed that Modu-Hub emerged as the winner with a score of 25 points. The-Rig came in second with 22 points, and Pro-Bench took third place with 15 points. The main factor in this decision was the high practical utility of Modu-Hub in a real-world application context. While all three concepts achieve similar overall scores as basic ideas in the previous utility analysis, qualitative differences in their application become apparent when a specific application scenario is considered.

The concept Modu-Hub stands out for its intuitive workflow and closed design. The clear structure and arrangement of the individual elements allow users to quickly access the tools and materials they need. Work on the plant trays doesn’t need to be interrupted, as all necessary tools are located in front of the user. Modu-Hub can also be easily adapted or reconfigured later on, allowing the platform concept to be flexibly adapted to a wide variety of requirements.

In addition, the design strikes a balance between compactness and functionality. Compared to more space-intensive designs like the Pro-Bench, its footprint remains moderate without compromising on working comfort. At the same time, compared to a design that is almost as compact as The-Rig, it offers the option of additional storage space thanks to its outer shell and fold-out work surface.

The overall evaluation shows that Modu-Hub stands out not because of any single outstanding feature, but rather due to its consistently high scores across all evaluation criteria. From the user’s perspective, this makes it the concept that offers the greatest value in practical use and has established itself as the preferred solution.

9 Final mobile working platform Design – FoldDeck

This chapter presents the final development process for the mobile working platform, building on the previous evaluation of the Modu-Hub, The Rig, and Pro-Bench concepts.

The starting point is a renewed and final idea phase based directly on the specific wishes, recommendations, and additional requirements of the DLR experts.

In particular, aspects of plant protection and the preservation of modularity were taken into account. Through a systematic comparison and evaluation of the new approaches, the development process leads to a final design.

In the following sections, the selected FoldDeck concept is elaborated in detail, covering all its functions. In addition to presenting the mechanical functions, ergonomic adjustments, and integration into the LAM, particular emphasis is placed on technical realizability in the form of a prototype.

This chapter bridges the gap between theoretical needs analyses and a realizable mobile working platform.

9.1 Final Idea phase

A team of experts from DLR Bremen evaluated the Modu-Hub, The-Rig, and Pro-Bench concepts in line with the previous steps. While the fundamental conceptual ideas were viewed positively, the experts outlined specific adjustments, new design requirements, and additional specifications.

One critical aspect concerned the horizontal movement of the platform. Due to the small distance to the plant racks, there is a risk of damaging plants that grow beyond the plant trays (the movement is similar to that of a grater). To further minimize the risk of plants becoming entangled in the rails, the experts recommend reducing the rail system to a single rail instead of using two rails stacked on top of each other. Another requirement for further development is the unrestricted functionality of the plant trays. Their removal via the existing rail system in which they are located must not be blocked by the platform concepts.

In the resulting process of generating new ideas and developing a concept (Figure 49), additional requests from Prof. Dr.-Ing. Daniel Schubert are also incorporated.

These are:

- Expanding the platform to span the entire width of the LAM corridor (regardless of the resulting obstruction of the passageway)
- Maintaining modular expandability through tools and accessories
- Designing the platform dimensions so that it serves as storage space for all tools and allows them to be removed by folding up the work surface.
- Developing a combination option where two platforms can be joined together
- Creating a feature that allows the worker to use the platform as a step to reach the top plant trays

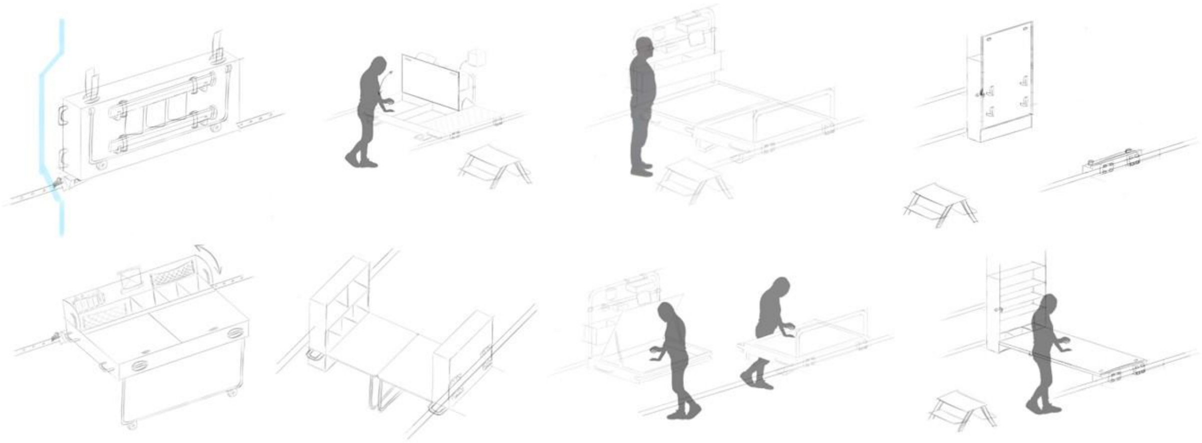


Figure 49: Overview of ideas from the second idea phase [34] [36]

To ensure a systematic comparison with earlier platform concepts, all five new designs have been evaluated based on the utility analysis conducted in the Subchapter 7.2, in which a maximum score of 10 points can be achieved.

The evaluation results in a score of 7 points for SplitDeck and 7.5 points for TwinDeck. Both GlideDeck and BridgeDeck achieve a higher score of 8.8 points, while FoldDeck leads the rankings with a total of 9.2 points.

For better visual illustration, the bar chart in Figure 50 shows both the new platform ideas and the concepts Modu-Hub, TheRig, and Pro-Bench, allowing their scores to be viewed in direct comparison.

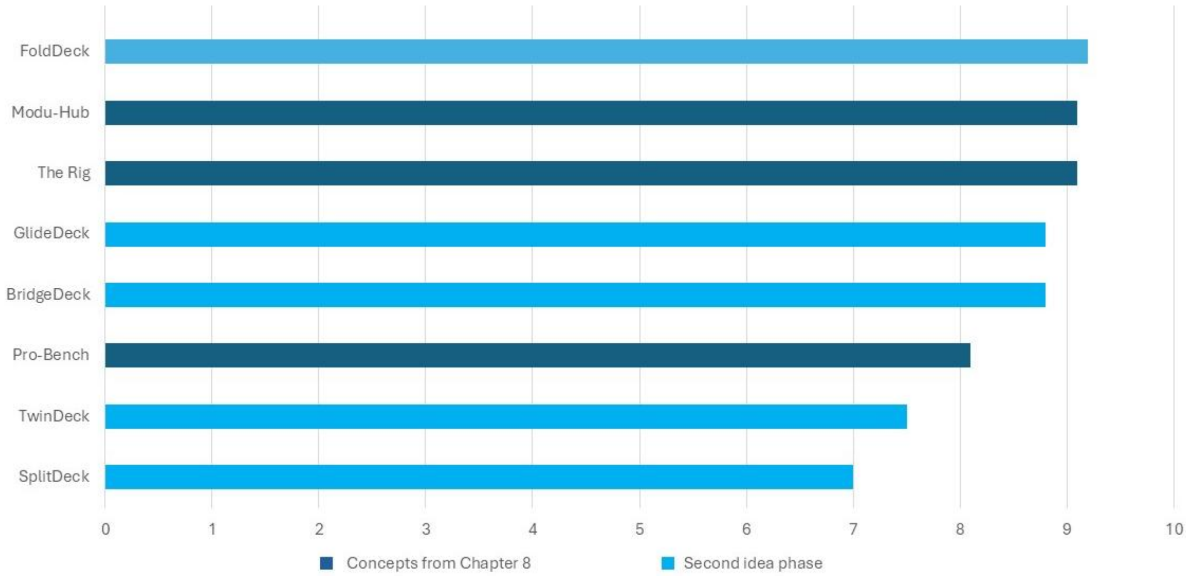


Figure 50: Comparison of the new ideas from the final idea phase with the concepts Modu-Hub, TheRig and Pro-Bench

The bar chart shows that FoldDeck received the highest score among the new platform concepts and, with 0.1 points, is also rated higher than Modu-Hub and TheRig, which each scored 9.1 points. This results in the full-scale implementation of FoldDeck.

The complete documentation of this design phase, including the sketches and modifications to the three original concepts aimed at preventing plant damage while ensuring the removal of the plant trays, can be found in appendix I, J and K. The comparison of the new ideas can be found in appendix M.

9.2 Mobile working platform - FoldDeck

The final design of the mobile work platform, called FoldDeck, is a foldable and horizontally sliding system mounted on the plant rack. Figure 51 shows FoldDeck in both the folded and unfolded states for illustrative purposes.

The system's purpose is to support workers in adopting variable work positions within the LAM, as well as to provide all necessary tools and equipment for both plant-based and non-plant-based tasks. A key functional feature is ensuring accessibility within the LAM corridor when not in use. FoldDeck combines a generously sized work surface with a slim design. The structure consists of two main components: the main body of the platform and a combination of a rail with a carriage-based support component.

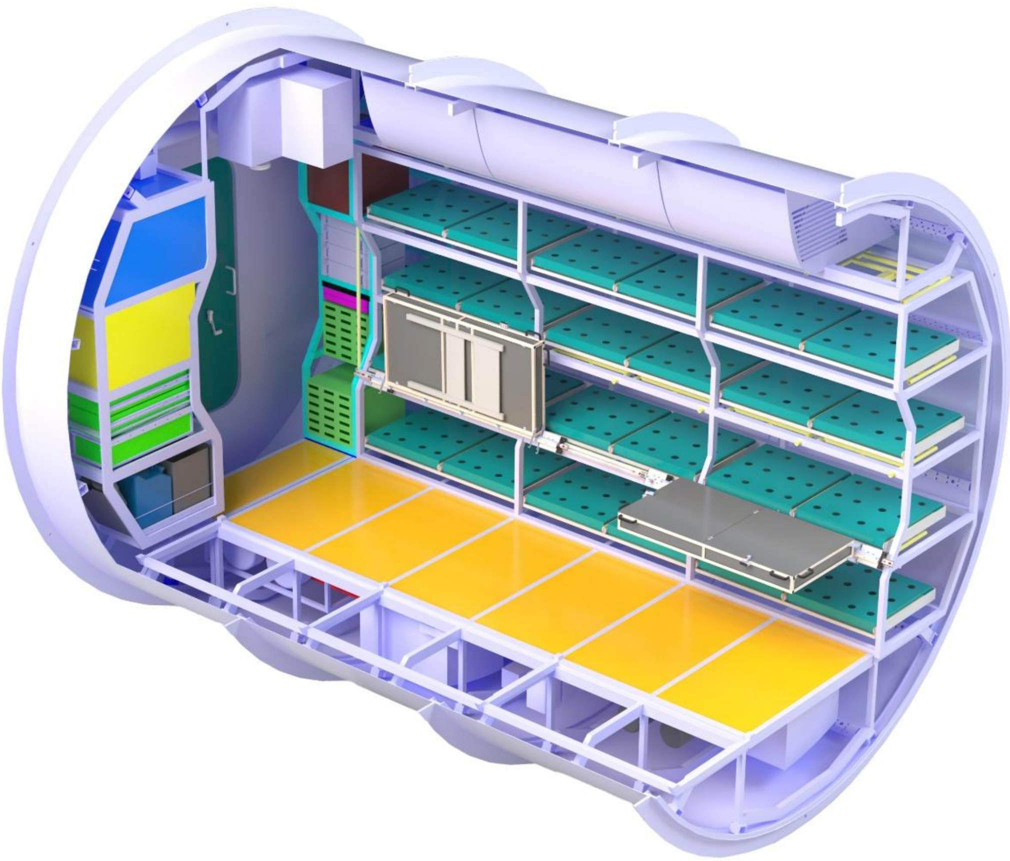


Figure 51: FoldDeck in a folded and unfolded position

9.2.1 Main body of the platform

The base of the platform features a rectangular work surface measuring 1400 mm x 700 mm with a height of 125 mm. As shown in Figure 52, the design features a two-part work surface. Both work surfaces are specified with dimensions of 700 x 700 x 5 mm, which allows for a form-fit placement of the plant trays with identical base dimensions. This layout allows workers flexible use, with one segment serving to position a plant tray while the opposite segment is available as a free work surface.

Functionality is enhanced by the foldable design of both work surfaces, which provides access to the internal storage compartment for task-specific tools and equipment. The work surfaces are oriented in a specific direction (Figure 52).

- **Left segment:** This segment can be swinged to the left. This configuration allows the user to guide the platform in front of them while the plant tray remains positioned on the opposite side.
- **Right segment:** This segment opens toward the front of the plant rack, while the plant tray remains positioned on the left work surface.

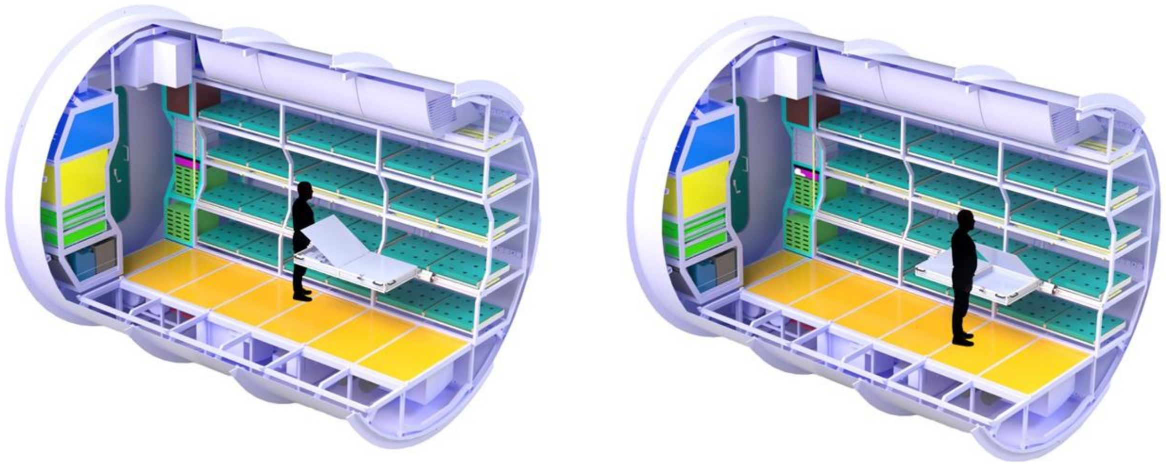


Figure 52: Different opening directions for the work surface [36]

Swivel locks (1) are used to secure the work surface (Figure 53), these engage with a 90° rotation. Ergonomic handling is ensured by handles (2) mounted on the front and side surfaces. These serve, on the one hand, to move the platform horizontally when it is unfolded and, on the other hand, as a gripping support during the folding and unfolding process.

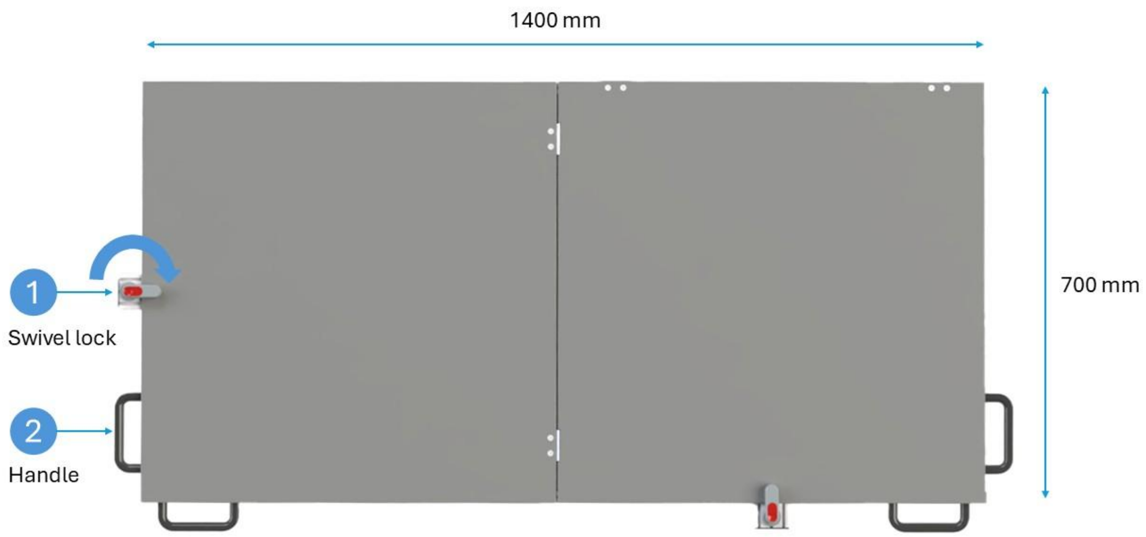


Figure 53: Supervision of FoldDeck

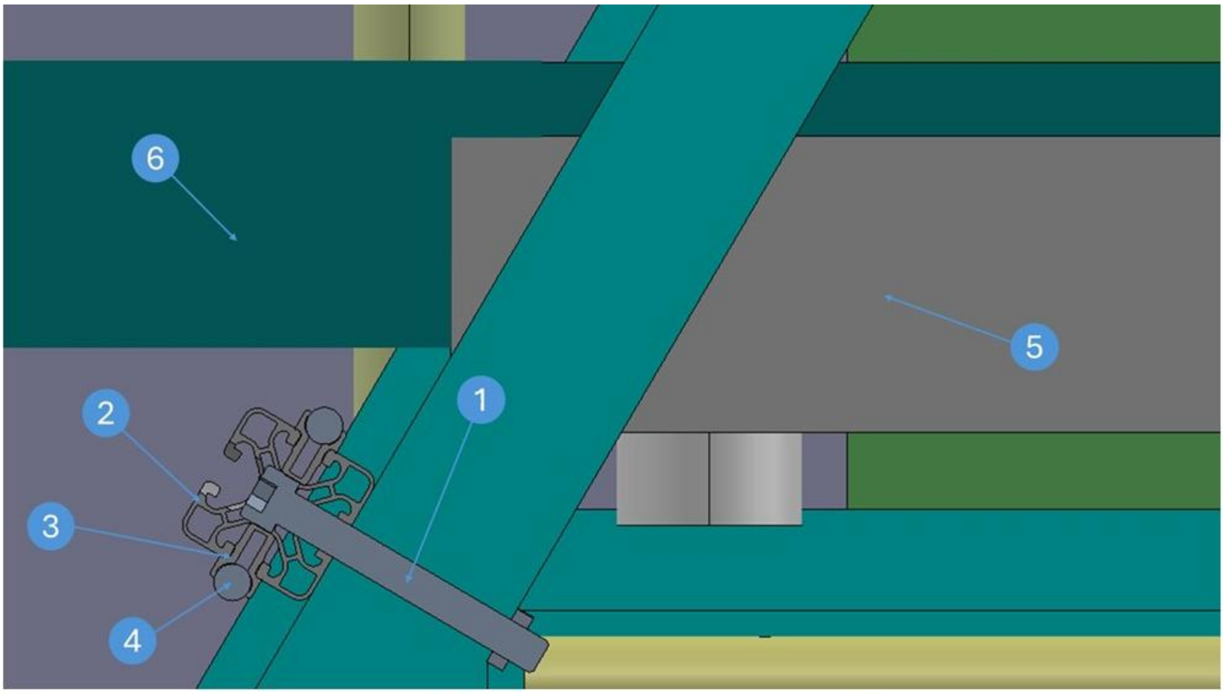
9.2.2 Rail and Carriage support structure

To enable linear translation of the platform's main body along the LAM corridor, it is mounted on a carriage support structure. This structure rests on a rail system (Figure 54), which extends along the entire length of the plant racks and is firmly integrated into the base structure via bolted connections (1).

The rail system is based on a 40x40 mm aluminum profile (2). A shaft clamping profile (3) with an integrated guide shaft (4) is embedded in each of the opposite side surfaces. These shafts function as precise linear guides for the carriage units of the support structure.

The rail is positioned vertically below the second level of the plant trays (5). This arrangement was chosen to ensure that the plant trays can be pulled out along their rail system without blocking the plant trays or the plants (6).

Furthermore, using only a single rail minimizes the risk of damage to plants. Since the platform has a smaller footprint when unfolded, the risk to plant parts that have grown beyond the trays is reduced. In particular, this prevents the effect of the rails acting like a grater on the plants, which occurs when two rails are mounted one above the other, as in the designs described in Chapter 8.



1 Bolted connection
2 40x40 mm aluminum profile
3 Shaft clamping profile
4 Guide shaft
5 Second level of the plant trays
6 Plant tray

Figure 54: Side view of the rail system

The platform's support structure consists of two linear rail carriages that are connected rigidly to one another via an aluminum profile (Figure 55). Within this frame structure, the platform's main body is positioned centrally between the carriage units. Above the aluminum profile, there is an additional support structure, the specific function of which will be discussed in the following chapter.

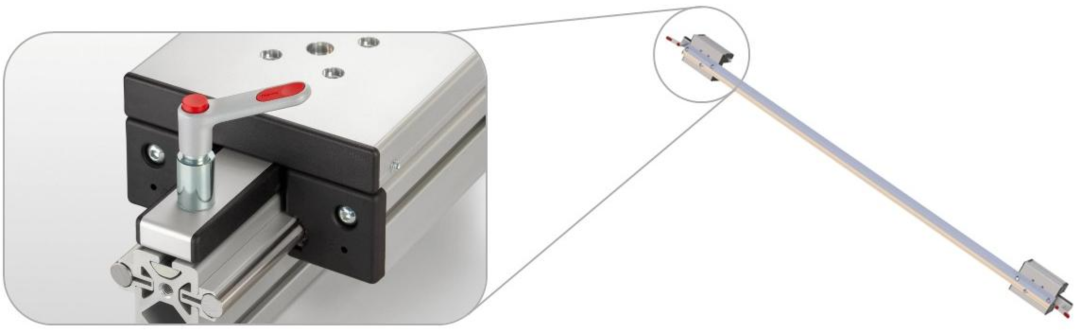


Figure 55: Close-up of the rail carriage with the carriage clamp [38]

To securely position and fix the platform on the guide rail during an operation, a carriage clamp is mounted on the underside of the rail carriage. The carriage is secured by the user manually operating a clamping lever. When secured, the platform is firmly positioned at the desired location. This prevents accidental movement of the platform while performing tasks.

9.2.3 Folding mechanism of the platform

To ensure accessibility within the LAM corridor when the platform is not in use, the system is designed to fold. An integrated folding mechanism allows the platform to be folded vertically toward the plant racks (Figure 56). The mechanical connection between the platform's main body and the support structure is achieved via hinges (1), which are secured in the grooves of the aluminum profiles by means of dowel pins.

To ensure safe handling during the folding process, a support structure (2) is integrated above the connecting aluminum profile of the carriage unit. This acts as a mechanical end stop and prevents the platform from falling uncontrollably toward the plant racks.

The platform is secured in its respective end positions using a hook-based locking system:

- **Vertical locking:** A swiveling steel hook on the underside of the platform allows it to be secured in the upright position. When rotated, the hook's recess engages positively with a spacer (3) mounted on the slide carriage, keeping the platform stable in its resting position.
- **Horizontal locking:** When unfolded, the platform is secured by a similar mechanism. Here, an extended steel hook on the top of the platform engages with the corresponding spacer on the carriage to prevent unintended movement during the work process.

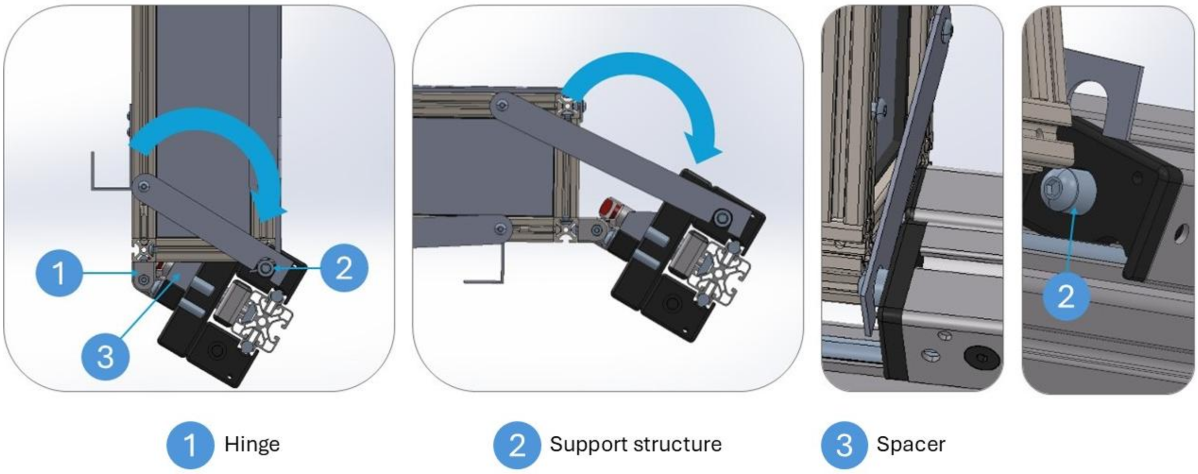


Figure 56: Folding mechanism in the folded and unfolded positions

9.2.4 Working Positions

To support workers, the LAM offers adjustable working positions, including a multifunctional step. To keep the corridor free during inactive work phases, the step can be stored safely and in a space-saving manner on the underside of the platform (Figure 57). Removal takes place while the platform is in the folded position, with the step hooked into four hooks on the underside of the platform and additionally secured with Velcro fasteners to prevent accidental release.

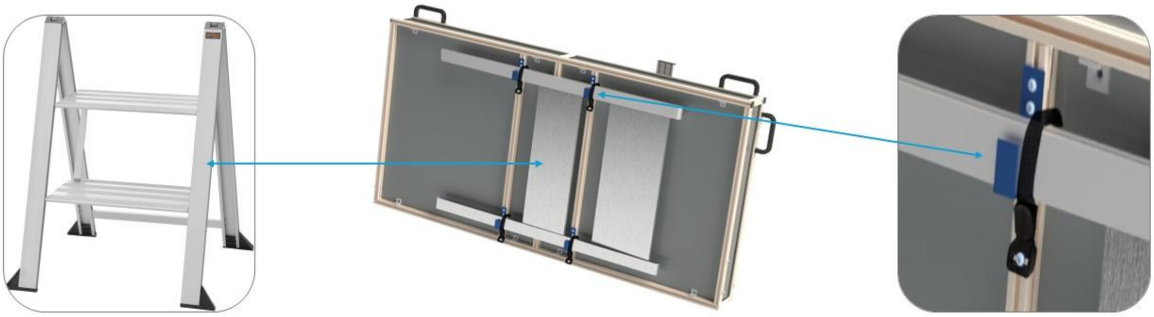


Figure 57: Step on the underside of the FoldDeck main body [39] [40]

The step serves two key functions (Figure 58):

- **Reaching the top plant tray level:** The step allows workers to climb onto it, thereby providing access to the top plant trays for inspection or removal.
- **Seating option:** In addition to serving as a climbing assistance device, it is designed to function as a seating option, offering a second alternative to work while standing.

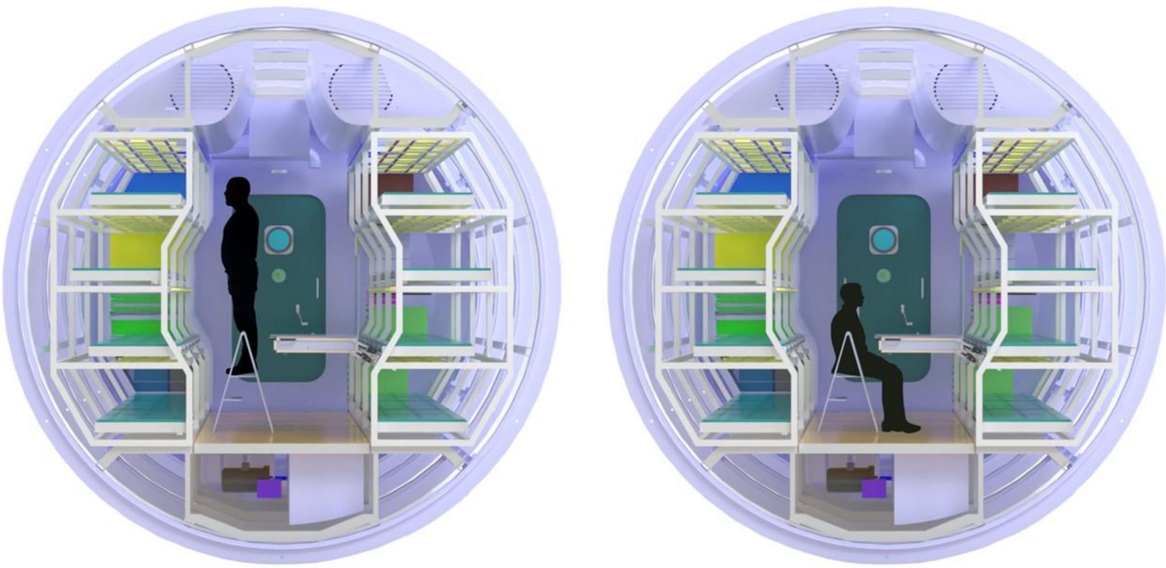


Figure 58: Possible uses of the step [36] [37]

The platform's work surface height is set at 826 mm to enable body-centered work. In combination with the various work positions and the step, this creates a work environment that meets the needs of workers within the LAM and meets the surface heights specified in Ergonomics Chapter 4.6. However, the main design driver for the rail's position and the resulting platform position was that the rail had to be positioned below the second plant tray level to ensure that the plant trays could be pulled out without being blocked by the rail.

When the platform is extended, there is a 650 mm clear passageway (without the step in between), which provides enough space to move around the platform unhindered.

9.2.5 Working platform depots and chosen tools

As shown in Figure 59, the main body of the platform is divided into two separate storage compartments beneath the fold-out work surfaces. These compartments are designed to hold the tools and accessories required for the respective tasks. To support cognitive ergonomics and the structural separation of work processes, the tools are categorized into plant-related tools and non-plant-related tools.

The selection and configuration of the tools and equipment carried are based on the needs analysis, consisting of the survey and expert interviews from Chapter 6.

Proper organization within the compartments is achieved through an inlay system, which is conceptually based on the inlays found in standard tool cases. Elastic straps are used to secure the tools. These not only ensure that the tools are always clearly visible and easily accessible, but also prevent them from accidentally coming loose or shifting when the platform is in the vertical position. An illustration of a toolbox insert that served as inspiration can be found in appendix L.

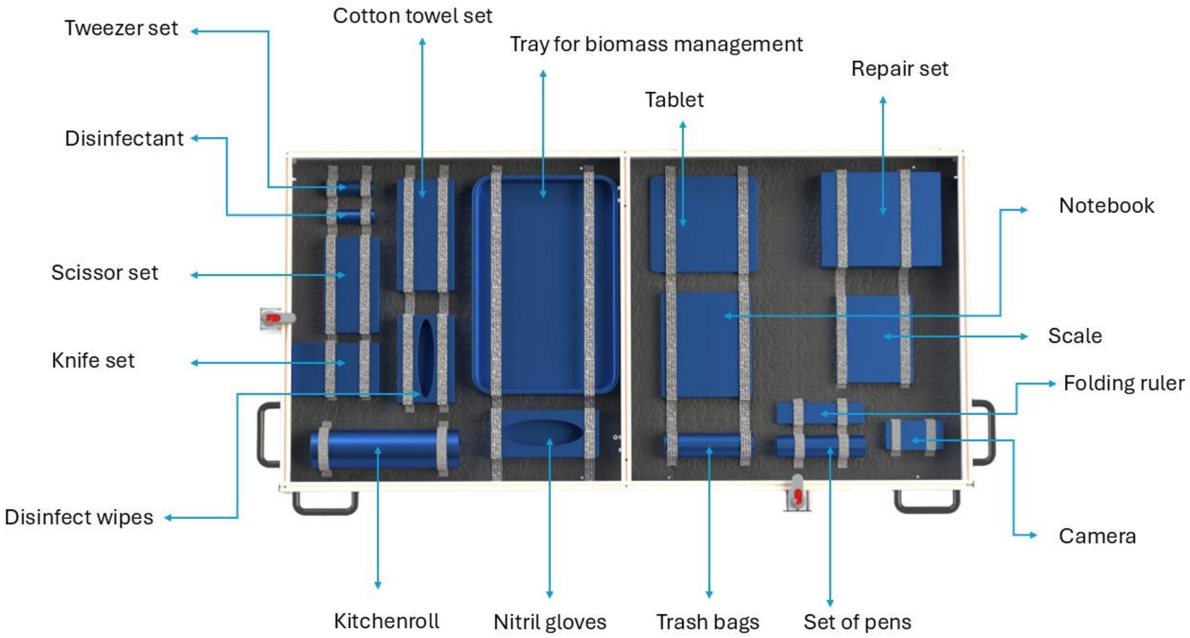


Figure 59: Plant-related and non-plant-related tools and equipment in the internal platform depot

9.2.6 Platform Expandability

To meet the need for platform adaptability identified in the requirements analysis, the platform was deliberately designed using a modular profile system developed by DLR partner item. This design allows workers to adapt the platform to specific work methods and ergonomic requirements by integrating functional extensions at a later stage. Various additional components can be flexibly mounted using the system slots in the aluminum profiles. These for example include tool holders for secure tool storage, mounting systems in the form of hooks, to hang trash bags or cylindrical storage units that allow frequently used tools to be positioned close to the body (Figure 60).

Figure 60: Extension set from item [41]

The modular expandability ensures that the primary work surface remains free of obstructions while also ensuring that tools are within easy reach.

9.2.7 Technical Implementation and Materials

Even during the design phase of FoldDeck, the feasibility of creating a prototype was taken into account, and components from DLRs partner item were utilized. This company offers a comprehensive range of profile systems for the construction of conveyor systems, workstations, and production facilities [54].

The decision to use a modular system with standardized components results in ease of maintenance, reparability, and simple scalability should mission requirements or adjustments change.

Main Body Structure

The platform's main frame consists of aluminum profiles with a cross-section of 20x20 mm. This profile size was chosen to achieve the desired compact and lightweight design. It is the smallest system size available from the manufacturer, which also allows for the integration of additional groove-based components. The profiles are connected using standard and automatic connection kits.

Wall and Floor Elements

The side and center walls are constructed using 2-mm-thick polypropylene (PP) panels. To integrate them into the frame structure, cover and sealing profiles designed specifically for the system are used to secure the panels in the grooves. This allows for screwless assembly using a clamping mechanism. The 2 mm material thickness is systemically specified by the cover and sealing profiles.

The floor elements have a material thickness of 4 mm and are also made of PP. They are attached to the underside of the main body frame using mounting angles to ensure secure load-bearing capacity.

Work Surfaces with Hinges

The fold-out work surfaces are made of 5mm-thick PP panels. To ensure a flush and secure fit on the main body frame, recesses for the hinges are cut into the underside of the panels. The hinges are attached using countersunk screws, which provide a flat surface without any raised areas. The hinges are secured in the grooves of the aluminum profiles using nut blocks.

System Weight

To get an idea of the system's total weight, the materials of the individual components were entered into the CAD program and analyzed. Only the platform system was analyzed, excluding its contents, as no data is available for the individual tools and accessories.

Main body: approx. 38 kg

Rail system: approx. 22 kg

Sled carrier: approx. 7.2 kg

The total system weighs 67.3 kg.

9.3 Prototype preparation for the LAM-GTD

To evaluate the usability, functions, and basic design concept, a support structure was developed for real-world use in the form of a planned prototype within the LAM-GTD. Since the primary support mechanism is designed for the gravitational conditions on the Moon, an additional support mechanism was designed to relieve the load on the platform on Earth (Figure 61).

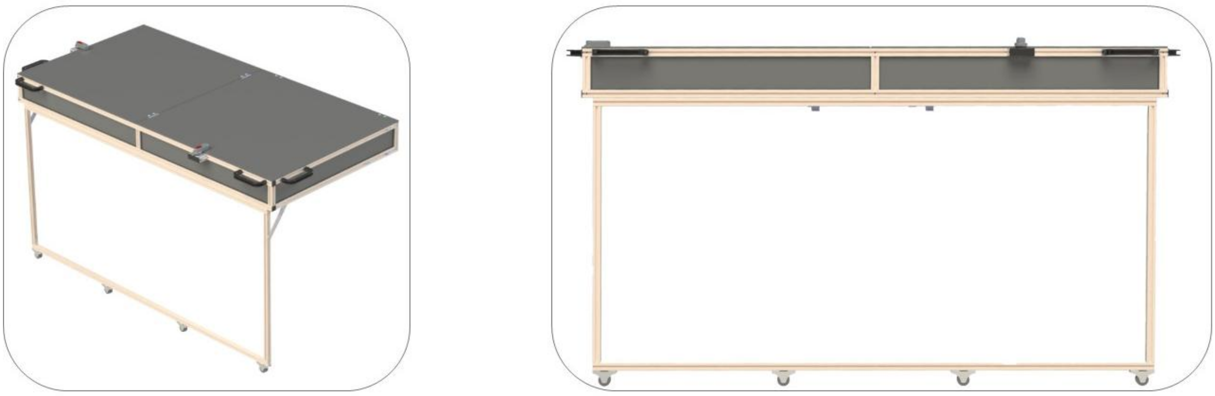


Figure 61: Substructure for the LAM-GTD platform prototype

This substructure is designed as a foldable system with built-in casters. The design allows for linear movement within the LAM-GTD while ensuring mobility and providing support for the platform.

9.3.1 Folding Mechanism

The folding mechanism of the support structure is based on standard foldable table leg systems available on the market. As shown in the sequence in Figure 62, the movement is enabled by a diagonal support with integrated guidance.

When the platform is lowered, the guide pin slides along the milled recess in the support strut.

When fully extended, the pin locks into the end position via a positive fit, with an opening in the strut ensuring that it cannot be overextended or give way.

When folded, the support structure lies flush against the underside of the main body to ensure proper folding and unfolding functionality as well as accessibility in the corridor.

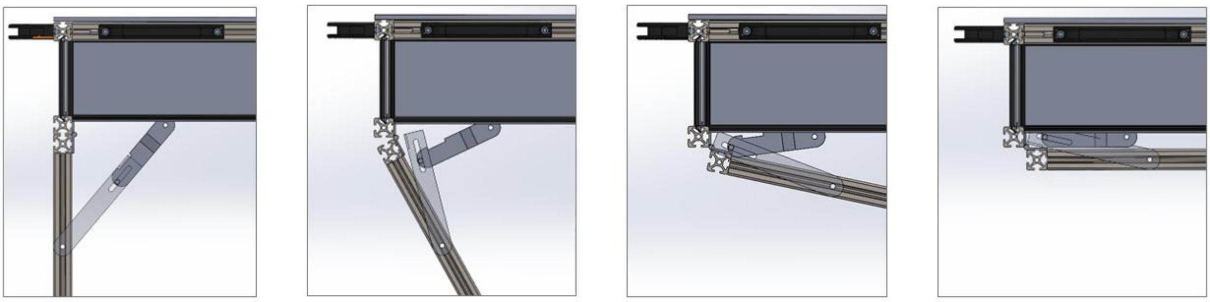


Figure 62: LAM-GTD Platform Prototype Folding Mechanism Sequence

10 Conclusion and Outlook

This final chapter of the thesis summarizes the key findings of this thesis and provides an outlook for the future.

It summarizes the entire development process of the mobile working platform, from initial research and previous missions, through ergonomics analyses, surveys, and expert interviews, to the final FoldDeck concept. The outlook outlines the next steps in further development, which will involve the planned implementation of a prototype for the LAM-GTD as well as future technical improvements such as automatic locking and detailed layout planning for the interior of the platform.

10.1 Conclusion

This thesis demonstrates the necessity and conceptual development of a mobile work platform for the LAM.

This development is based on a comprehensive study and analysis of work processes conducted as part of a previous mission, such as EDEN ISS. By creating a persona, it was indicated that work in the LAM may be less efficient and ergonomically constrained without such a system.

The ergonomic analysis shows two key factors. The first factor is the physical aspect where the analysis include reach distances, standing and sitting positions, and the avoidance of forced postures. The second factor concerns cognitive ergonomics, which, in a high-tech environment such as the LAM, requires a minimalist design to keep mental strain to a minimum.

Another key finding of the systematic market and patent research was the realization that, for this specific application, which combines mobility, plant care support, and confined spaces such as the LAM corridor, no technical solution currently exists.

The methodological development process, supported by an internal DLR survey and expert interviews, resulted in a clear list of requirements that favors a rail-based system. Using systematic product development methods such as the morphological box and a utility analysis, three concepts, Modu-Hub, TheRig, and Pro-Bench, were initially selected from a large number of designs and developed in detail.

The decisive turning point in the design process came with a final evaluation by DLR experts. The identified need for even better protection of the plants against mechanical damage led to a final iteration and the development of the final Fold-Deck concept.

Fold-Deck is a mobile platform that translates theoretical knowledge from the research phase into a user-centered design. By mounting it on the plant rack and using a rail-based system, the platform integrates seamlessly into the existing infrastructure of the LAM. Important features such as the folding mechanism to save space in the corridor, the integrated step to reach the upper level of the plant trays, and provided tools meet the requirements of user-centered design. Furthermore, the use of system profiles from DLR partner item not only ensures the technical feasibility of a prototype using commercially available components but also enables modular expandability to meet future mission requirements.

10.2 Outlook

Based on the findings of this master's thesis, several avenues for the further development of the mobile working platform have emerged. This design represents a conceptual and prototype-oriented solution. It serves as the fundamental framework upon which future developments can be built in the case of possible mission changes. Structural load verification, locking-force analysis, cleaning validation and user testing were not conducted within the scope of this thesis.

A key next step in validating the conceptual design is the transition of Fold-Deck into a functional prototype. This prototype is to be integrated into the DLR's LAM-GTD mockup in order to test the platform concept's functionality under physical conditions within the LAM-GTD corridor. Particular focus will be placed on verifying operational efficiency and determining the extent to which the platform actually is expected to support workflow optimization and requires prototype validation within the plant cultivation module compared to the current state, in which a platform has not yet been integrated.

From a technical standpoint, the current design allows for specific optimizations of details. Further development of the locking mechanism is advisable. While the current solution requires manual engagement of the hooks, a future automated locking mechanism could improve ease of use without the need to manually operate the hooks on the side of the platform. Furthermore, comprehensive load calculations must be performed for actual use in space. This involves verifying whether the platform can withstand the load of a plant tray on the Moon without additional support structures. The utility analysis, with its evaluation criteria for assessing the concept, was based on subjective assumptions that can be validated or adjusted during the implementation of the prototype in order to confirm or disprove their validity.

In addition, the organization of the storage compartments and the inserts requires detailed planning. In the current version of the thesis, the inserts for tools and accessories were defined as solid objects without specific, accurate dimensions. Future work on the platform should include a more precise layout, better utilization of storage space, and defined dimensions.

Beyond the specific implementation of the FoldDeck, the needs analysis conducted as part of this thesis and the numerous sketches generated serve as inspiration for related topics. The results of the survey and the expert interviews can be used for future work on the LAM. Therefore, this thesis not only contributes to solving a specific problem in the LAM but also provides a creative foundation for the design of future work platforms for lunar or martian modules.

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Appendix

For a better and clearer presentation, the appendix is divided into sections A–L.

Appendix M is the digital appendix.

Appendix A: LAM-GTD Subsystems

Explanation of the individual HabSims that make LAM-GTD (Figure 63) possible.

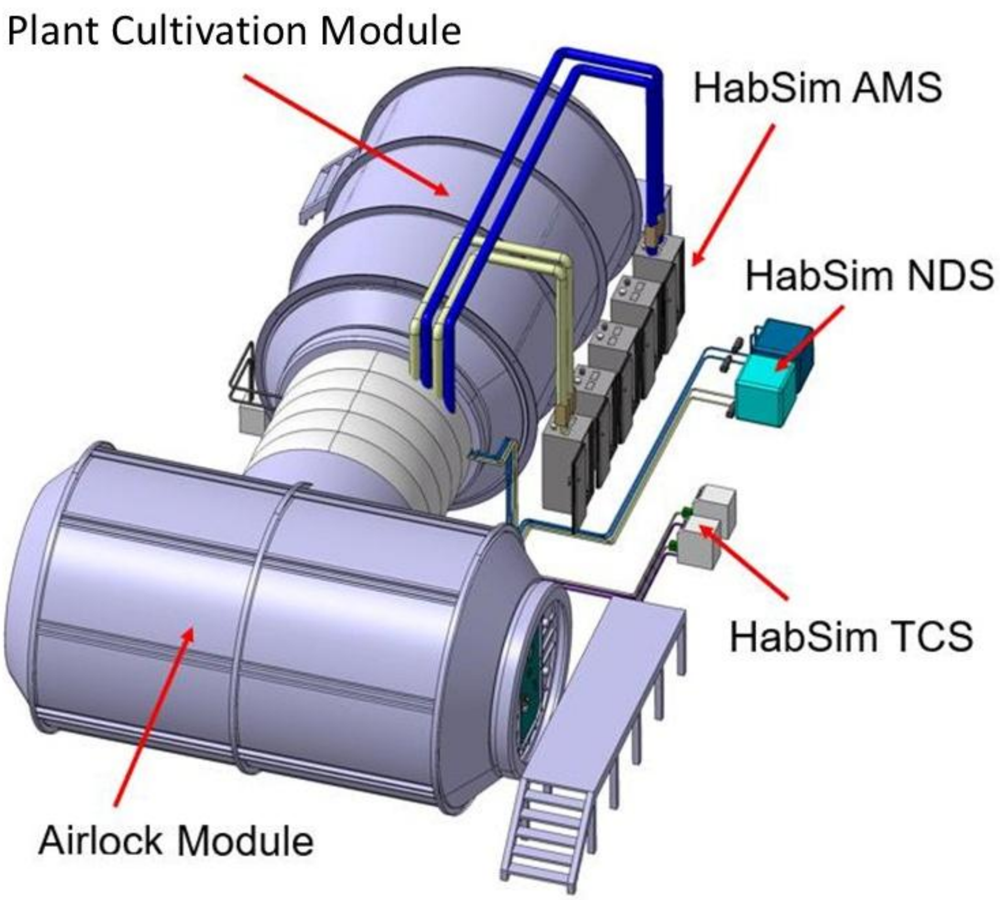


Figure 63: LAM-GTD configuration (edited by the author) [4]

HabSim AMS

To simulate the exchange of air between the habitat and the plant cultivation module the HabSim AMS (Figure 64) is used. It consists of two reservoirs for extracting air from the module and returning it. The incoming air is processed into a gas mixture in a mixing chamber within the first reservoir using additional pressurized gas tanks and temporarily stored there before being directed back into the plant cultivation module. The second reservoir is used exclusively to collect the air exhausted from the module [12].

HabSim NDS

The HabSim NDS (Figure 64) is responsible for testing the exchange of fluids with the agricultural module. This includes fluids such as fresh water, wastewater, and special nutrient solutions for the plants. The system consists of several tanks, pumps, and valves [12].

HabSim TCS

The HabSim TCS (Figure 64) is responsible for regulating the temperature of the cooling fluid that is directed into the agricultural module. It primarily consists of and utilizes heat rejection units that control the cooling fluid temperature. It also includes pumps and valves to precisely control the flow rate in the respective supply and return lines [12].

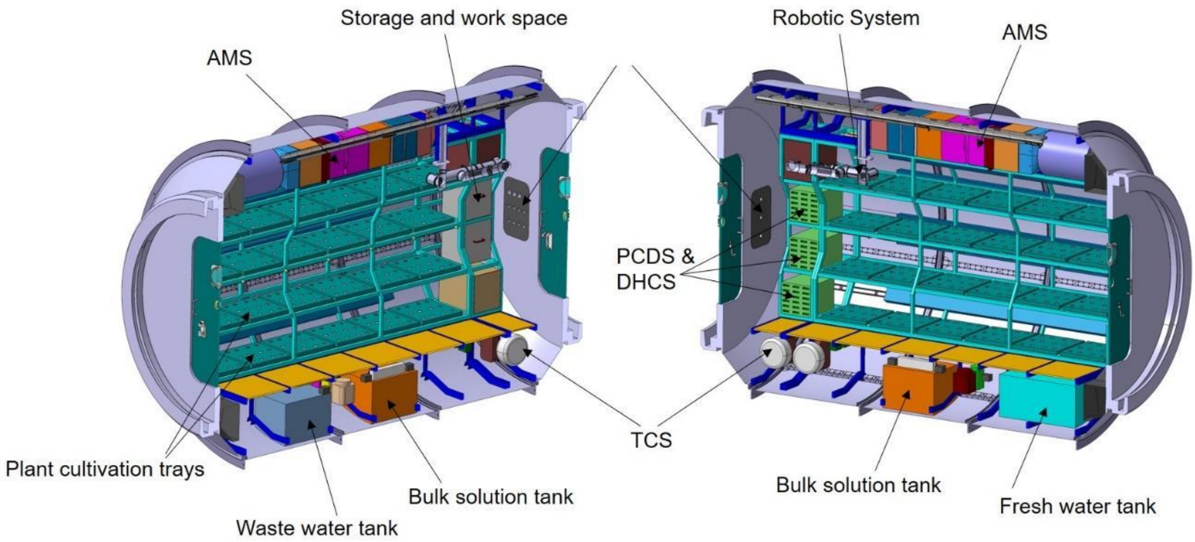


Figure 64: Cross-section of the greenhouse module [4]

Appendix B: EDEN ISS crop production

All plant groups, types, and cultivars can be found in the Table 12.

Table 12: Overview of the plants grown during the EDEN ISS mission [16]

Plant Group	Type	Cultivar
Lettuces	Frisée	*Expertise RZ*
	Romaine	*Dragoon and Outredgeous*
	Green leaf	*Waldmann's green*
	Batavia	*Othilie RZ*
	Oakleaf	*Cook RZ*
Leafy greens	Asian green	*Tatsoi and Shungiku*
	Mustard green	*Red Giant, Amara and Frizzy Lizzy*
	Pak choi	*Rosie and Pak Choi (extra dwarf)*
	Kale	*Red Russian and Nero Di Toscano*
	Swiss chard	*Bright Lights*
	Wasabi	*n/a*
	Rucola	*n/a*
Herbs	Basil, oregano, peppermint, lemon balm and water cress	*n/a*
Fruit-bearing crops	Tomato	*Cherry, Pick-a-Tom,orange, Hoffmanns Rentita and Rotkäppchen*
	Cucumber	*Picowell RZ*
	Pepper	*Cupid and 1601-M*
Tuber crops	Radish	*Raxe*
	Kohlrabi	*Superschmelz and Korist*

Appendix C: Workdays EDEN ISS MTF

A selection of workdays and activities within the MTF can be found in Table 13 and Table 14.

Table 13: Overview of four days at the MTF, including a list of activities [15]

Table 6: Greenhouse CT workday data day A and day B.

Day A - August 14th, 2018			
Start time	**End time**	**CT [min]**	**Task**
09:00	09:30	30	Breakfast
09:30	10:00	30	Preparation of MTF supplies
10:00	10:20	20	Cloth changing, walk to MTF, cloth changing
10:20	10:40	20	ISPR plant cultivation system check
10:40	11:48	68	Harvesting of crops
11:48	11:56	8	Sowing of crops
11:56	12:10	14	Cloth changing, walk to NM III, cloth changing
12:10	13:00	50	Lunch
13:00	15:00	120	Contact with mission control
15:00	15:15	15	Break
15:15	15:50	35	Harvest processing
15:50	16:10	20	Food quality and safety sampling
16:10	17:00	50	Food safety sample preparation
17:00	18:00	60	Office work
18:00	18:30	30	Free time
18:30	19:30	60	Dinner
19:30			Free time

Day B - October 19th, 2018			
Start time	**End time**	**CT [min]**	**Task**
08:45	09:00	15	Breakfast
09:00	09:15	15	Office work
09:15	09:30	15	Preparation of MTF supplies
09:30	09:50	20	Cloth changing, walk to MTF, cloth changing
09:50	10:10	20	Daily system and plant check
10:10	10:49	39	Harvesting of crops
10:49	10:55	16	Nursery and radish transfer
10:55	11:18	23	Cloth changing, walk, to NM III, cloth changing
11:18	11:25	7	Harvest processing
11:25	11:30	5	Break
11:30	11:43	13	Preparation of freeze drier
11:43	12:14	31	Preparation of samples for freeze drying
12:14	13:00	46	Lunch
13:00	13:45	45	Contact with mission control
13:45	15:55	130	Nitrate measurements
15:55	16:05	10	Micro Biological Survey (MBS) test kits result documentation
16:05	16:30	25	Office work
16:30	18:30	120	Free time
18:30	19:30	60	Dinner
19:30			Free time

Table 7: Greenhouse CT workday data day C and day D.

Day C - September 07th, 2018			
Start time	**End time**	**CT [min]**	**Task**
09:15	09:30	15	Breakfast
09:30	10:00	30	Cloth changing, walk to MTF
10:00	10:20	20	Shoveling snow in front of entrance
10:20	10:30	10	Cloth changing, unpacking of supplies
10:30	10:40	10	Leak sensor check
10:40	10:50	10	ISPR check
10:50	11:40	50	Harvesting of crops

Day D - November 6th, 2018			
Start time	**End time**	**CT [min]**	**Task**
09:15	09:30	15	Breakfast
09:30	09:45	15	Subsystem telemetry check
09:45	10:30	45	Cloth changing, transport CO_2 and filters to MTF
10:30	10:45	15	Unpacking supplies, cloth changing
10:45	11:00	15	Measuring heater dimensions
11:00	11:05	5	Cleaning tray lids
11:05	11:10	5	Lettuce transfer from nursery to trays

Table 14: Overview of two days at the MTF, including a list of activities [15]

Day C - September 07th, 2018			
Start time	**End time**	**CT [min]**	**Task**
11:40	11:48	8	Miscellaneous subsystem checks
11:48	12:07	19	Cloth changing
11:57	12:07	10	Shoveling snow from platform
12:07	12:22	15	Walk to NM III, cloth changing
12:22	13:36	74	Lunch
13:36	13:49	13	Office work
13:49	14:15	26	Cloth changing, walk to MTF
14:15	14:28	13	Leak sensor exchange
14:28	14:40	12	Sowing 20x lettuce, 10x tomato
14:40	14:53	13	Transfer Kohlrabi
14:53	14:58	5	Tomato transfer
14:58	15:09	11	Pruning Tomato - Bogus Fruchta
15:09	15:30	21	Pruning Pepper - Cupid
15:30	15:42	12	Removal Pepper - 1601-M
15:42	16:07	25	Lettuce harvest
16:07	16:30	23	Packing of harvest, cloth changing
16:30	16:50	20	Walk to NM III, cloth changing
16:50	17:20	30	Break
17:20	18:30	70	Harvest processing
18:30	19:30	60	Dinner
19:30			Free time

Day D - November 6th, 2018			
Start time	**End time**	**CT [min]**	**Task**
11:10	11:15	5	Nursery cleaning
11:15	11:18	3	Cucumber side shoot pruning
11:18	12:05	47	Cloth changing, transport empty CO_2, drive to NM III, cloth changing
12:05	12:35	30	Lunch
12:35	13:05	30	Office work
13:05	14:05	60	Meeting (phone call)
14:05	14:30	25	Cloth changing, drive to MTF, cloth changing
14:30	16:35	125	Harvesting of crops
16:35	16:45	10	Cloth changing, drive to NM III, cloth changing
16:45	17:00	15	Support other crew members
17:00	17:30	30	Harvest processing
17:30	17:40	10	Daily station briefing
17:40	18:00	20	Support of other crew members
18:00	18:30	30	Dinner
18:30			Free time

Appendix D: Exterior and interior views of the MTF in Antarctica

Figure 65: Exterior view of the MTF [42]

Figure 66: Interior view of the MTF [43]

Appendix E: Experience report of the Harvesting process

To deepen their theoretical knowledge of the work processes involved in the EDEN-ISS project at the Neumeyer III station, the student was given the opportunity to carry out a complete harvesting process and cleaning activities at the EDN LAB in Bremen.

The laboratory consists of a worktable in the middle of the room and plant racks arranged on both sides of the room. These are divided into two levels and not into four levels as in the LAM-GTD, as shown in Figure 67.

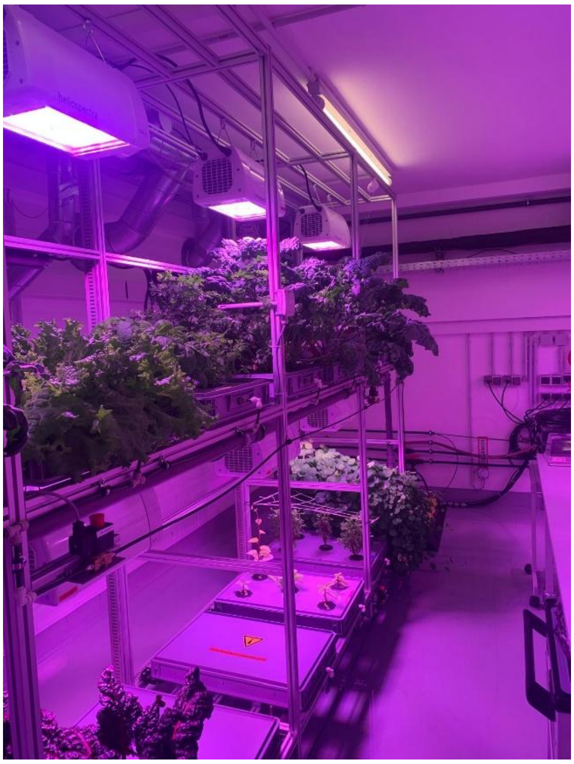


Figure 67: EDEN LAB two level plant rack

Before entering the laboratory, protective and hygiene measures must be observed:

- Wearing safety goggles to protect the eyes from UV light
- Putting on shoe covers
- Disinfecting the hands

These measures serve to minimize the risk of contamination by foreign substances.

Harvesting edible biomass

The edible biomass was harvested manually by picking the ripe fruit by hand. The harvested edible biomass was collected in a designated tray, which was clearly too large for the task, as shown in Figure 68 (left). To reduce the amount of walking within the EDEN LAB, the tub was often placed on the plant rack structure instead of being placed on the central table after each work step, as shown in Figure 68 (right).This procedure increased work efficiency by minimizing walking distances.

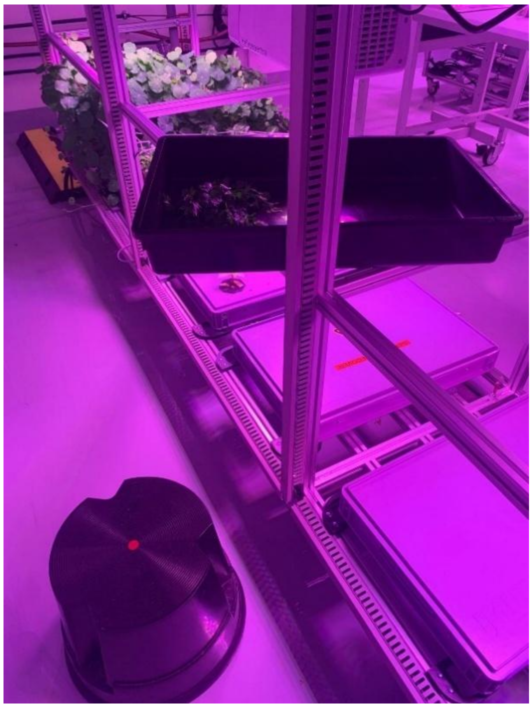


Figure 68: Biomass management using trays (left) and placement on the plant rack (right)

In terms of natural posture and ergonomic conditions, it was found that harvesting the upper plant trays was most comfortable as they could be reached and worked on in an upright and normal standing position. However, harvesting the lowest trays required constant bending, while work on the upper trays was not possible without the use of a rolling stool, as shown in Figure 69.

Figure 69: Standing on a rolling stool to reach the upper level of the plant rack

Cleaning overgrown trays

Increased plant growth occurred particularly at the openings of the trays, through which the plants grew out of the substrate, as can be seen in Figure 70. The trays were cleaned in the service area of the laboratory, which is used as a storage room in addition to housing various cleaning utensils.

Figure 70: Increased plant growth on the openings of the plant tray

Complete cleaning and removal of overgrown roots was carried out using brushes and water. Cleaning agents were deliberately not used in order to avoid possible residues and potential adhesion of cleaning agents to the plastic surfaces of the trays. Intensive cleaning was carried out in particular when both root mass and other plant residues had to be completely removed. Cotton cloths were used to dry the trays after cleaning.

Further observations and conclusions from the work processes at EDEN LAB

Several practical observations were made during the harvesting, trimming, and cleaning work. For activities on the upper levels of the plant racks, the use of a rolling stool was essential to ensure safe and ergonomic access. In addition, simple fastening materials such as cable ties or extendable ropes were available, as shown in Figure 71. These were used both for temporary and permanent fixation of the plants and to support vertical plant growth.

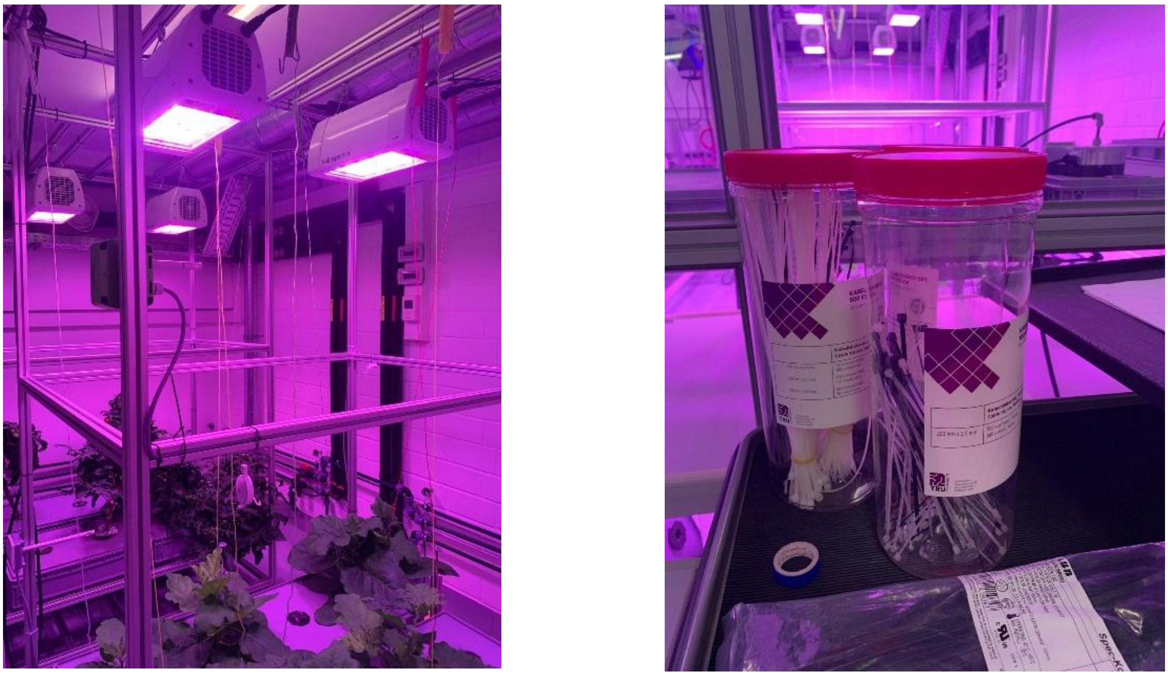


Figure 71: Fastening features consisting of string (left) and cable ties (right)

During the work process, it became apparent on several occasions that tools, especially scissors, had been misplaced or that the biomass container had been left on the plant rack structure. This highlights the importance of having an immediately accessible workspace where tools can be stored safely and tidily. Another observation was that the tools and aids used were scattered around the laboratory and did not have a central storage location.

From these observations, it can be concluded that the establishment of a central, easily accessible, and mobile work platform would be helpful. This should enable the structured storage of all necessary tools and aids and at the same time provide sufficient work and storage space for trays and containers for collecting edible and inedible biomass.

Such optimization of the working environment would contribute to greater efficiency in work processes, as all necessary work equipment would be available in the immediate vicinity, while at the same time reducing the risk of losing tools and aids.

Appendix F: Workstations on space stations

Figure 72: Orbital workbench [44]

Figure 73: Foodtable on the ISS [45]

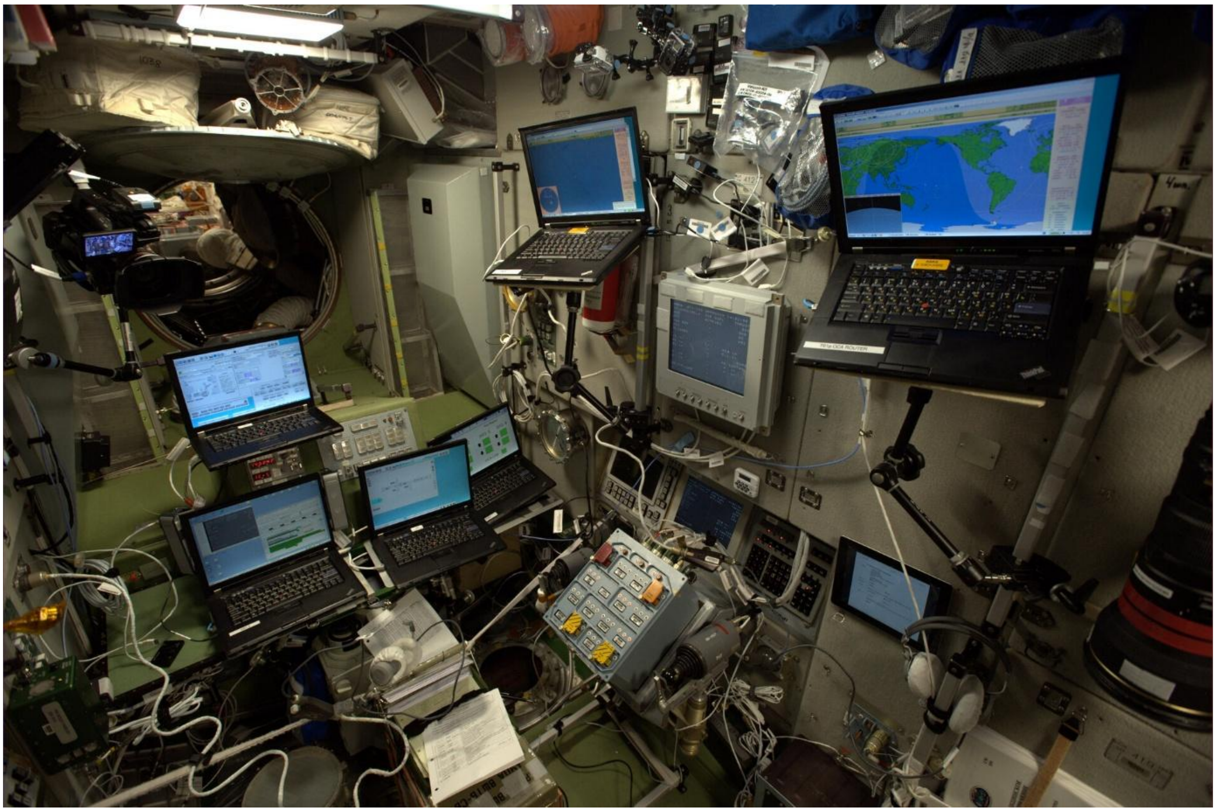


Figure 74: Storage areas on the ISS with laptops on them [46]

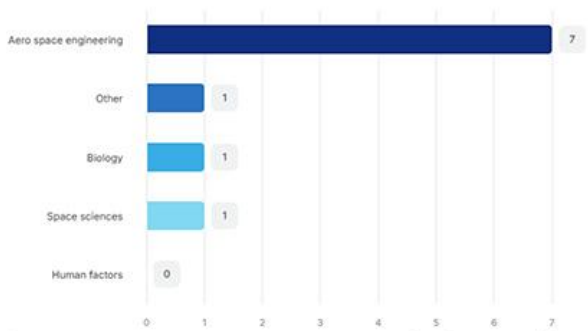
Appendix G: Survey

Background profile of survey participants – Questions 1-4

The nine people who took part in the survey have a highly specialized background, as the survey was only sent to DLR employees in Bremen. A clear majority of the participants surveyed, namely seven people, work in the field of aerospace engineering, while two others work in the fields of biology and space science, and one in an unspecified professional field. To enable a detailed response, a follow-up question was added to describe the field of expertise in more detail. Three participants specified their areas of expertise as CEA Technologies, GHM on Moon and Mars, BLSS, ISRU, plant science, crew metrics, and campaigns in extreme environments.

The picture is mixed when it comes to professional experience. While two participants have over 15 years of professional experience, there were six other responses that were evenly distributed between 10 years of professional experience and zero years. It is particularly noteworthy that all participants in the survey are familiar with the EDEN ISS and LAM GTD projects.

1. What field are you currently working in?



2. Was your area of expertise not listed? What is your area of expertise?

ANTWORT	ANZAHL	VERHÄLTNIS
Plant science Areas of expertise: plant science, crew metrics, test campaigns in extreme environments	1	25%
CEA Technologies; GHM on Moon and MArs	1	25%
BLSS and ISRU	1	25%
B.Eng aerospace engineering	1	25%

3. For how long have you been working in your field of expertiserelated to plant cultivation or food production? (in years)

ANTWORT	ANZAHL	VERHÄLTNIS
15	2	22.2%
9	1	11.1%
7	1	11.1%
4	1	11.1%
10	1	11.1%
0,5	1	11.1%
0,25	1	11.1%
0	1	11.1%

4. Are you familiar with the EDEN ISS or LAM GTD projects?

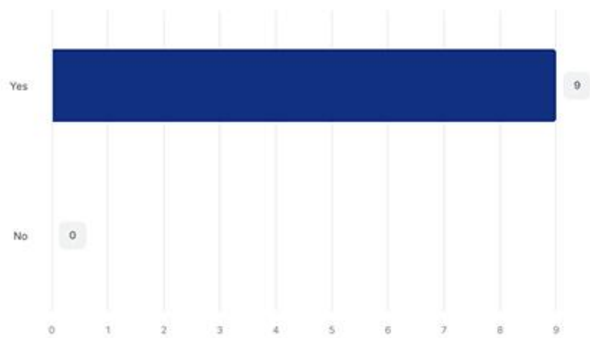


Figure 75: Expert Survey Questions 1–4

Identification of the main tasks of the working platform – Questions 5-6

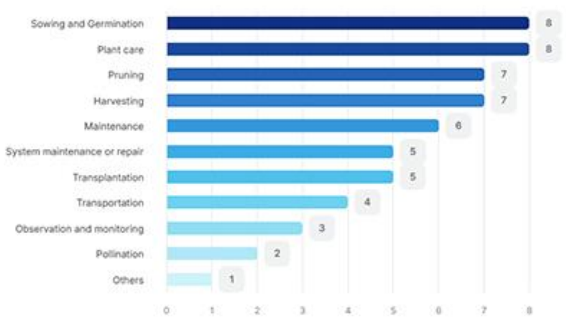
One of the main aspects of the survey was to determine the areas of responsibility that the platform to be developed must cover. Eight participants stated that the most important activities were “sowing and germination” and “plant care.” These were closely followed by “pruning” and “harvesting”, each with seven mentions.

Another important task is “maintenance” with 6 mentions, followed by “system maintenance and repair” which was considered important with 5 votes.

Transportation, with 4 votes, observation and monitoring, with 3 votes each, and pollination were considered less relevant tasks.

In a feedback comment on the tasks, it was added that the tasks are highly dependent on mission objectives and that areas such as cleaning and disinfecting and assembly and integration should be taken into account.

5. What are the main tasks that a working platform should support in the LAM GTD?



6. Was there no suitable answer for you? What would you add?

ANTWORT	ANZAHL	VERHÄLTNIS
Maybe the question 5 is not very clear! The tasks depend on the mission objectives.	1	33.3%
Cleaning/Disinfecting	1	33.3%
Cleaning, Assembly and integration	1	33.3%

Figure 76: Expert Survey Questions 5-6

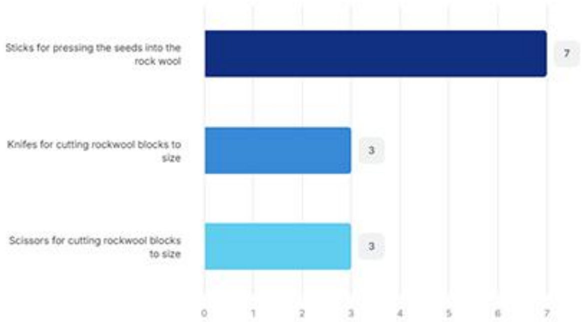
Required tools for the tasks – Questions 7-16

This section of the survey analyzed in greater depth what tools the participants surveyed felt needed to be immediately available.

Sowing and germination:

With 7 votes, sticks for placing the seeds in the rockwool were mentioned. Knives and scissors for cutting the rockwool for this task were mentioned significantly less often, with 3 votes. An important piece of feedback was given twice in a follow-up question, namely that cutting the rockwool should ideally take place outside the greenhouse and not inside it. Other important additions were tweezers for handling the seeds, gloves, and cleaning materials such as cleaning cloths and a bucket. Something for documenting, such as a notebook or electronic notepad, was mentioned as an important tool.

7. Which tools should be available nearby for sowing and germination?



8. Something important was missing. Please write down what tools or items were missing.

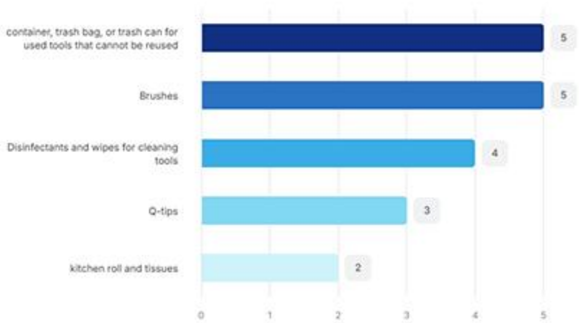
ANTWORT	ANZAHL	VERHÄLTNIS
tweezers for putting seeds into rockwool blocks	1	20%
Rockwool cutting should only be performed in the laboratory... same as the adjustment of the trays. What about the cleaning elements like gloves when handling seeds/plants? Cleaning clothes and bucket? Tweezers for handling seeds?	1	20%
preperation of rockwool cube should be done outside of the greenhouse.	1	20%
Please see my answers sent via email.	1	20%
Pipette and/or tweezers to handle the seeds, (disposable) gloves for the operators, a notebook or electronic notepad to document the sowing / transplanting	1	20%

Figure 77: Expert Survey Questions 7-8

Pollination:

Pollination focuses on cleaning and waste management. With a majority of 5 mentions, containers for waste and brushes are required. Disinfectants, cleaning cloths, and brushes received 4 mentions. This is followed by Q-tips for pollination with one less mention. Kitchen roll tissues were considered less important, with 2 mentions. In addition, 2 participants stated that it is not necessary to carry pollination tools, as active pollination is only required for very few plant species. One commercially available option that was mentioned is a dedicated electronic pollination wand.

9. Which tools should be available nearby for pollination?



10. Something important was missing. Please write down what tools or items were missing.

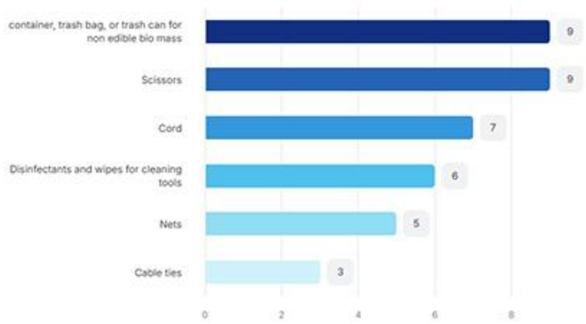
ANTWORT	ANZAHL	VERHÄLTNIS
The user! It is very easy to tap the plants to enduce pollination. No tools required! One commercially available option that isn't listed is a dedicated electronic pollinating wand. Looks like an electric toothbrush but without the brush on the end.	1	33.3%
I dont think tools for pollination are required. Active pollination is only required for a small set of plant species.	1	33.3%
Disinfectants: the correct one should used otherwise plants affected.	1	33.3%

Figure 78: Expert Survey Questions 9-10

Pruning and plant care:

Storage containers for non-edible biomass and scissors were again mentioned the same number of times (9). With 7 votes for cord and 6 mentions for disinfectant/cleaning agents for cleaning tools, these were also rated as very important. In second-to-last place with 5 mentions were nets, while cable ties were considered unimportant with 3 votes. In an additional comment, yoyo cables and nitrile gloves, e.g., for tomato plants, and a scale, in case inedible biomass needs to be weighed, were mentioned as additions.

11. Which tools should be available nearby for pruning and plant care?



12. Something important was missing. Please write down what tools or items were missing.

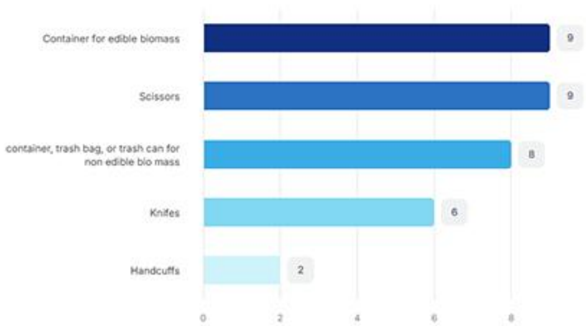
ANTWORT	ANZAHL	VERHÄLTNIS
Yoyo- cables are very useful for plantcare	1	33.3%
nitril gloves. touching e.g. tomato plants requires gloves.	1	33.3%
A scale in case inedible biomass needs to be weighed	1	33.3%

Figure 79: Expert Survey Questions 11–12

Harvesting:

With the same result as pruning and plant care, containers for edible biomass and scissors were each mentioned 9 times. Containers, trash bags, or trash cans for storing non-edible biomass were mentioned 8 times as very important. With a narrow majority of 6 votes, knives for working were also highlighted. As a supplement in the form of a comment, nitrile gloves and documentation options such as notebooks or electronic notepads were mentioned again. In addition, a scale for weighing biomass, a handheld camera, and cleaning utensils were again requested.

13. Which tools should be available nearby for harvesting?



14. Something important was missing. Please write down what tools or items were missing.

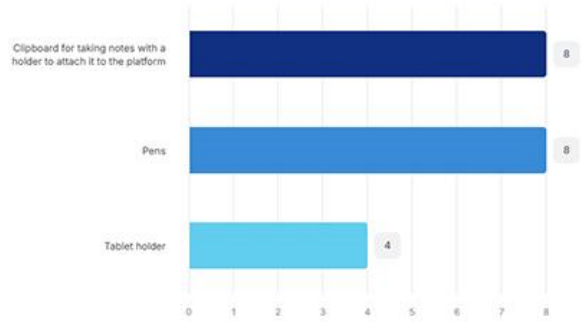
ANTWORT	ANZAHL	VERHÄLTNIS
nitril gloves. touching e.g. tomato plants requires gloves.	1	25%
Handcuffs???	1	25%
A notebook or electronic notepad to document the harvesting process	1	25%
Again, a scale for weighing both edible and inedible biomass A handheld camera, and materials to clean the tools (as listed in question 12) would also be useful for harvesting. Paper towels or wipes are also useful for cleaning debris or plant liquids.	1	25%

Figure 80: Expert Survey Questions 13-14

Observation and monitoring:

With an equal number of 8 mentions, a clipboard for taking notes with a holder attached to the platform and pens are desired for this task area. With 4 votes, a tablet holder is considered not so important. In the additional comments on whether anything important had been forgotten, a camera, measuring instrument, and booklet were mentioned.

15. Which tools should be available nearby for oberservation and monitoring?



16. Something important was missing. Please write down what tools or items were missing.

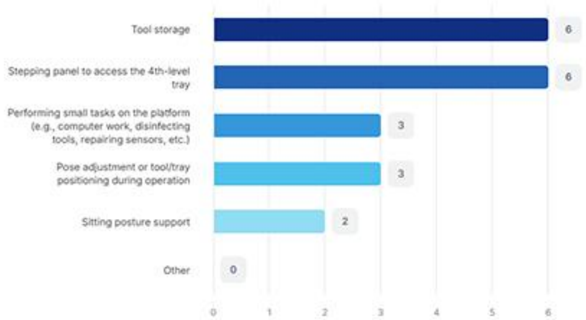
ANTWORT	ANZAHL	VERHÄLTNIS
Potentially some hand-held sensors or instruments to take measurements.	1	33.3%
Booklet?	1	33.3%
A camera that the user can use	1	33.3%

Figure 81: Expert Survey Questions 15-16

Functions of the platform – Questions 17-26

Among the proposed functions of the platform, tool storage and only one of the requests for a stepping panel to reach the top level, the plant trays, achieved the highest priority with 6 mentions each. With less than half of the votes, small tasks such as computer work, pose adjustment, tray positioning, and sitting posture support were considered less relevant.

17. Which of the following functions do you consider the highest priority in the LAM-GTD?



18. Something important was missing? Please write down what functions were missing.

Noch keine Antworten

Figure 82: Expert Survey Questions 17-18

Storage options:

With 7 votes, drawers are the preferred storage option, along with 5 votes for tool holders. Respondents were not convinced by open boxes (4 mentions) and nets (0 votes).

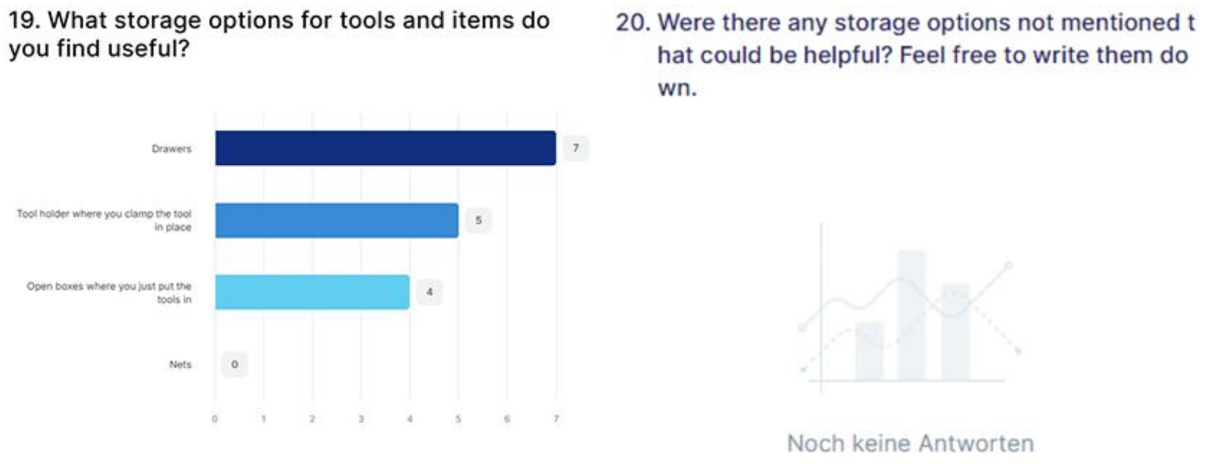


Figure 83: Expert Survey Questions 19-20

Modularly expandable:

There is clear agreement among participants, with 7 votes, that the platform should be modularly expandable so that it can be customized or adapted to other tasks.

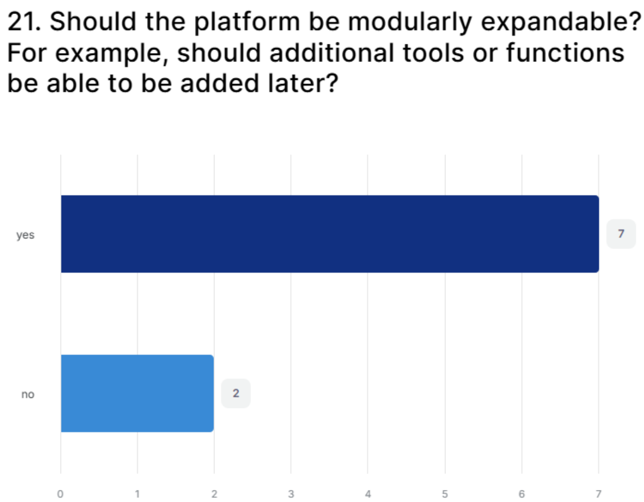


Figure 84: Expert Survey Question 21

Seating option:

When asked about an integrated seating option, respondents were almost divided (5 yes, 4 no) on whether this was really important. However, the follow-up question, question 23 of the survey, in which the seating option also serves as a stepping panel to reach the top plant trays, convinced 7 participants to vote for a solution that can be sat on and also serves as a stepping panel.

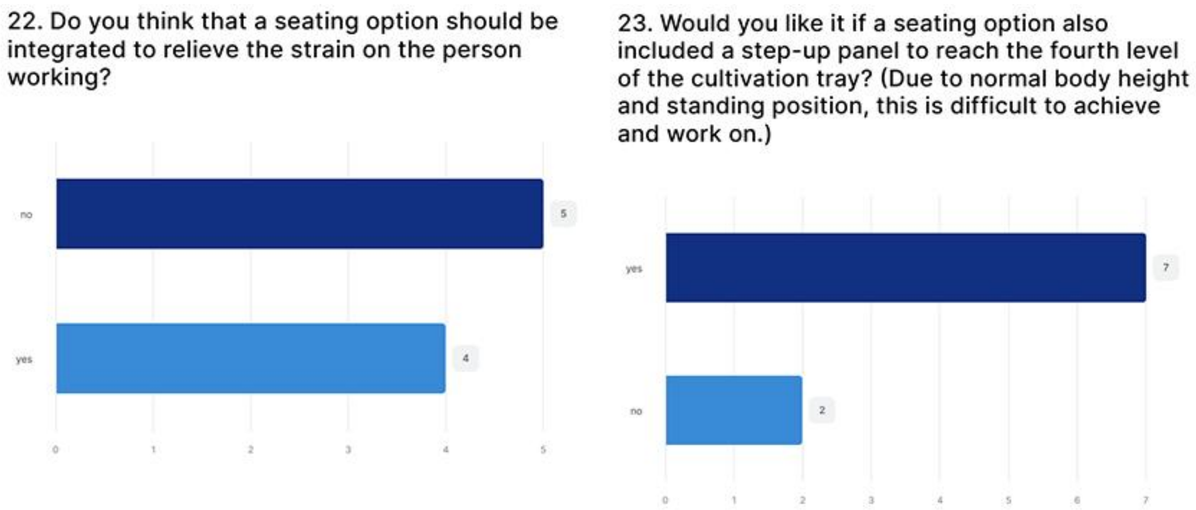


Figure 85: Expert Survey Questions 22–23

Positioning and mobility:

Participants had to rate this question with up to 5 stars (1 star poor, 5 stars very good). Precise positioning is very important to participants, as 3 participants rated it 5/5 stars, 3 participants rated it 4/5 stars, and 3 participants rated it 3/5 stars. This results in an average of 4 out of 5 stars. There is no preferred solution for the platform's mobility, as 5 participants chose casters/wheels while 5 votes were cast for a rail-guided system on the plant rack. It was noticeable that 6 respondents favored a freely positionable option such as a tool trolley. Meanwhile, 3 votes favored a purely linear movement option.

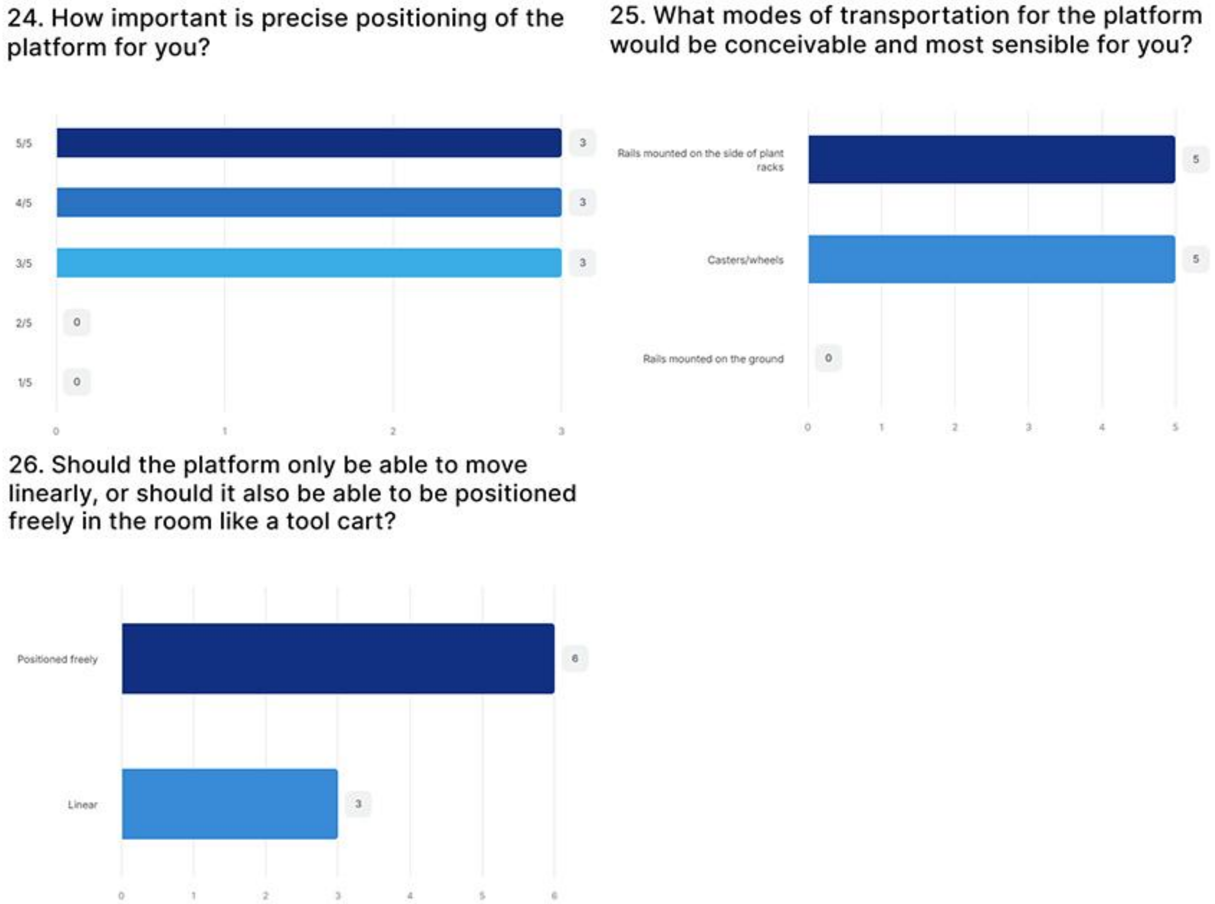


Figure 86: Expert Survey Questions 24-26

Evaluation of design options – Questions 27-30

In these four questions, participants evaluated visual concepts. They were shown images of the tool holder from the patent search, a tool trolley, a mobile workstation, and a modular, adjustable workstation. The results show a clear contradiction to the previous answer regarding freedom of movement.

Rail-mounted work platform attached directly to the plant racks:

This concept received the best average rating of 3.6 out of 5 points. It is striking that 5 participants gave the best rating of 5 points, which was not the case for the other results.

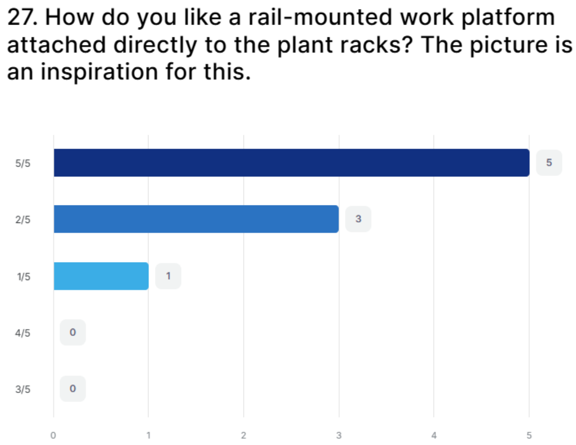


Figure 87: Expert Survey Question 27

Tool trolley:

The tool trolley occupies the middle ground with an average rating of 2.8 out of 5 points.

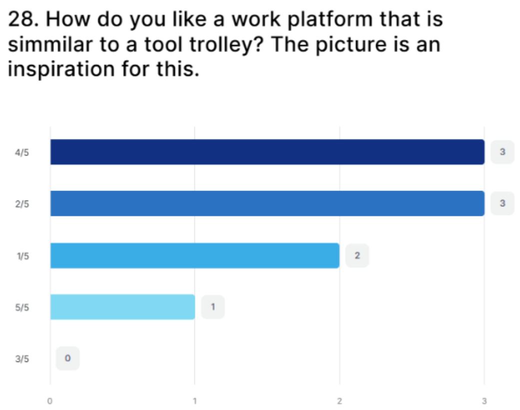


Figure 88: Expert Survey Question 28

Mobile workstation:

This working platform concept received 2.3 out of 5 points, placing it just behind the tool trolley.

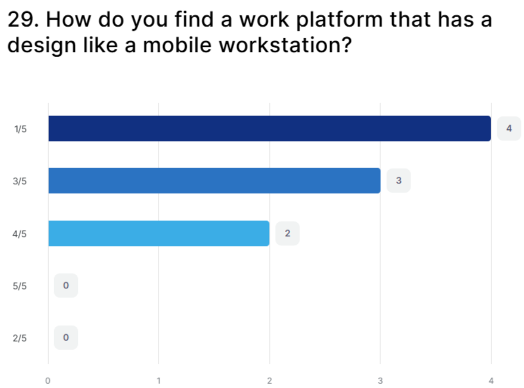


Figure 89: Expert Survey Questions 29

Modular, adaptable workstation:

This option was rated the worst of the four options. With an average rating of 1.9 out of 5 points, it came in last place.

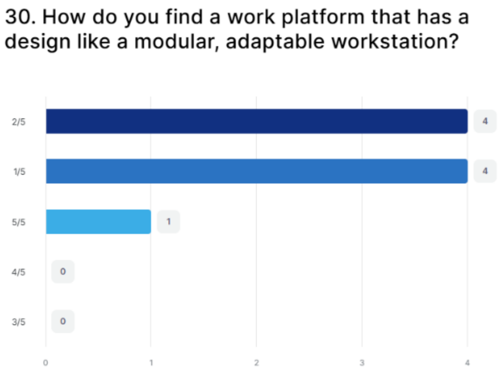


Figure 90: Expert Survey Question 30

Final question and feedback – Question 31

The last question gave participants the option to leave their wishes and feedback in a free text field. Two participants took advantage of this option. One participant summarized his preferred solution. The participant would like to see a combination of separately usable elements such as a step stool, which can be used to reach the top plant trays and also as a seating option. In addition, a separate tool drawer or work table could be installed nearby with a mechanism for attaching it to the shelf. It is important to the participant that the platform and its elements are compact enough to be stored in a space-saving manner. Under no circumstances should the platform block the LAM GTD corridor when not in use. Another participant describes a tool trolley that was used in the EDEN ISS project. It was very clunky and annoying to use. It was always in the way and got in the way because it could not be collapsed and the corridor was very narrow.

31. Final question. Was there anything missing that you think should be taken into account? Feel free to write your ideas and suggestions here.

ANTWORT	ANZAHL	VERHÄLTNIS
The options in #27-30 are based on the work cart that was in EDEN ISS. I cannot stress how annoying and clunky this was. It was always in the way in some capacity, since it could not be collapsed and the corridor was narrow. More complicated designs also mean more difficulty in keeping clean. The current LAM-GTD design doc and Preve Chobert-Passot's Master's thesis include work structures that have been designed with consensus by the LAM-GTD team as improvements over what was used in EDEN ISS.	1	50%
A combination of elements which can be utilized separately would be my current preferred solution. E.g. a step stool or similar for sitting and/or accessing the top level of trays. A (separate) tool drawer / working table which can be installed nearby, with fixation mechanism to the rack(s). The mobile working platform (elements) should be compact enough to be stored out of the way and should NOT block the corridor (either completely or partially) when not in use.	1	50%

Figure 91: Expert Survey Question 31

Appendix H: List of requirements

Based on the findings of the research, a detailed list of requirements was created. To ensure the most objective evaluation possible, the requirements are defined by precise and measurable targets wherever possible.

The requirements are taken into account as early as the idea phase, and the resulting, further-developed concepts must be consistently aligned with the defined requirements.

The primary goal of the requirements list is to enable a measurable comparison of actual versus target performance, so that it can be validated later on to what extent the developed mobile working platform meets the established requirements.

A distinction is made between fixed requirements (F) and optional requirements (O), which are considered wishes. The latter do not constitute mandatory conditions but describe desirable characteristics that are aimed for but not required.

Table 15: List of Requirements

Nr.	Requirement	F/O	Description
1.	**The product**		
1.1	The system	F	The system must be a mobile working platform for the LAM.
1.2	Functional coverage	F	The mobile working platform must support workers in the work areas: • sowing and germination • plant care • pruning • harvesting • maintenance • system maintenance and repair • cleaning
2.	**Mobility**		
2.1	Mobility concept	F	There must be a rail system in place that allows the user to move the work platform within the LAM-GTD.
2.2	Precise positioning	F	It must be possible to position the work platform precisely at the desired work area.

Table 16: List of Requirements – Continuation of Table 15

2.3	Fixation	F	The platform must offer the option of being fixed to the selected location.
3.	**Design**		
3.1	Existing structure	F	The mobile working platform must adapt to the existing structures of LAM.
3.2	Integration into the LAM-GTD	F	The mobile work platform must be able to be integrated into the LAM-GTD in order to validate its functionality.
3.3	Hybrid solution for a sitting and stepping option	F	The mobile platform must offer a solution that allows workers to sit down and use the same device to stand on. It must support reaching the top level of the plant trays.
3.4	Biomass management	F	A storage solution must be available for storing edible and non-edible biomass.
3.5	Waste management	F	There must be a storage solution for waste that is not biomass.
3.6	Storage system	F	There must be a system in place in which all tools required for performing the function can be safely stored.
3.7	Toolholders	O	Toolholders should be able to be attached to the mobile working platform as an additional storage option for tools.
3.8	Work surface	F	There must be a work surface measuring at least 70x70 cm that can fit a plant tray.

Table 17: List of Requirements - Continuation of Table 16

3.9	Item System	O	The basic structure should be realized using components from DLR partner item.
4.	**Tools**		
4.1	**Plant related tools**		
4.1.1	Tweezer set	F	When handling seeds, you must have a set of tweezers consisting of: • Wide tip • Thin tip • Angled tip
4.1.2	Weigh pan	O	There should be a weighing pan available for storing seeds while sowing.
4.1.3	Brush set	O	A brush set consisting of at least two brushes should be available for pollinating the plants.
4.1.4	Scissor set	F	A set of scissors must include four different pairs of scissors: • Small scissor • Medium scissor • Garden scissor
4.1.5	Knife set	F	A set of knifes should be included: • Small knife • Medium knife
5.1.6	Jojo cables	O	A set of Jojo cables should be available to help stabilize the plants.
5.1.7	Magnifying glass	O	A magnifying glass to inspect the plants for damage like fungal infestation should be available.
5.1.8	Cord	O	A bundle of cord on hand to secure the plants should be available.
5.1.9	Nitril gloves	F	Nitrile gloves must be within reach of workers on the mobile work platform to protect against skin irritation.

Table 18: List of Requirements - Continuation of Table 17

5.1.10	Nets	O	Nets should be integrated into the storage system so that they can be secured above the plants to support them as they grow.
4.2	**Cleaning related tools**		
4.2.1	Disinfect wipes	F	Disinfectant wipes must be available to disinfect the tools used.
4.2.2	Hydrogen peroxide	F	Hydrogen peroxide must be available as a disinfectant to disinfect the tools used. (Hydrogen peroxide is not harmful to plants.)
4.2.3	Kitchen roll	F	A kitchen roll must be available on the mobile work platform to remove dirt or wipe up liquid.
4.2.4	Cotton cloth	F	Cotton cloths must be included as a cleaning tool to wipe down wet surfaces or absorb liquid that drains from plant trays.
4.3	**Documenting and monitoring related tools**		
4.3.1	Handheld camera	F	A handheld camera must be include to visually document the progress of the plants and the research.
4.3.2	Tablet	F	A Tablet must be include to digitally document the plants progress.
4.3.3	Scale	F	A scale must be installed for the purpose of documenting plants and biomass.
4.3.4	Notebook	O	A notebook for taking notes should be included.

Table 19: List of Requirements - Continuation of Table 18

4.3.5	Pens	O	Pens should be available as writing materials to supplement the note-book for documentation purposes.
4.3.6	Folding ruler	F	A folding ruler for measuring and documenting plant growth must be included.
4.4	**Maintanence related tools**		
4.1	Repair kit	F	A repair kit must be available on the mobile work platform for repairs and maintenance.
5.	**Ergonomics**		
5.1	Cognitive ergonomics	F	All functions of the mobile working platform must be intuitively under-stood without further explanation.
5.2	Arbeitsflächenhöhe	F	The work surface height must be: • Minimum of 680 mm • Maximum of 1250 mm
5.3	Reach	F	All tools must be within easy reach while working.
5.4	Barrier-free processes	F	When not in use, the mobile work platform must not hinder the worker's movements in the LAM.
6.	**Cleaning**		
6.1	Smooth surface finish	F	The surface of the work area must be smooth so that it can be wiped clean without any irregularities in which bi-omass or contaminants can stick.
6.2	Slit avoidance in the working area	O	The work surface to be cleaned should have as few slits as possible where dirt could accumulate.

Table 20: List of Requirements - Continuation of Table19

7.	**Material**		
7.1	Corrosion resistant	F	The mobile working platform must be made of corrosion-resistant materials, as the greenhouse has higher air humidity and liquid from the plant trays could find its way into the interior and surface of the mobile working platform.
8.	**Safety**		
8.1	Crushing points	O	Crushing points should be prevented so that workers do not accidentally injure themselves.
8.2	Plant safety	F	The mobile work platform must be designed in such a way that damage to plants cannot happen.

Appendix I: Sketches without using a morphological box

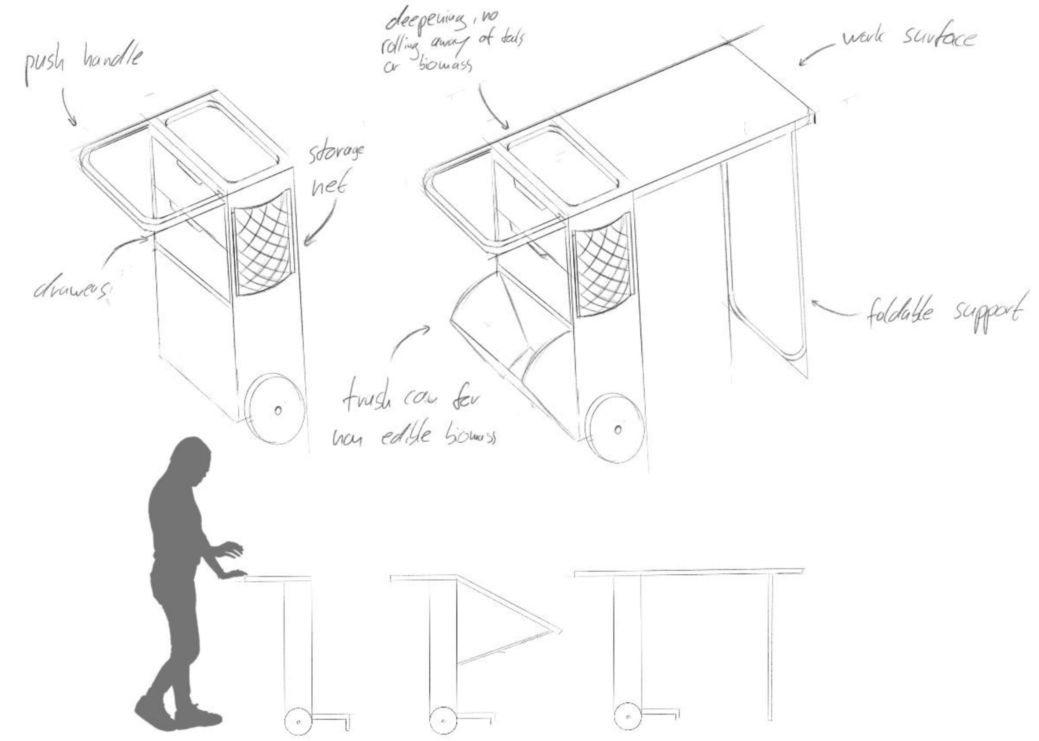


Figure 92: Sketch of a sliding trolley [34]

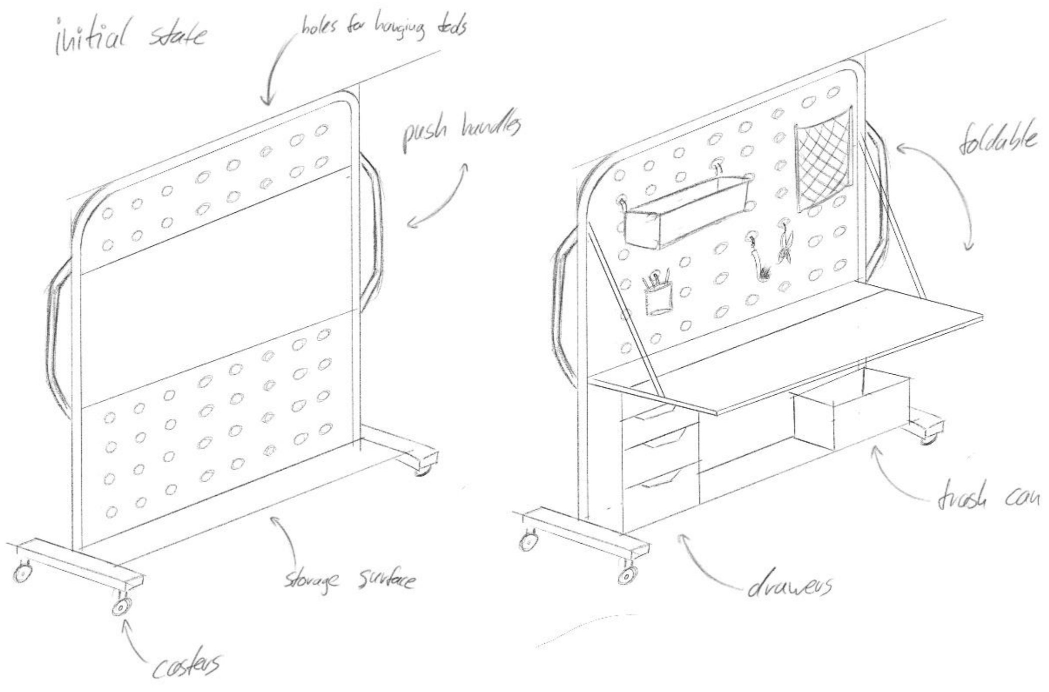


Figure 93: Sketch of a sliding system, similar to a folding workbench

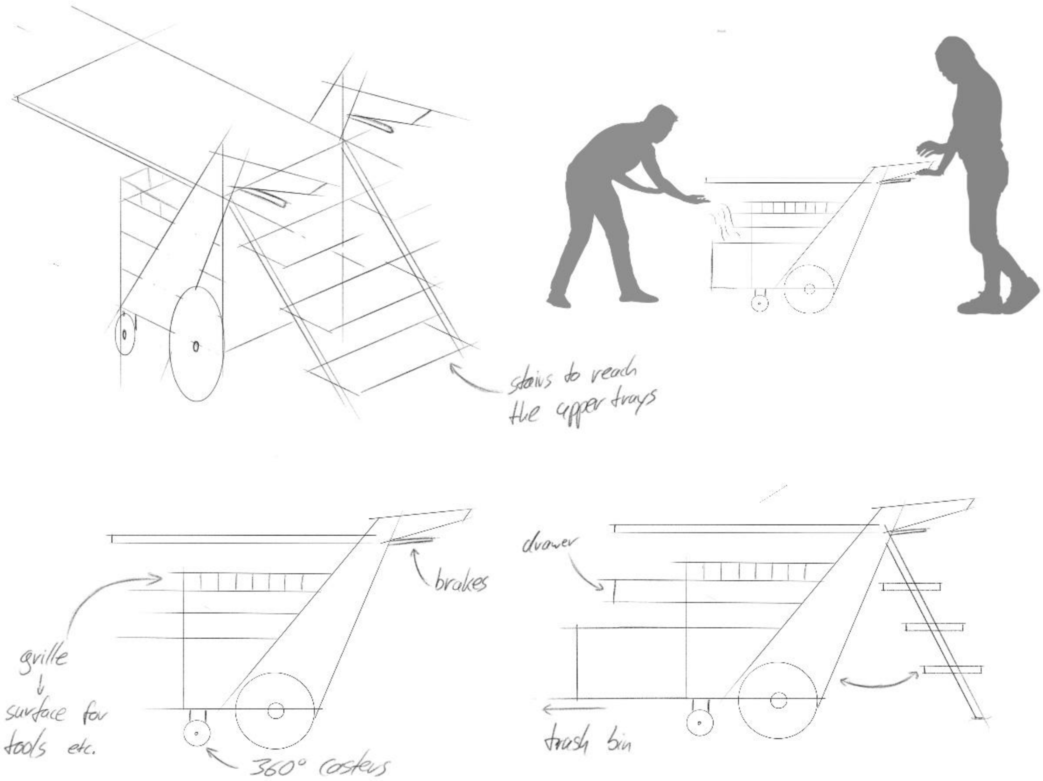


Figure 94: Sketch of a tool trolley inspired workplace [9] [34]

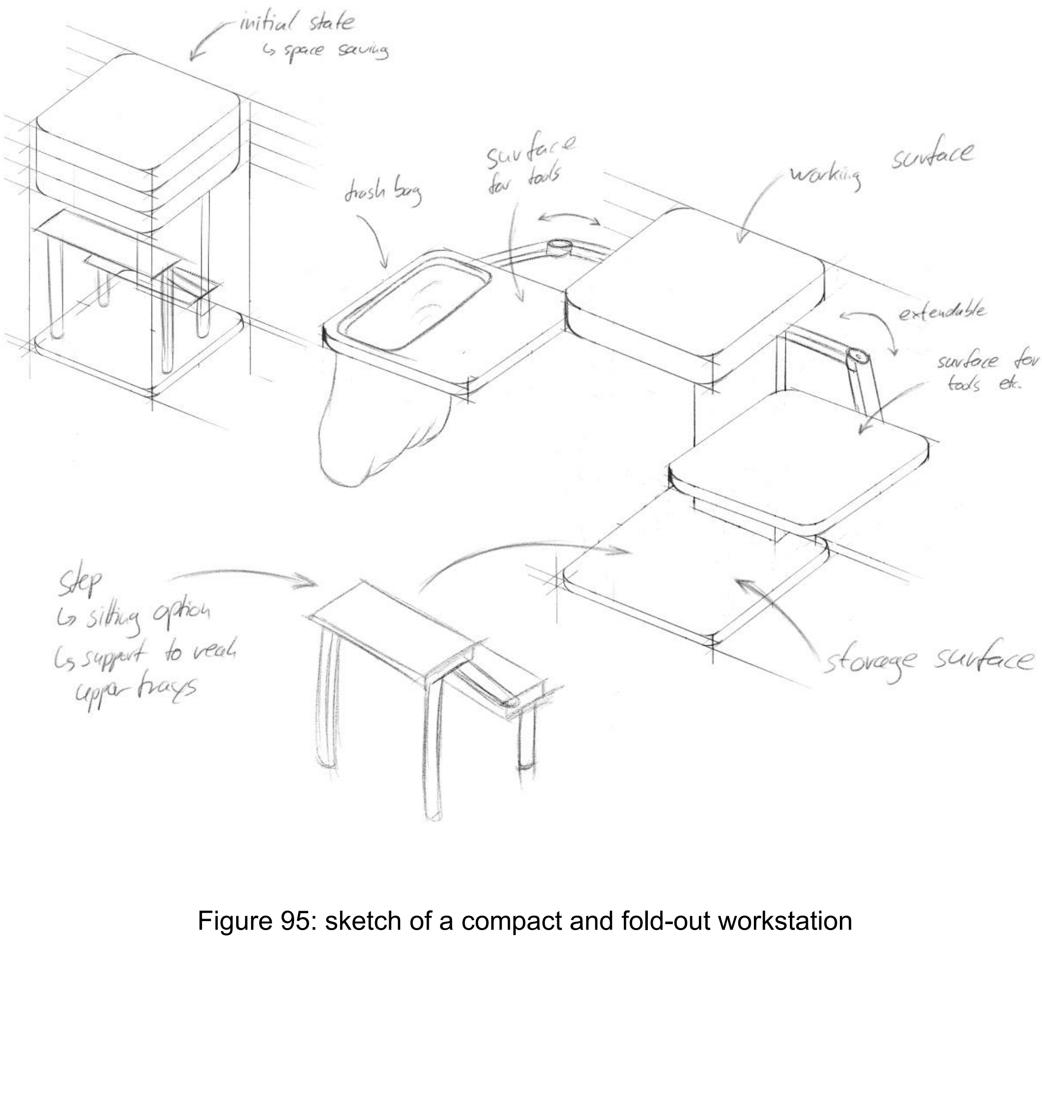


Figure 95: sketch of a compact and fold-out workstation

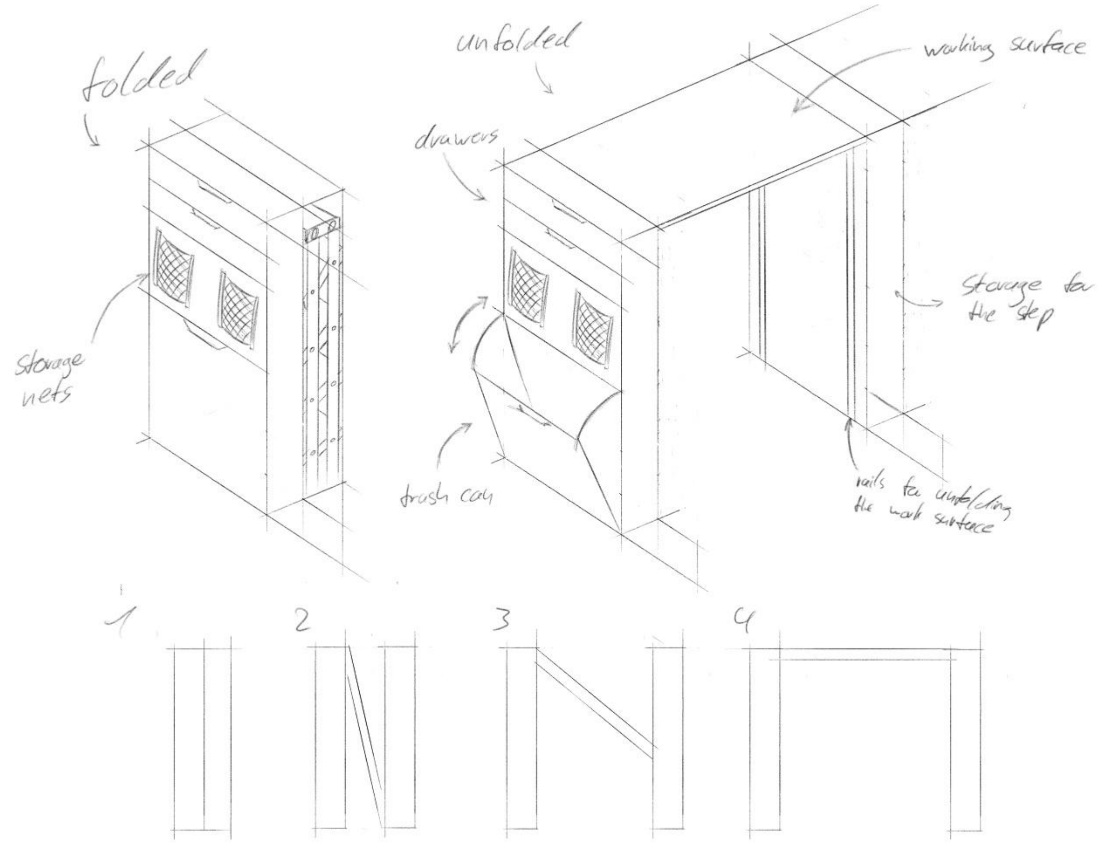


Figure 96: Extendable workstation

Appendix J: Revised rail positions

The following section shows the revised rail positions for the TheRig, Modu-Hub, and Pro-Bench designs, followed by the second phase of the concept development.

Revised rail positions

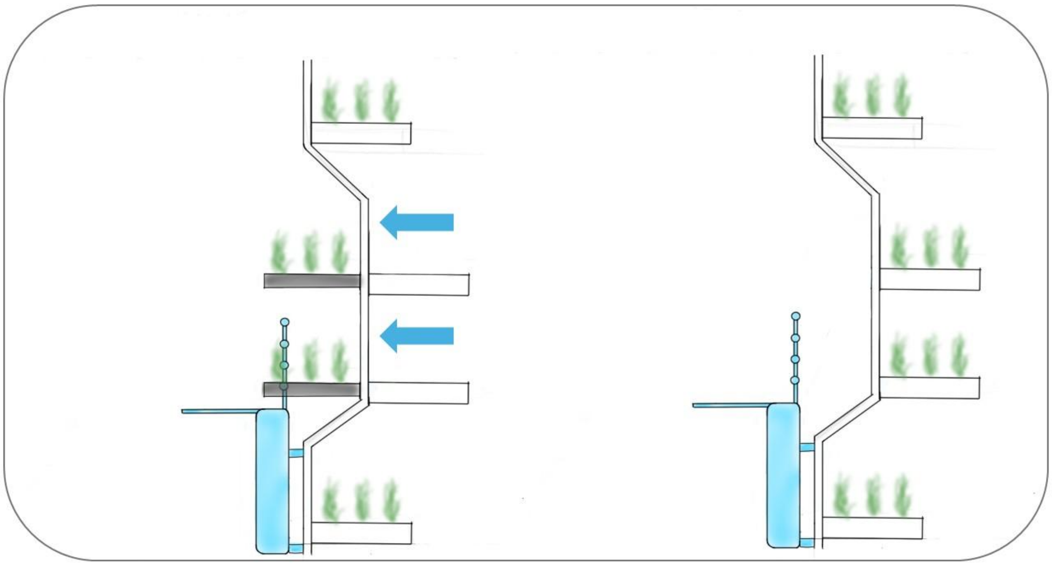


Figure 97: Revised rail position for the concept ProBench

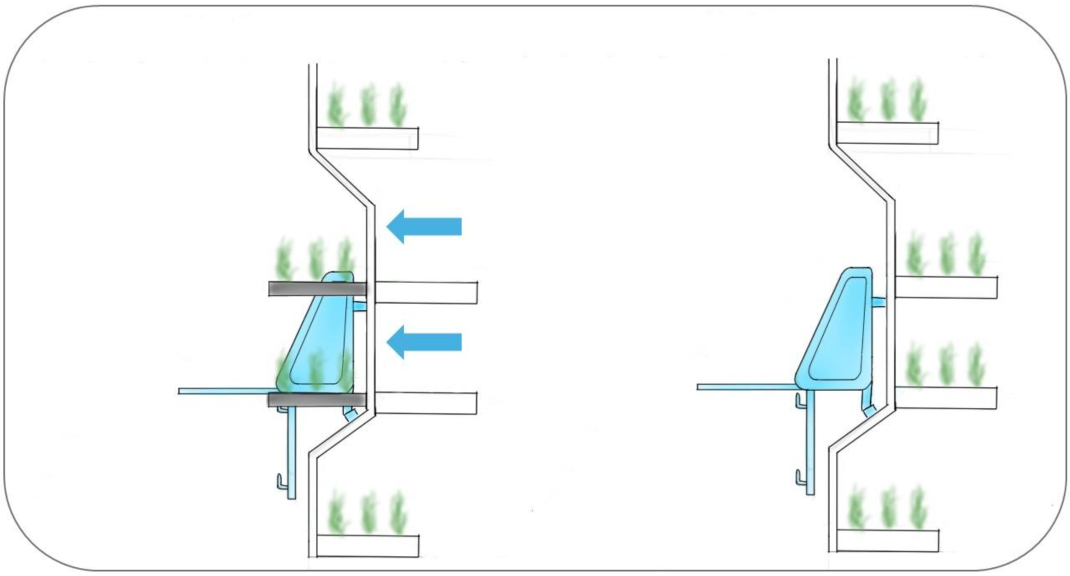


Figure 98: Revised rail position for the concept ModuHub

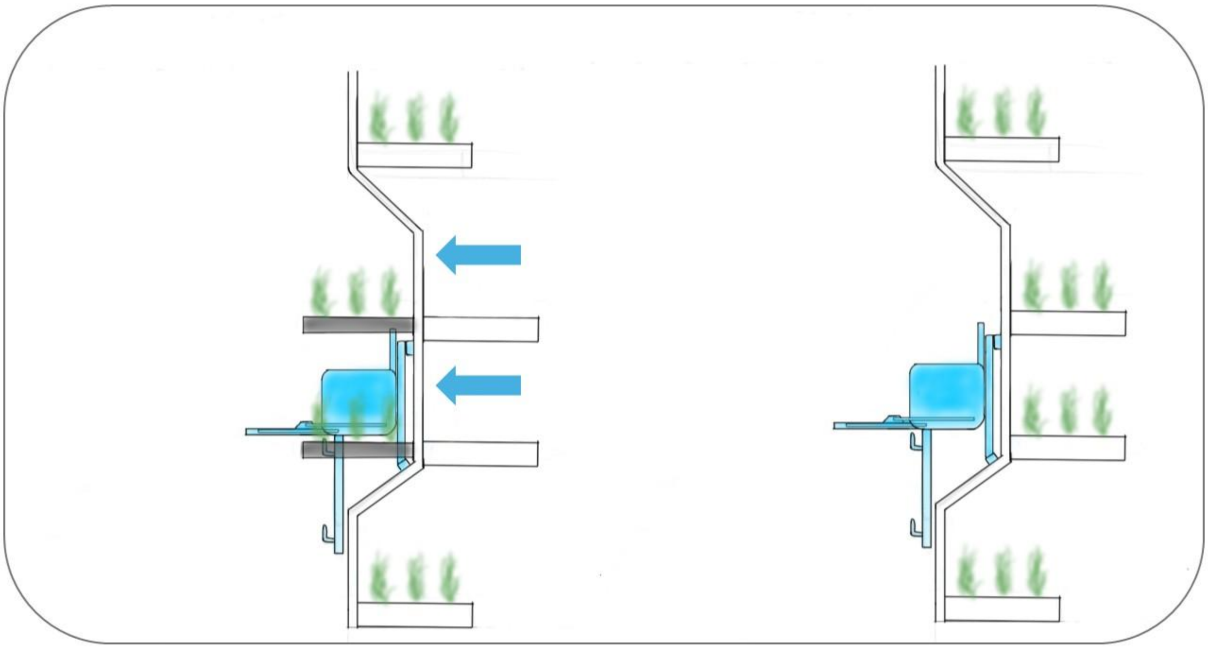
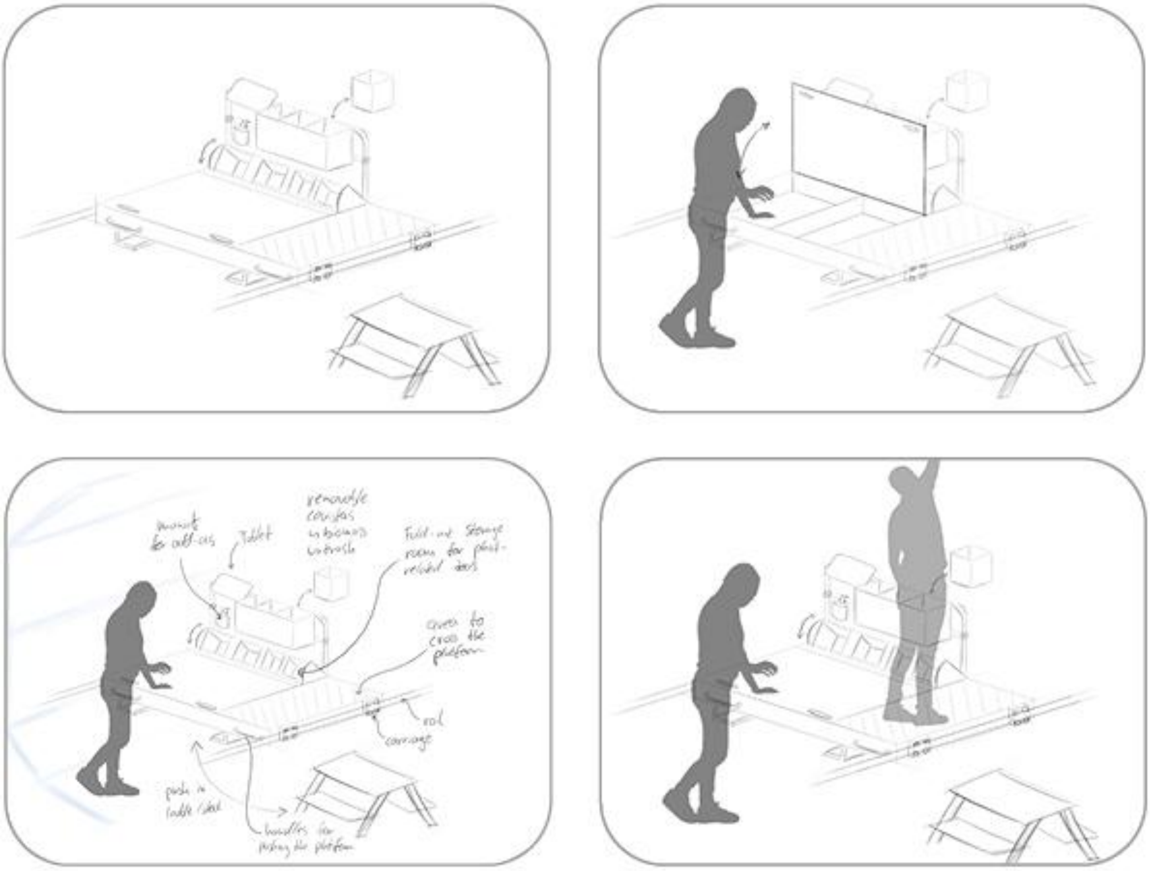


Figure 99: Revised rail position for the concept TheRig

Appendix K: Idea phase 2



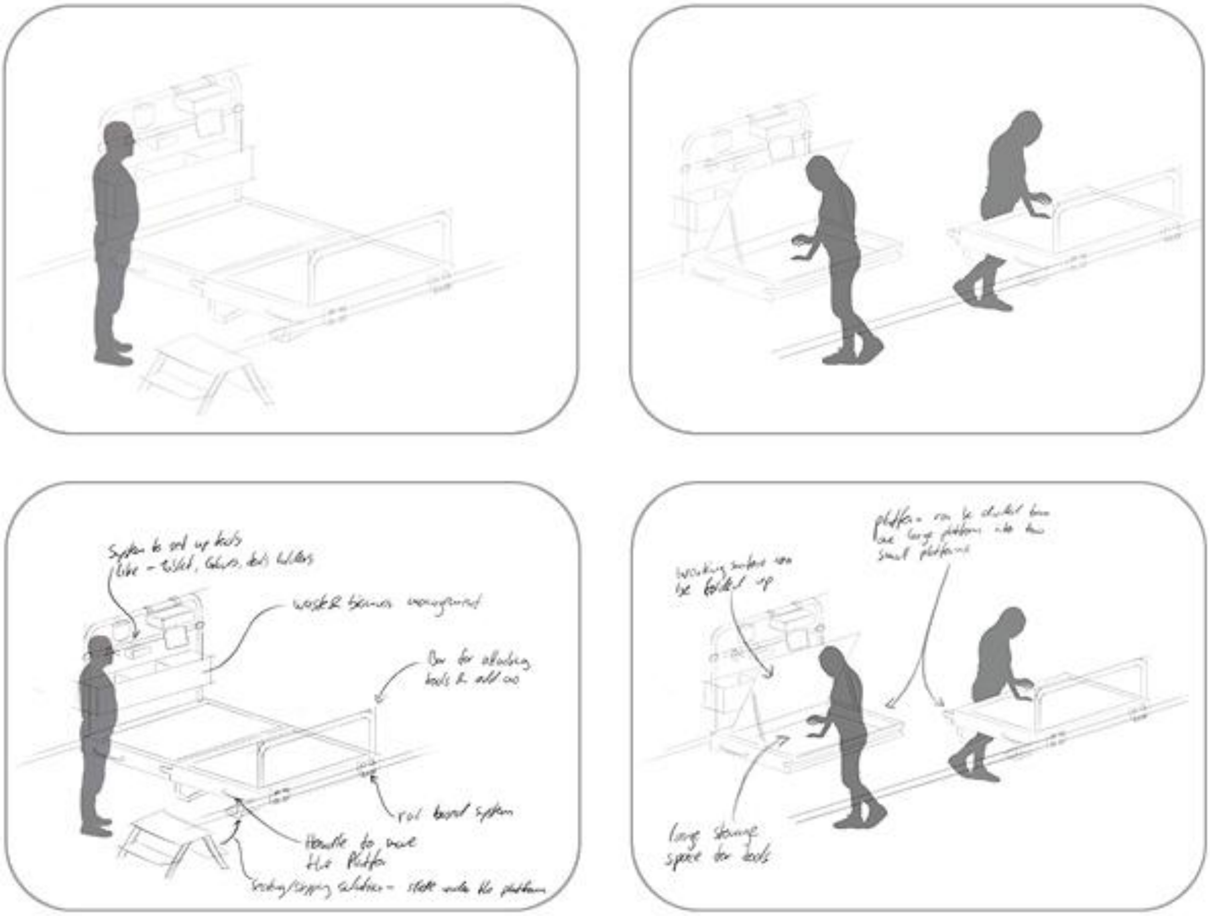
Pros

- Very large worksurface
- Lots of storage space for tools and equipment
- Bar system for attaching tools or other add-ons

Cons and general questions

- Blocks the whole corridor
- No easy way around it
- You have toget over it.
- To access tools, always open the surface.
- Perhaps simply too large for the tasks it is supposed to perform.
- Can also be achieved with a smaller system

Figure 100: Idea overview of SlideDeck [10] [34]



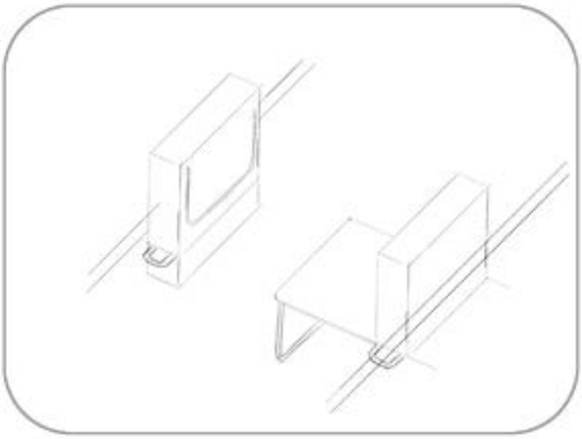
Pros

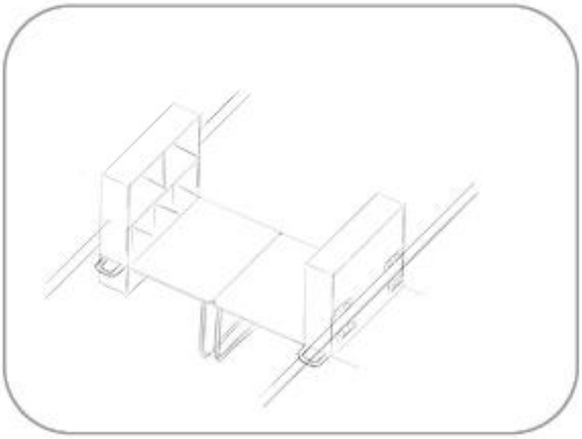
- Does not block the corridor when the platform is divided into two parts.
- When the platform is separated, workers can work in different locations.
- Bar system for attaching tools or other add-ons

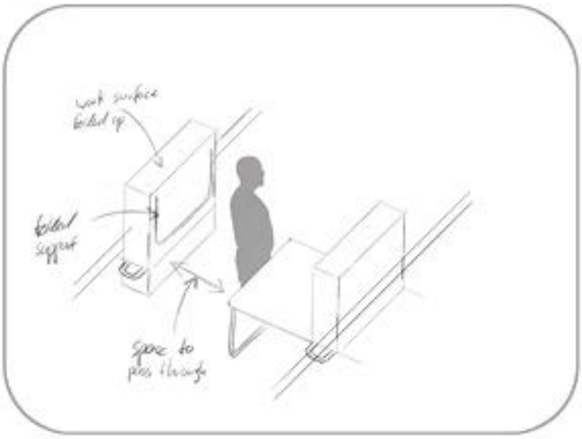
Cons and general questions

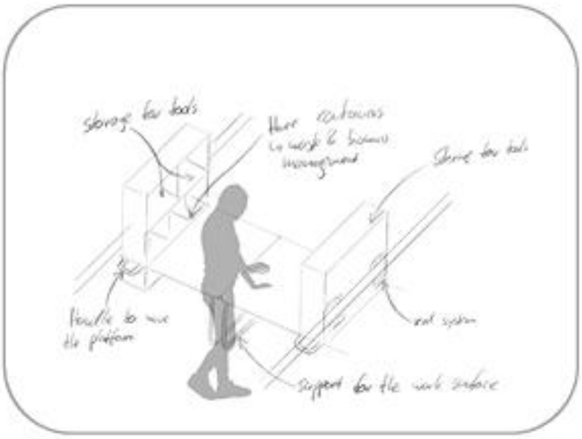
- Why two working surfaces/platforms?
- Not all tools are centralized in one place.
- Are they spread across different platforms?
- Could it be difficult to work out how the platforms could merge into one large platform?

Figure 101: Idea overview of SplitDeck [34] [36]









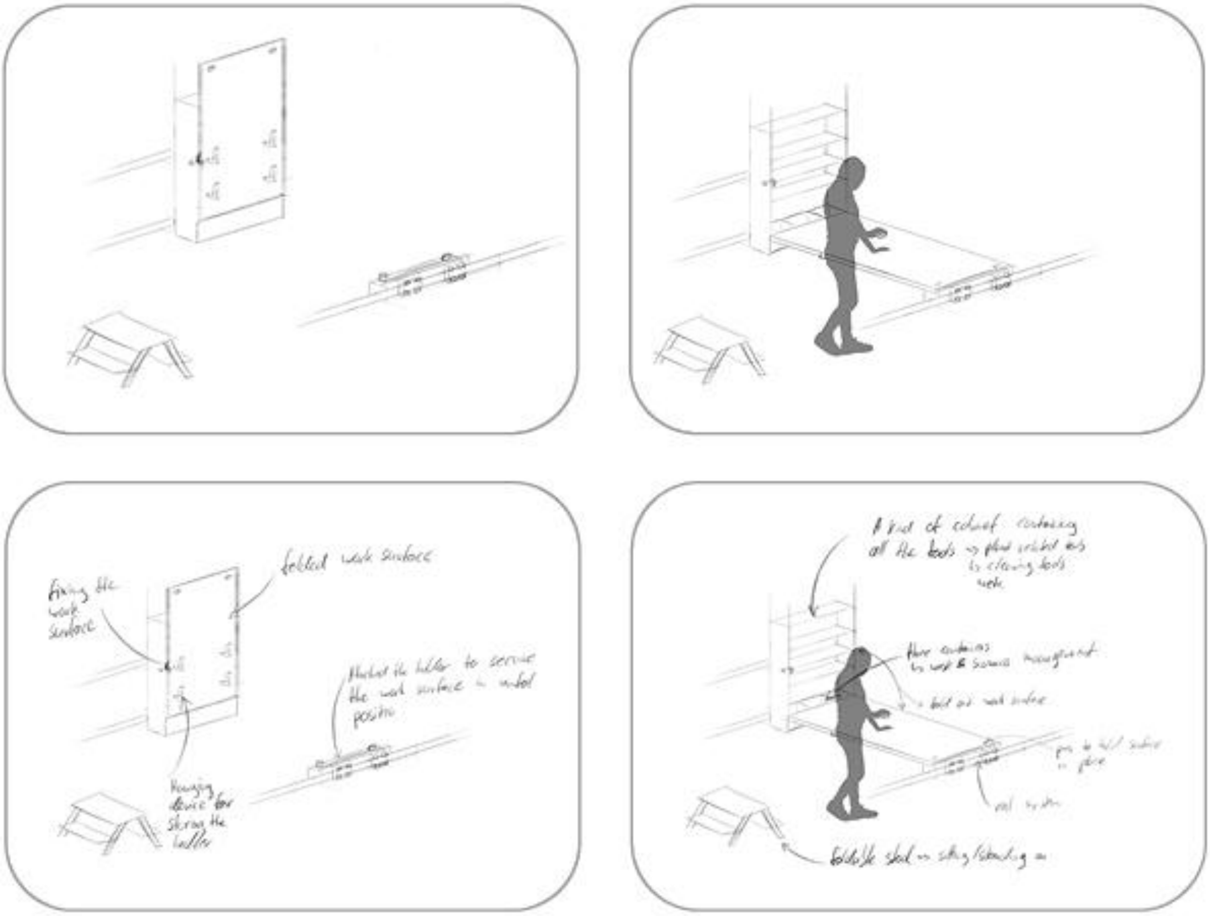
Pros

- Very large work surface
- If the work platform is not fixed in place, simply push it in front of you to the next working area

Cons and general questions

- Is almost like the favorites concept from the concept phase
- Only narrower, and the work surface ex tends across the entire corridor
- The system that locks the work surface in place must always travel with the platf orm and be positioned at the same time.

Figure 102: Idea overview of TwinDeck [34] [36]



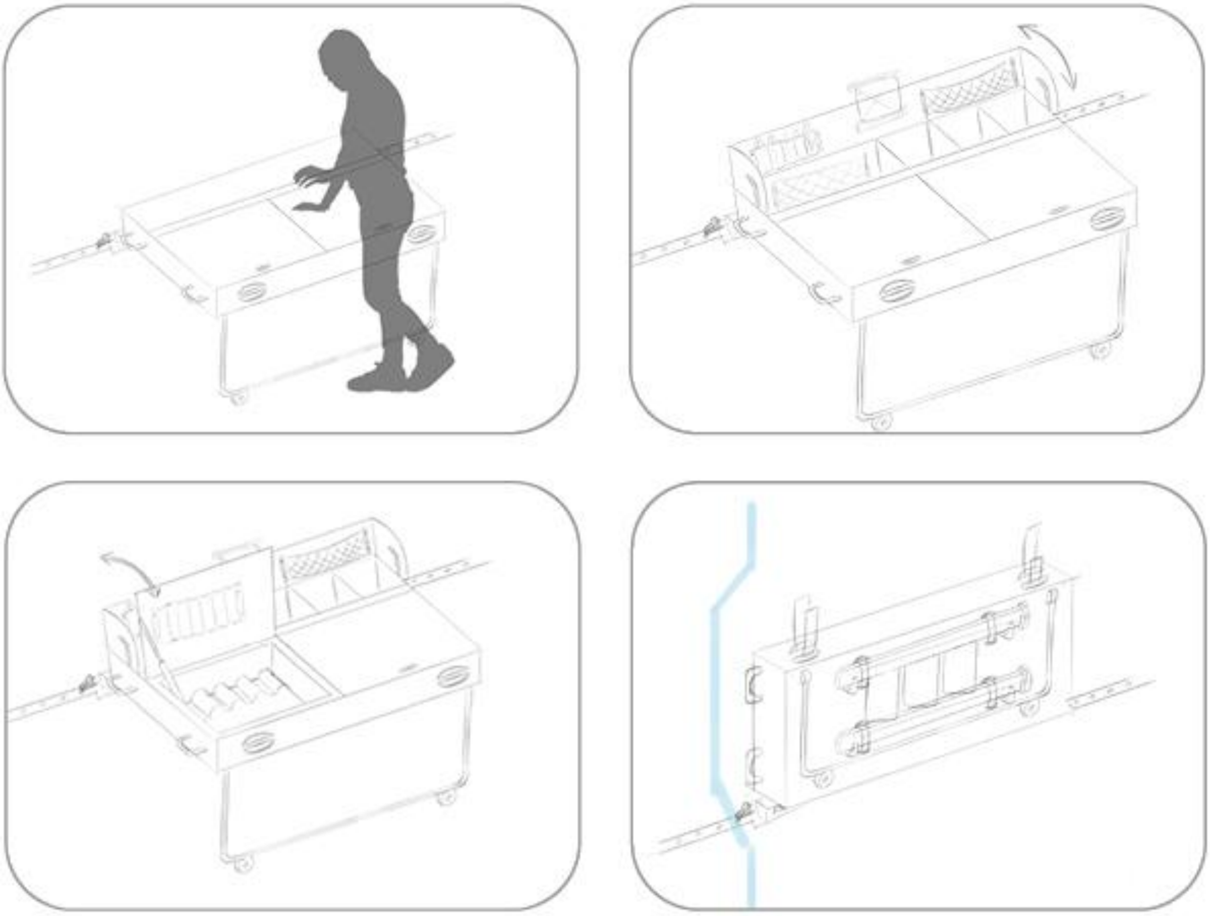
Pros

- very large working surface
- Plenty of storage space
- not blocking the corridor

Cons and general questions

- Big storage system wich needs two rail to hold
- The opposite carriage must always be moved separately in order to position the workpiece on it
- Blocking the corridor while working

Figure 103: Idea overview of BridgeDeck [34]



Pros

- Does not block the corridor when the platform is folded up.
- Plenty of storage space, divided into two storage systems
- Very large worksurface
- The platform itself serves as storage space
- Modular and customizable thanks to the planed profile-based construction system

Cons and general questions

- Open the worksurface to reach the tools
- A safe mechanism for folding the platform must be found
- A solution for securing the tools within the platform needs to be developed
- A solution needs to be developed so that we don't always have to open the work flows and can place tools in advance.

Figure 104: Idea overview of FoldDeck [34]

Appendix L: FoldDeck Inlay inspiration

Toolbox inlay that served as inspiration for the FoldDeck inlay.

Figure 105: Toolbox inlay [47]