Vertical Farming Workshop

July 2022

HELMUT SCHMIDT UNIVERSITÄT

Hamburger Klimaschutzstiftung für Bildung und Nachhaltigkeit

ayya ARAB-GERMAN YOUNG ACADEMY OF SCIENCES AND HUMANITIES

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DOCUMENTATION

Introduction

The purpose of this document is to document and explain the steps and materials behind making two prototypes in a DIY style for home farming.

The prototypes were developed by the team Value Creation of the Laboratory of Production Engineering (LaFT) at the Helmut-Schmidt-University / University of Federal Armed Forces Hamburg (HSU) for a workshop of the Arab-German Young Academy of Sciences and Humanities (AGYA) about Vertical Farming (July 2022). The aim was to create two prototypes (one outdoor version and one indoor version) that can easily be replicated with the help of this documentation.

The journey for both versions started with idea-hunting online: A simple research on the web gave us inspiration for what we wanted to do. The web is full of ideas, so we brought together different styles and adjusted them to our specific conditions. A site inspection was performed to understand some parameters, such as the size limitations of the outdoor prototype[1].

Both versions of the prototypes were first set-up during the AGYA workshop 'Vertical Farming and Innovative Urban Agriculture', which was conducted 4-6 July 2022 at Gut Karlshöhe, the headquarters of the Hamburger Klimaschutzstiftung. The workshop was initiated by AGYA Alumni Dr. Henda Mahmoudi, International Center for Biosaline Agriculture (ICBA), Dr. Sonja Buxbaum-Conradi, HSU, Dr. Salma Balazadeh, Leiden University, and Dr. Nageh Allam, American University in Cairo. During the workshop researchers and practitioners discussed success stories of sustainable farming in Egypt, Germany, Oman, Saudi Arabia, Sudan, Tunisia, and the United Arab Emirates.

[1] Both versions are scalable by reducing or increasing the size. The scalability also influences the size of the used materials: e.g., for a smaller outdoor version, smaller beams should be used.

Outdoor version

The outdoor version concept is an easy, low-tech DIY project. Easy-to-find materials, such as wood beams and rain gutters, were used. The design and layout were chosen based on the planned location on a brick wall and the requirements of the plants that were considered for growing. The size of the prototype was also chosen as a compromise between the number of levels and the ease of maintenance without a ladder or other aids.

Materials and costs

This paragraph illustrates the Bill of Materials (BOM) for the outdoor version (Table 1).

Note: Costs may vary according to region, shop, and period. The links may be used as a reference to find the same or a similar item for your conditions. The prices do not include the costs for plants, seeds, seedlings, and water.

Table 1: Bill of Material (BOM) for the outdoor prototype.

Item	Description	Quantity	Size	Link	Price per Unit	Price	Note
Rain Gutters	Marley Dachrinne Kunststoff halbrund Schokoladenbraun RAL 8017 NW	4	150 x 2000 mm	Link	15,95 €	63,80 €	
Rain Gutters' End Pieces	Marley Rinnenendstück Kunststoff halbrund Schokoladenbraun RAL 8017 NW	8	150 mm	Link	5,45 €	43,60 €	
Coconut Mat	Natursache Coconut erosion protection mat, coconut 225 g/m² on jute fabric, 300 g/m²	1	1,1 x 10 m	Link	46,47 €	46,47 €	
Pump (Irrigation System)	Esotec WaterDrops, Professional Solar Irrigation System	1	-	Link	119,00 €	119,00 €	
Soil	Soil peat-free & with biochar	8		Link	6,99 €	55,92 €	Available only in Germany
Wood Beams	Douglas fir	13	45 x 70 x 2000 mm	Link	15,95 €	207,35 €	
Wood Oil	Protective wood oil	1	-	Link	21,95 €	21,95 €	

Table 1 (continued): Bill of Material (BOM) for the outdoor prototype.

Item	Description	Quantity	Size	Link	Price per Unit	Price	Note
Wood Screws long	-	1	4,5 x 70 mm	Link	10,00 €	10,00 €	Pack of 100 Screws
Wood Screws	-	100	3 x 25 mm	Link	4,95 €	4,95 €	
Butterfly Hinges	-	2	90 x 60 x 1,25 mm	Link	1,95 €	3,90 €	
Water Container	With lid and base	1		Link	43,99	43,99	
Total							**576,94 €**

Building manual

This section explains the steps followed to design and build the outdoor version.

Step 1: CAD design

The CAD file was prepared using a CAD software. The purposes of having a CAD file are:

- Proof of concept: With a technical CAD design, it is possible to see (to a certain extent) if the design is feasible and stable. Some CAD software has integrated features to evaluate the mechanical properties of the project. Therefore, creating a 3D model makes assessing the idea's functionality easier.
- Clearer understanding of the materials to be purchased: With the CAD design, the dimensions are known; therefore, less waste is produced during the production phase.
- Reduce the error rate while producing and assembling: With a 3D model as a reference, it is easier to follow the idea. Furthermore, by designing the project digitally, the steps during the assembly are more transparent.
- Replicability: CAD files allow people to share their projects and replicate others'[2].

[2] This is particularly important when digital techniques (such as 3D printing, laser cutting and CNC milling) are used to produce the parts.

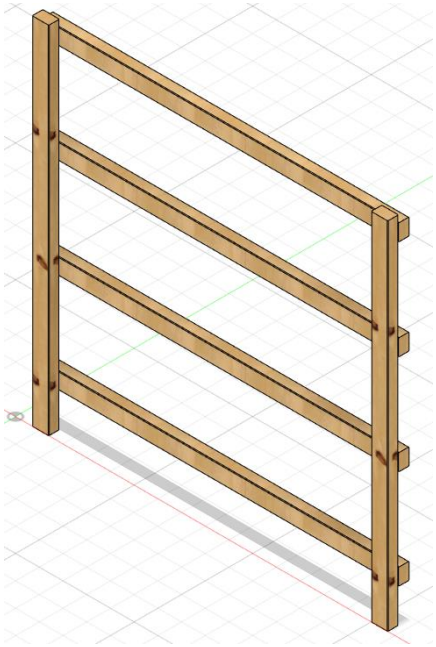


Figure 1: Back frame, CAD drawing.

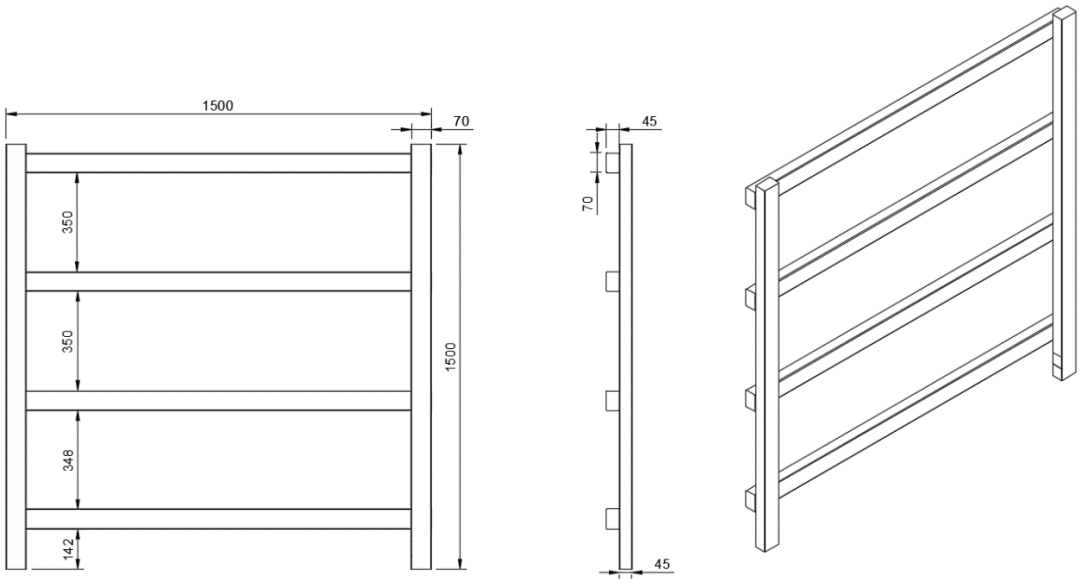


Figure 2: Back frame, technical drawing.

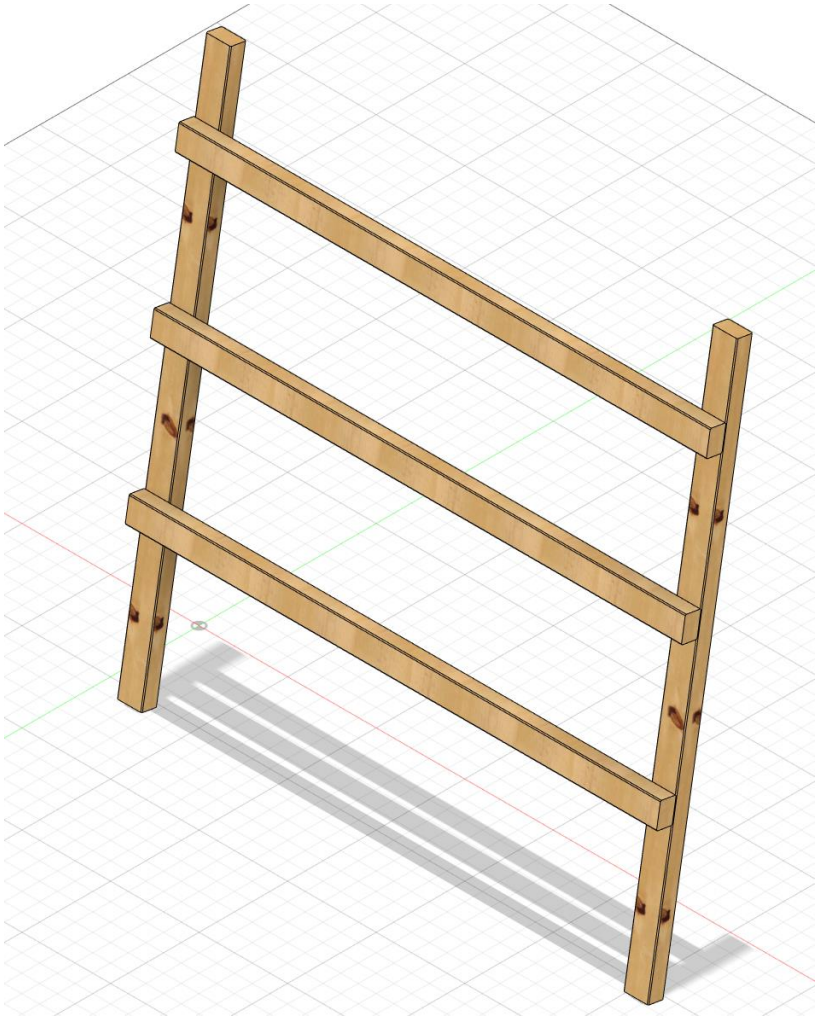


Figure 3: Front frame, CAD drawing.

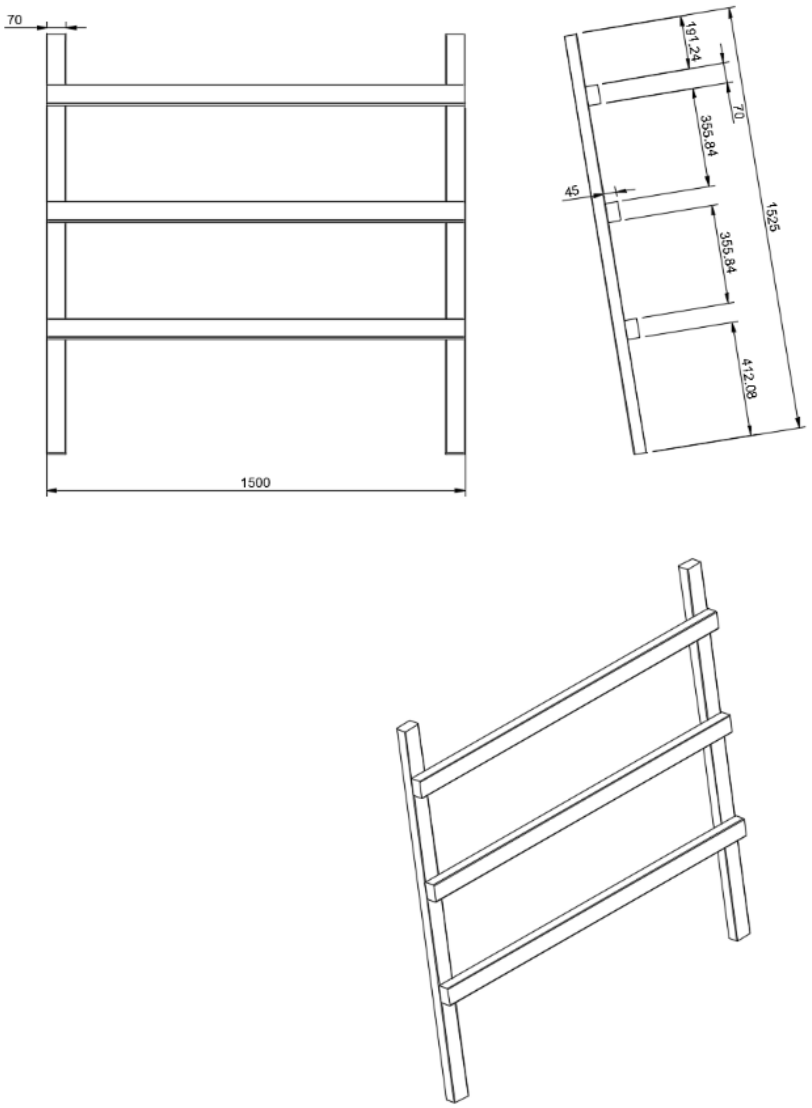


Figure 4: Front frame, technical drawing.

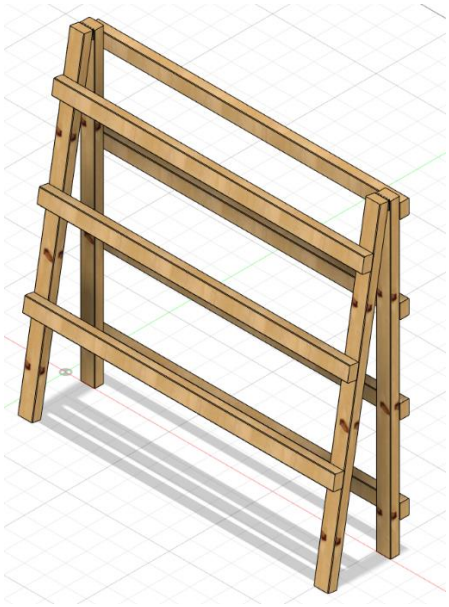


Figure 5: Ensemble, CAD drawing.

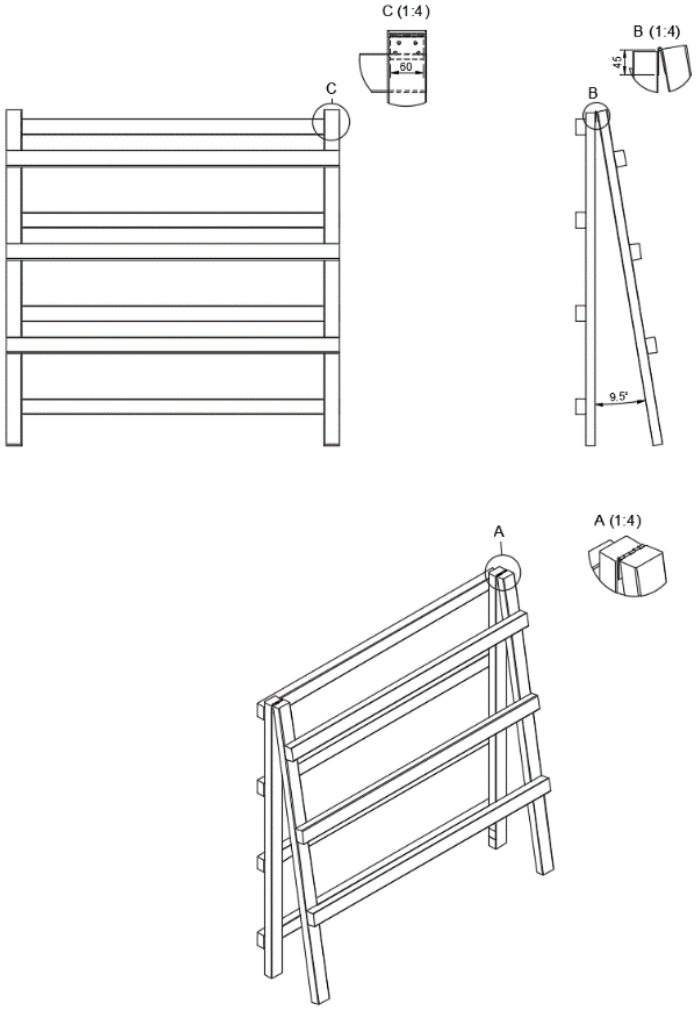


Figure 6: Ensemble, technical drawing.

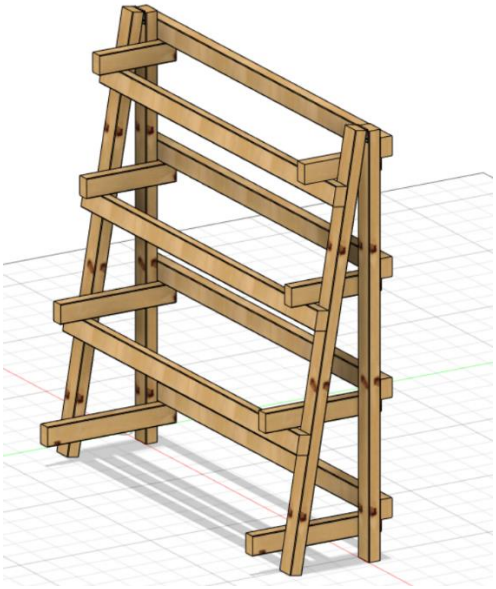


Figure 7: Complete frame, CAD drawing.

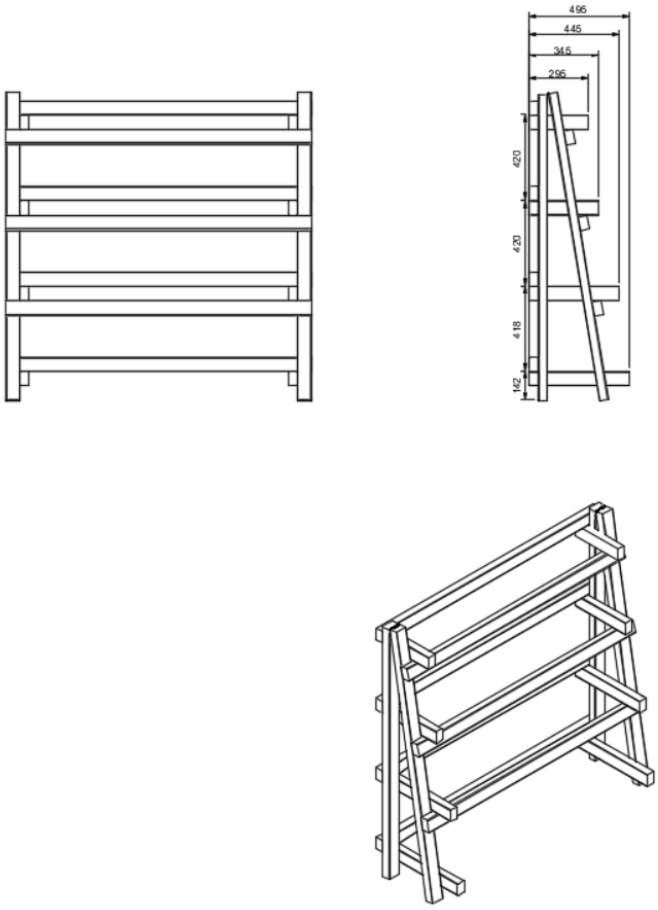


Figure 8: Complete frame, technical drawing.

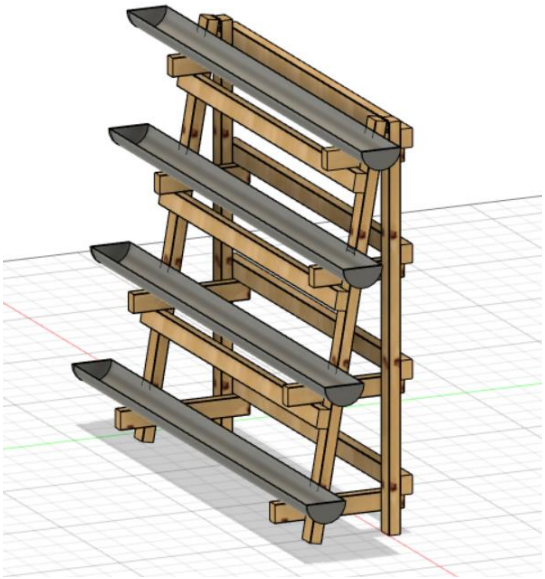


Figure 9: Indoor prototype, CAD drawing.

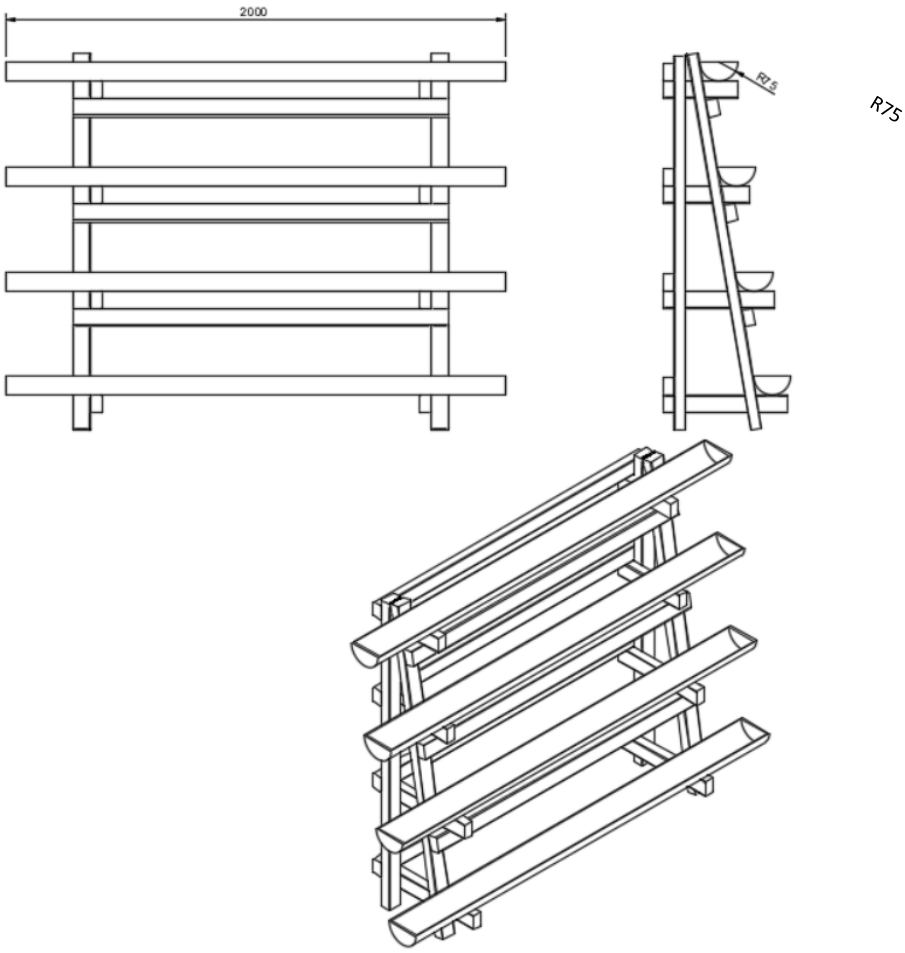


Figure 10: Indoor prototype, technical drawing.

Step 2: Materials procurement

Materials were purchased from different sellers, considering the price, quality, and shipping times. For a detailed view, refer to the Bill of Materials (BOM).

Step 3: Construction

a. Cutting the wood beams

The wood beams were cut to the correct size according to the BOM with a circular saw:

- 2 x 1525 mm
- 2 x 295 mm
- 2 x 345 mm
- 2 x 445 mm
- 2 x 495 mm
- 9 x 1500 mm

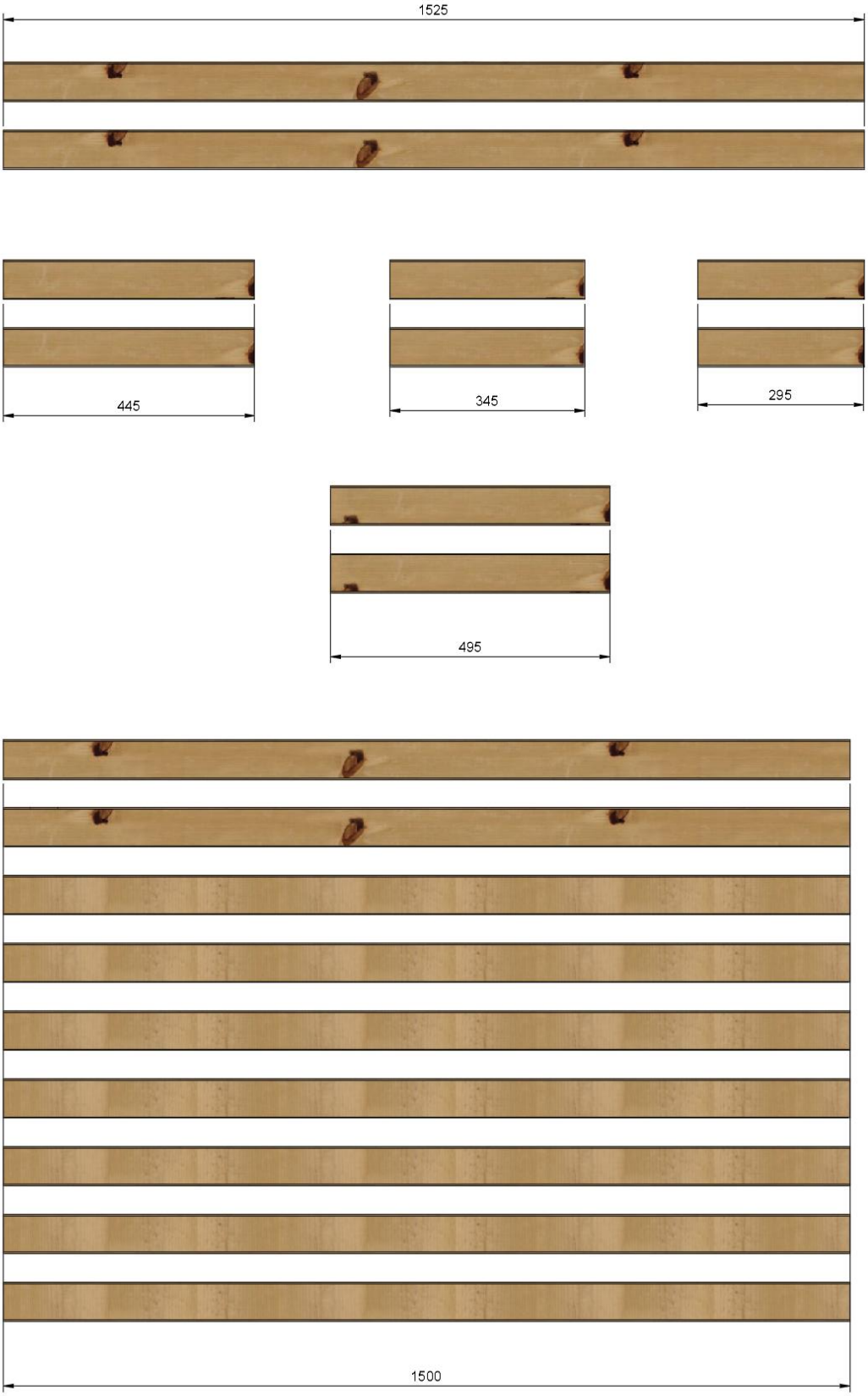


Figure 11: **Guideline for sawing the wooden beams.**

b. Building the back frame

For this step we used:

- 6 x 1500 mm wooden beams
- 6 x wood screws

The frame was built according to the CAD drawing. The 6 x 1500 mm wooden beams and 8 x long wood screws (1 per contact point) were used.

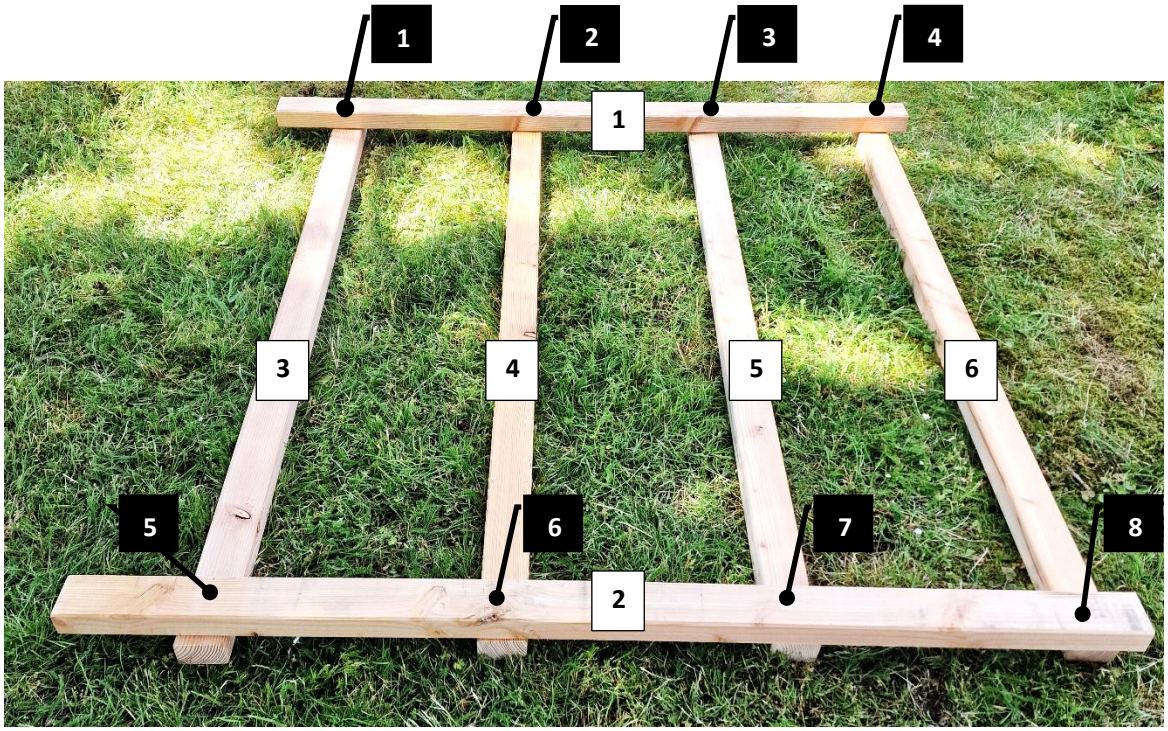


Figure 12: Assembly of the back frame using the wooden beams (1-6) and the screws (position 1-8).

c. Building the front frame

For this step were used:

- 2 x 1525 mm wooden beams
- 2 x butterfly hinges
- 16 x wood screws

The 1525 mm wooden beams were connected to the back frame with hinges.

Figure 13: Assembling of the front frame.

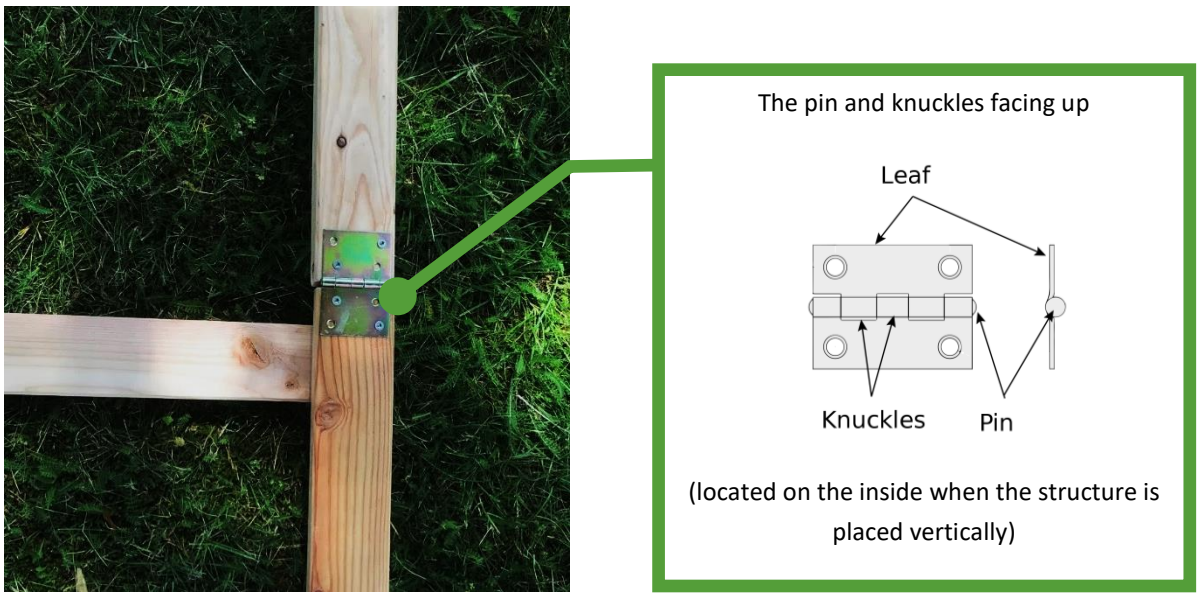


Figure 14: Assembling of the front frame using hinges – in detail.

d. Fastening the struts

For this step were used:

- 2 x 295 mm wooden beams
- 2 x 345 mm wooden beams
- 2 x 445 mm wooden beams
- 2 x 495 mm wooden beams
- 32 x long wood screws

For this step the so-far-assembled structure was set up flush against a wall. The angle created between the back and front frames was set to be approximately 9,5° in regard to stability. The struts were fastened, longest at the bottom and shortest at the top.

Figure 15: Adding the struts.

Figure 16: Assembling of the struts – in detail.

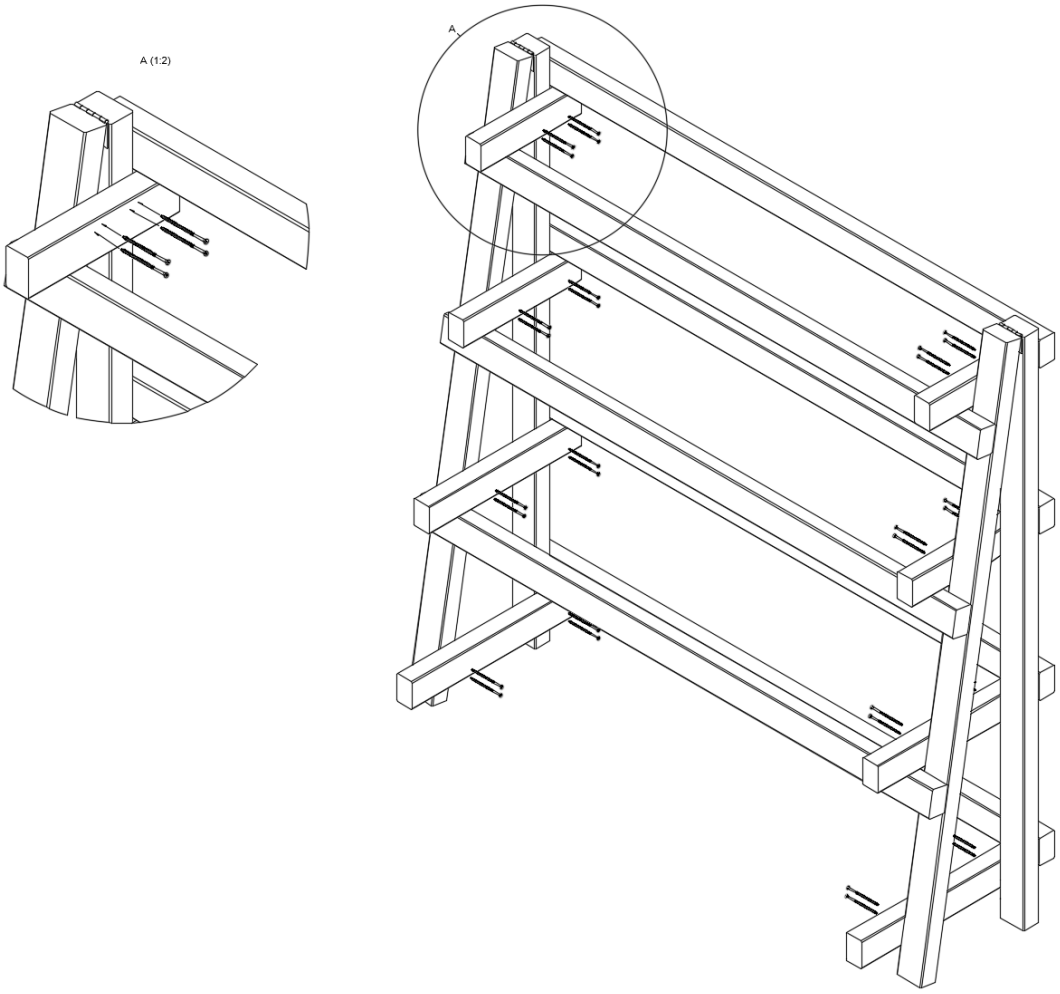


Figure 17: Position of the screws to attach the struts.

e. Staining the frame

To protect the wood from all weather conditions, the structure was stained with protective eco-friendly oil.

Figure 18: Staining of the wooden frame.

Step 4: Final assembly at the chosen location

In our case, the frame was transported to the "Umweltzentrum Gut Karlshöhe" of the Hamburger Klimaschutzstiftung in the North of Hamburg.

a. Securing the frame to the wall

The structure was secured and attached to the wall using brackets, screws, and plugs.

Figure 19: Placement of the frame in its final position.

b. Fastening the rain gutters

The rain gutters with the end pieces were secured to the front frame through 1 short wood screw on each side. The struts give support thanks to gravity force.

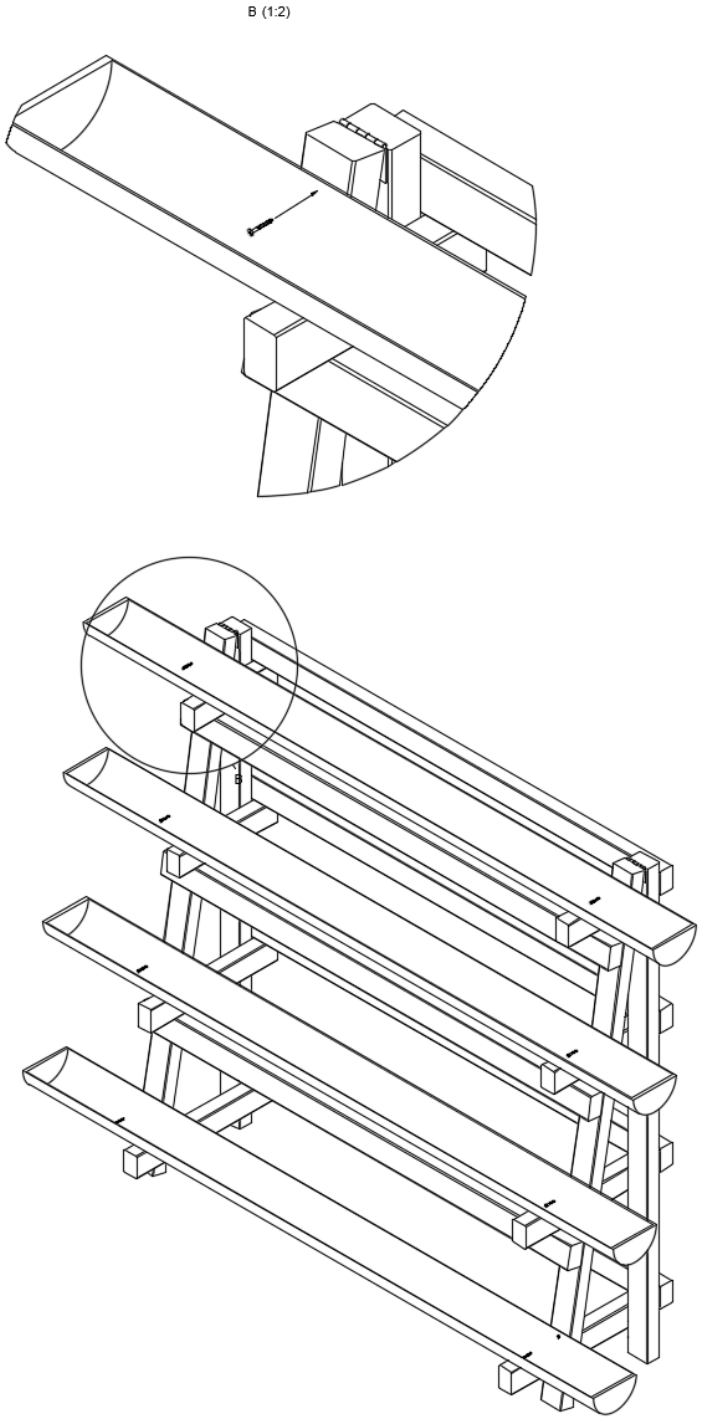


Figure 20: Position of the screws to fix the rain gutters.

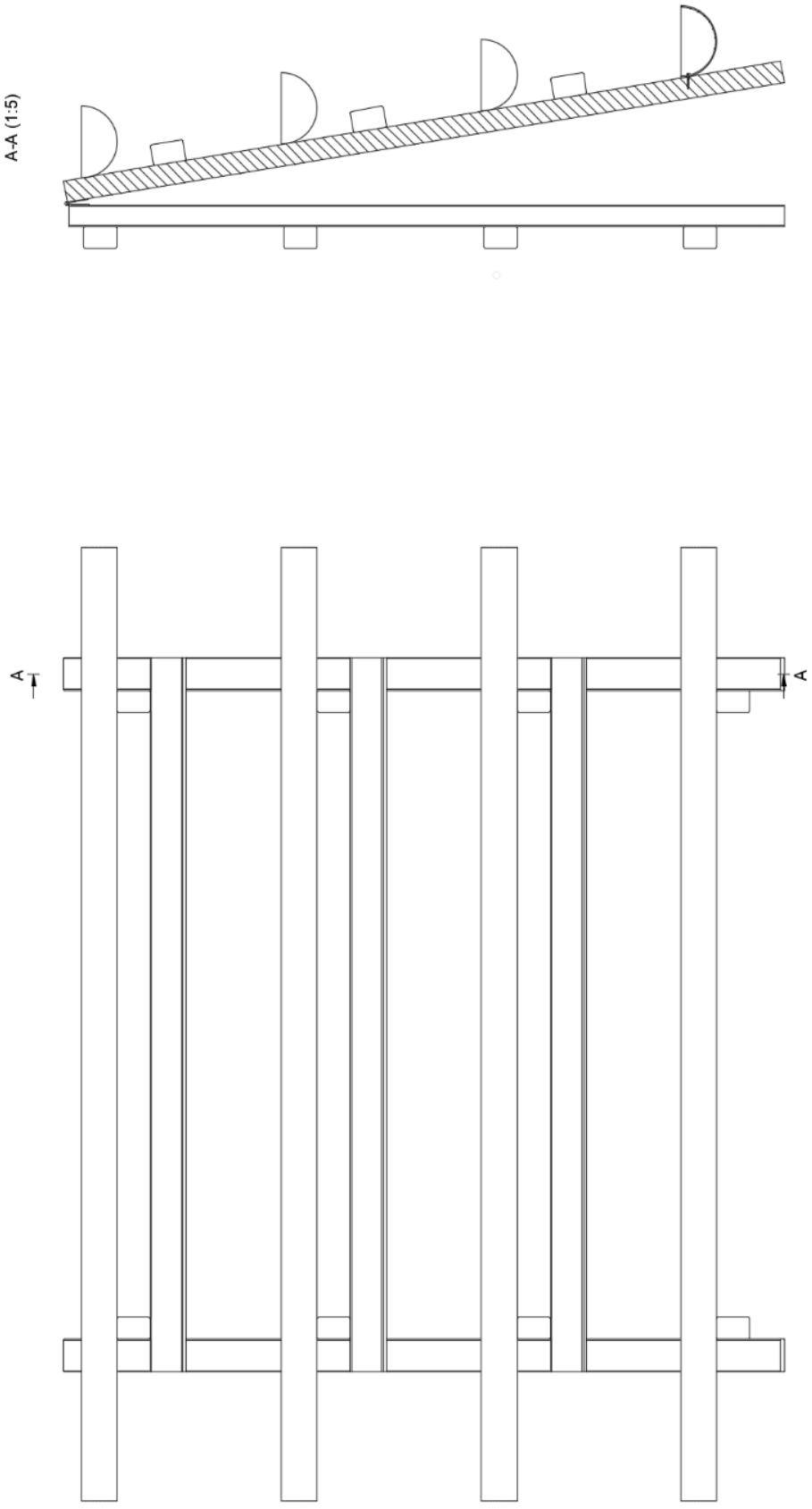


Figure 21: Attaching the rain gutters to the frame in a section detail, technical drawing.

Figure 22: Rain gutters fastened to the frame.

Figure 23: Complete structure with the rain gutters.

Drainage holes were drilled along the whole length of the gutters at intervals of approximately 15 cm.

Figure 24: Drilling the drainage holes.

c. Preparing and placing the coconut fiber mat

The gutters were covered on the inside with coconut fiber mats to prevent the soil from falling out. They further act as a filter for the draining water, so the plants on the lower level are not getting dirty. The mat was cut in pieces as long as the gutters and wide twice the half circumference of the gutters. In our case, the mat was cut in rectangles 2000 x 470 mm ca. (This step doesn't require high precision, as long as the gutters are entirely covered by the mat.) The mats were then placed in the gutters in a double layer (by bending it along the centerline).

Figure 25: Preparation of the coconut mats.

Figure 26: Placing the coconut fiber mats in the gutters.

d. Filling the rain gutters with the soil

The rain gutters were filled with at least 20 l of soil and topped off after a couple of days.

Figure 27: Rain gutters filled with soil.

Step 5: Planting

a. Laying out the seedlings

The seedlings still in their pots were laid out to visualize their final position.

These general recommendations were followed:

- Taller plants were placed at the top.
- Climbing plants were placed close to the wood beams.
- Plants that may take over others (for example, mint) were given their own gutter (when possible).

Because of the sloped frame, exposure wasn't an issue: Each level can get sunlight and is not covered by the other layers.

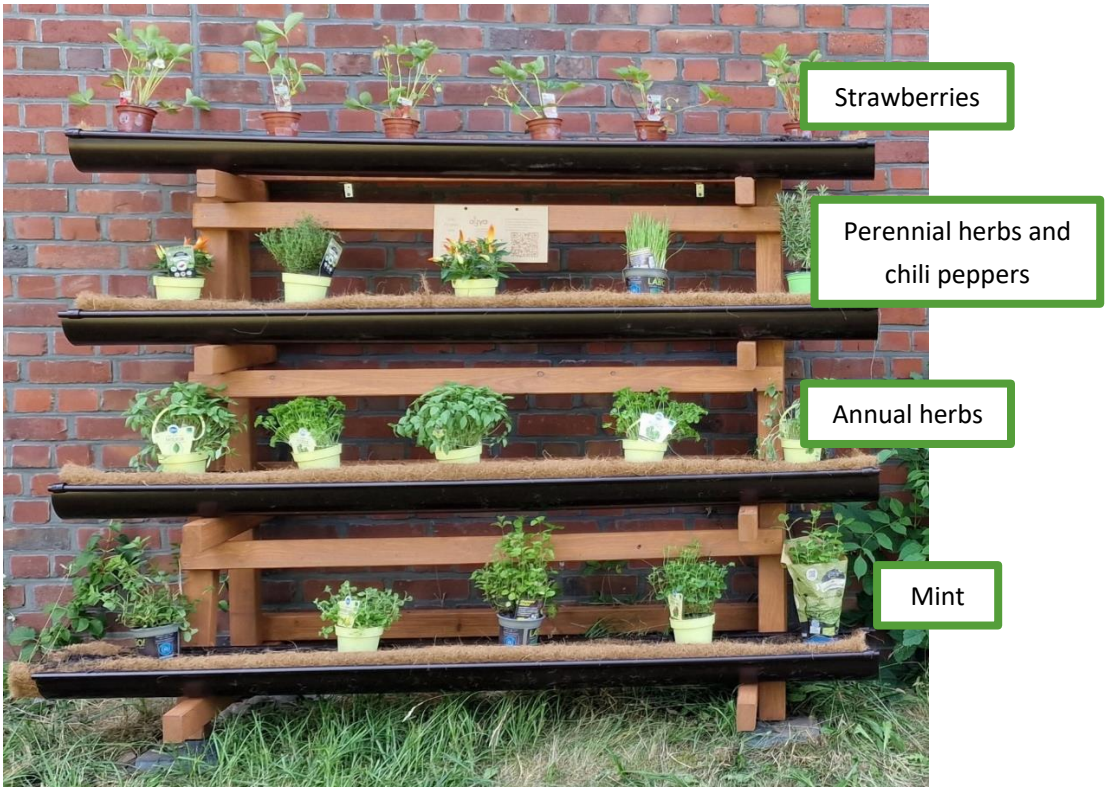


Figure 28: Layout of the plants (first unit).

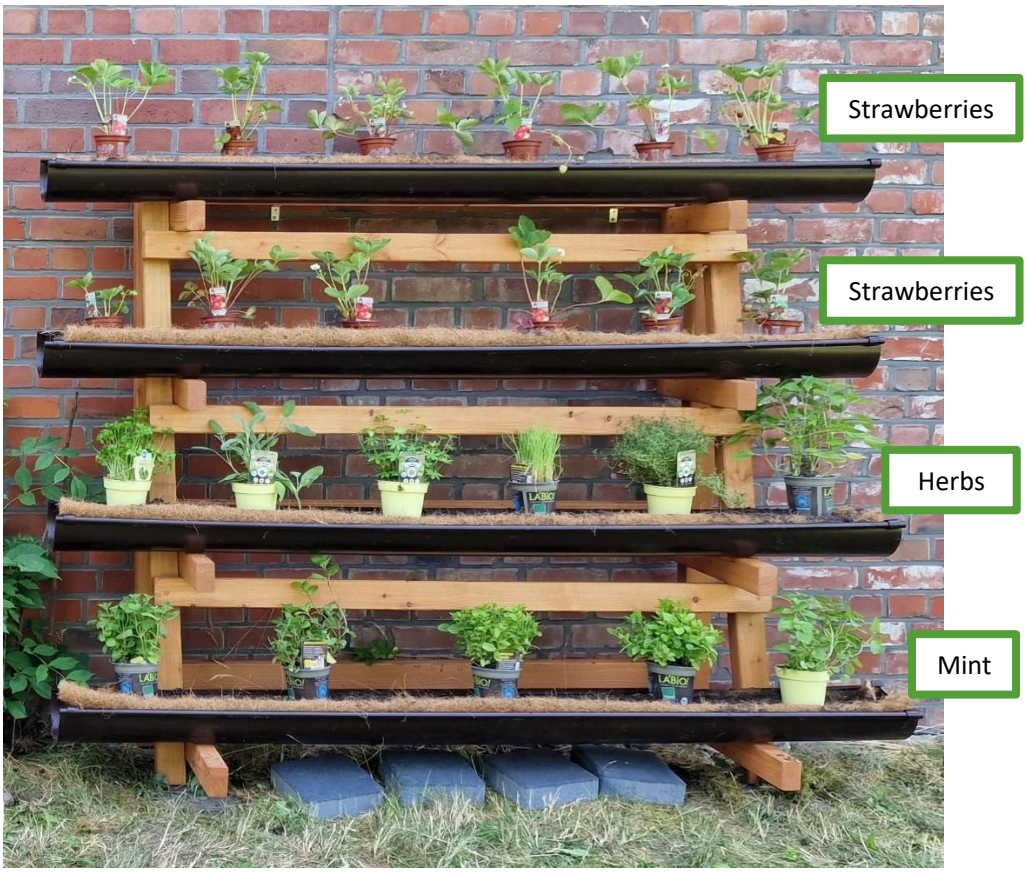


Figure 29: Layout of the plants (second unit).

b. Installing the water dropping irrigation system

The irrigation system was installed according to the instructions. The droppers and soil spikes were placed closed to where the seedlings were later transplanted.

Figure 30: The irrigation system
(Source: https://www.amazon.de/gp/product/B08Z7VJPNF/ref=ox_sc_act_title_1?smid=A3CYEBNQ2OKI7M&psc=1)

Figure 31: From left to right: Droppers and soil spikes
(Source: https://www.amazon.de/gp/product/B08Z7VJPNF/ref=ox_sc_act_title_1?smid=A3CYEBNQ2OKI7M&psc=1).

Figure 32: Placement of the droppers.

The small solar panel that charges the pump was mounted in a sun-exposed area, and the water tank (300 l) was placed between the pump and the prototype.

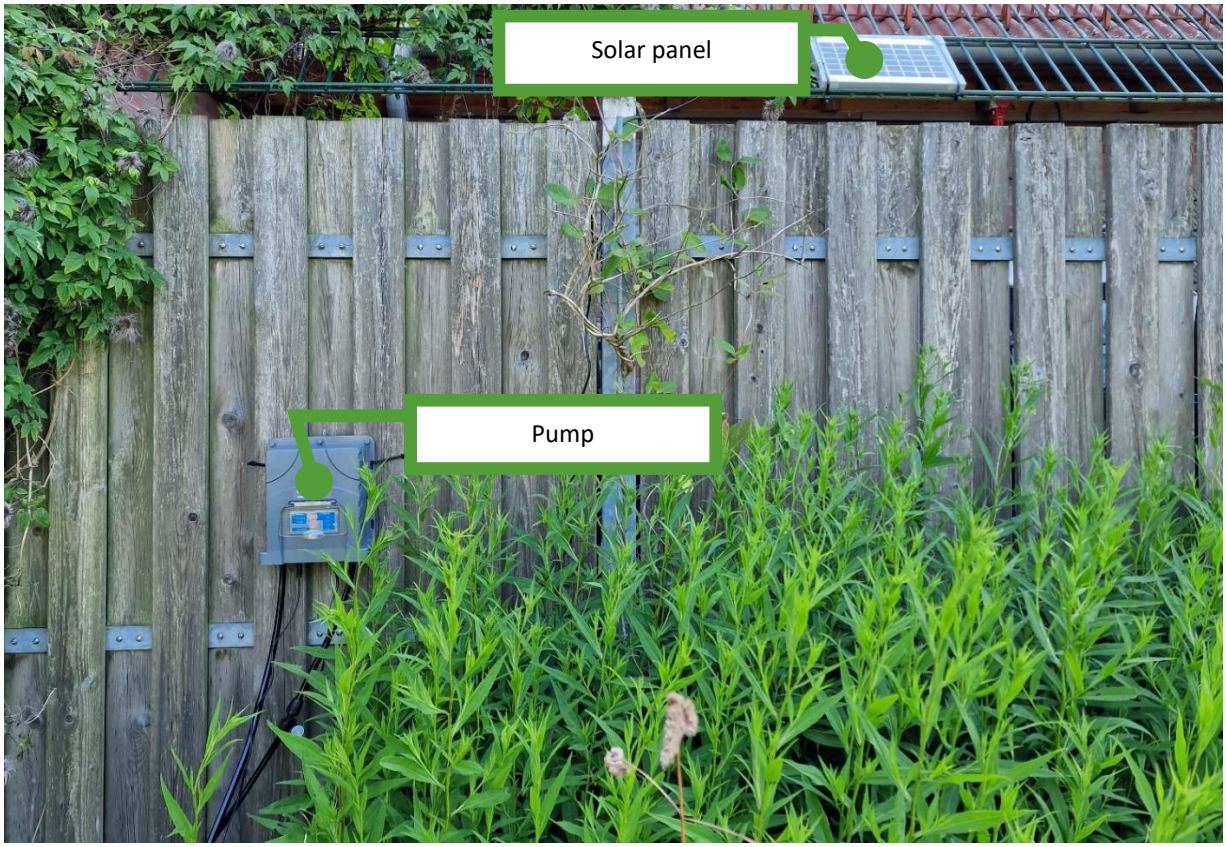


Figure 33: Setup of main components of the watering system.

The seedlings were then transplanted into the soil. However, some of the gutters were left free for the workshop's participants to enjoy in a hands-on transplant.

Figure 34: Transplanting the seedlings.

Figure 35: Setup of the outdoor prototype before the workshop.

Indoor version

The indoor version concept is a high-tech, digitally manufactured DIY project. More technical materials, such as acrylic and aluminum profiles, were used.

Materials and costs[3]

Note: Costs may vary according to region, shop, and period; the links may be used as a reference to find the same or a similar item in your country. The prices do not include the costs for plants, seeds, seedlings, and water.

Table 2: Bill of Materials (BOM) for the indoor prototype.

Item	Description	Quantity	Size	Link	Price per Unit	Price	Note
Pump	Landrip DIY Garden Irrigation Kit, Automatic Greenhouse Sprinkler	2	-	Link	53,99 €	107,98 €	
Growing Lights	T5 LED Plant Lamp Full Spectrum Plant Light with Auto Cycle Timer, two strips	2	-	Link	18,99 €	37,98 €	
Acryl	Acrylic plate	18	600 x 600 x 6 mm	Link	26,89 €	484,02 €	
Aluminum T-slotted profiles	Aluminium Profile 20x20 I-Typ slot 5	12	20 x 20 x 1000 mm	Link	6,12 €	73,44 €	
T-nut slot 5 M4	T-nut with spring ball, with guidance I-Type slot 5 [M4]	400	-	Link	21,30 €	85,20 €	
Brackets 20	Bracket 20x20 I-type Slot 5, 10 x bag	9	-	Link	2,84 €	25,56 €	
Screw	DIN 7380, 100 x bag	2	M4 8	Link	10,53 €	21,06 €	
Screw	DIN 7380, 100 x bag	3	M4 10	Link	10,53 €	31,59 €	
Plant Box	Indoor Greenhouse Propagation Box 2 Pieces 38 x 24 x 18 cm	2	38 x 24 x 10 cm	Link	23,90 €	47,80 €	

[3] Materials were purchased, among others, in these shops: https://www.alusic.com/fr/produits-et-catalogues?fbclid=IwAR07inxzEiMEjsVFviVWz-BxiaFimruARabmniu3XSprF-wemfn0-XsdTqE; https://online.flippingbook.com/view/667286/?fbclid=IwAR0FVJEXA5pZuTG7_uvOouZ5Wi-0xa8NLj1Ir0AdJZo7UAy5mFJ4LrJOwi0; and http://www.sigma-alu.com/fr

Table 2 (continued): Bill of Materials (BOM) for the indoor prototype.

Item	Description	Quantity	Size	Link	Price per Unit	Price	Note
Water Canister	JOYBOY 4 PIECE water canister, 10l foldable	1	20,5 x 22 x 21 cm	Link	18,99 €	18,99 €	Any water container that can fit in the cube is ok.
Coconut Fibers	Peat-free growing medium	3	-	Link	3,39 €	10,17 €	
Total							**943,79 €**

Building manual

This section explains the steps followed to design and build the Indoor Version.

Step 1: CAD design

The CAD was essential for the indoor prototype, and great attention was given to debugging and mistakes-proofing.

- Proof of concept: With a technical CAD design, it is possible to see (to a certain extent) if the design is feasible and stable. Some CAD software has integrated features to evaluate the mechanical properties of the project. Therefore, by having a 3D model, it is easier to evaluate the functionality of the idea.
- Clearer understanding of the materials to be purchased: With the CAD design, the dimensions are known. Therefore, less waste in the production is made.
- Reduce the error rate while producing and assembling: With a 3D model as a reference, it is easier to follow the idea. Furthermore, by designing the project, the steps in assembling may be clearer.
- Replicability: CAD file allows people to share their projects and replicate others'[4].

[4] This is particularly important when digital techniques (such as 3D printing, laser cutting and CNC milling) are used to produce the parts.

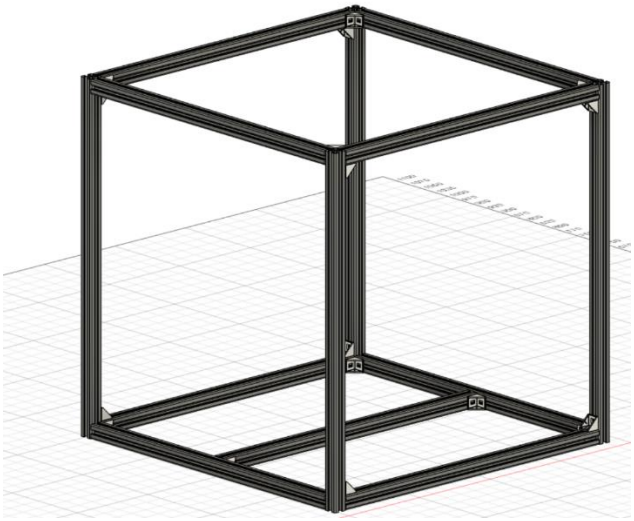


Figure 36: Aluminum profile frame, CAD drawing.

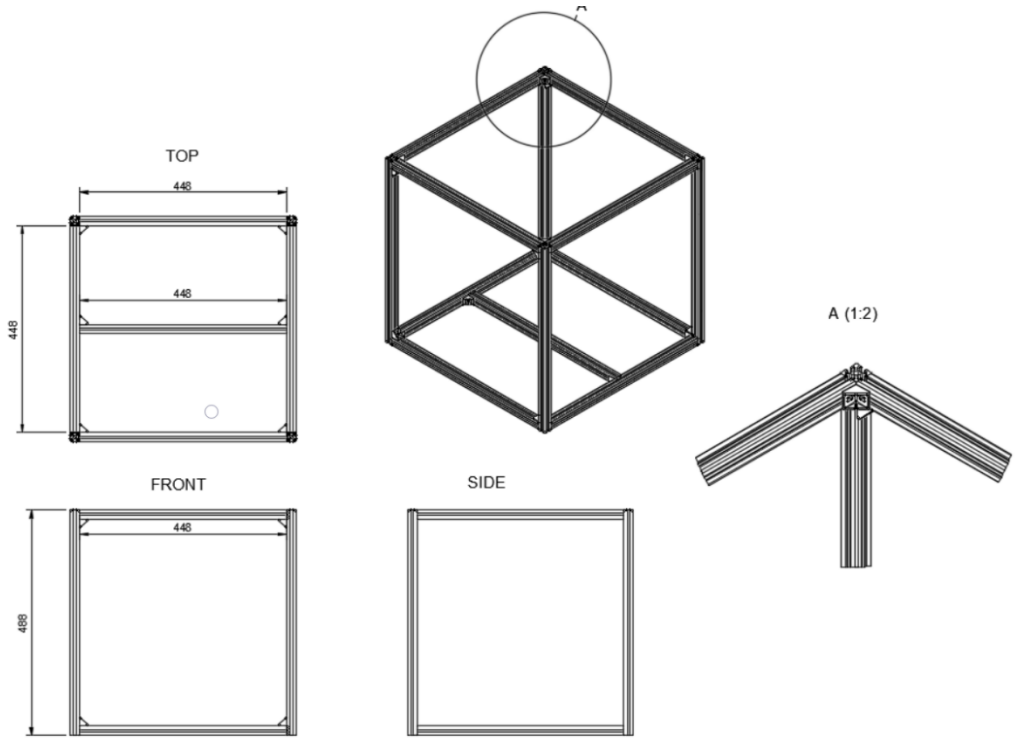


Figure 37: Aluminum profile frame, technical drawing.

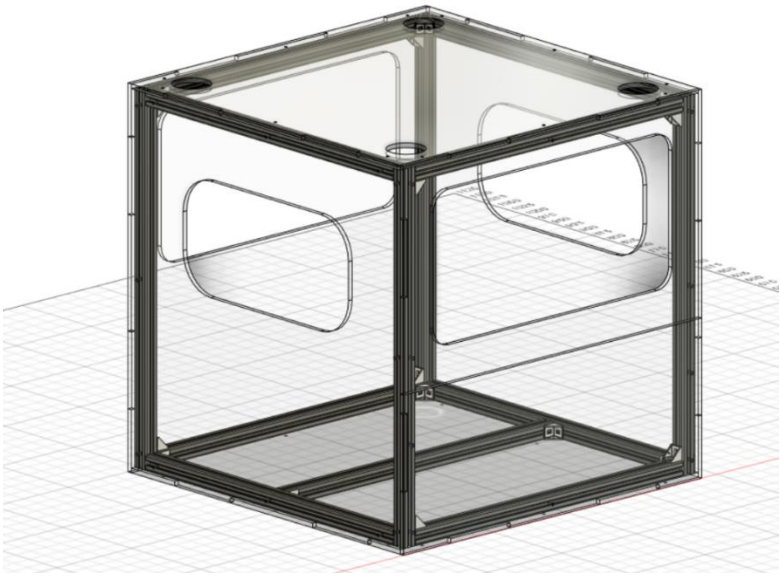


Figure 38: Frame with panels, CAD drawing.

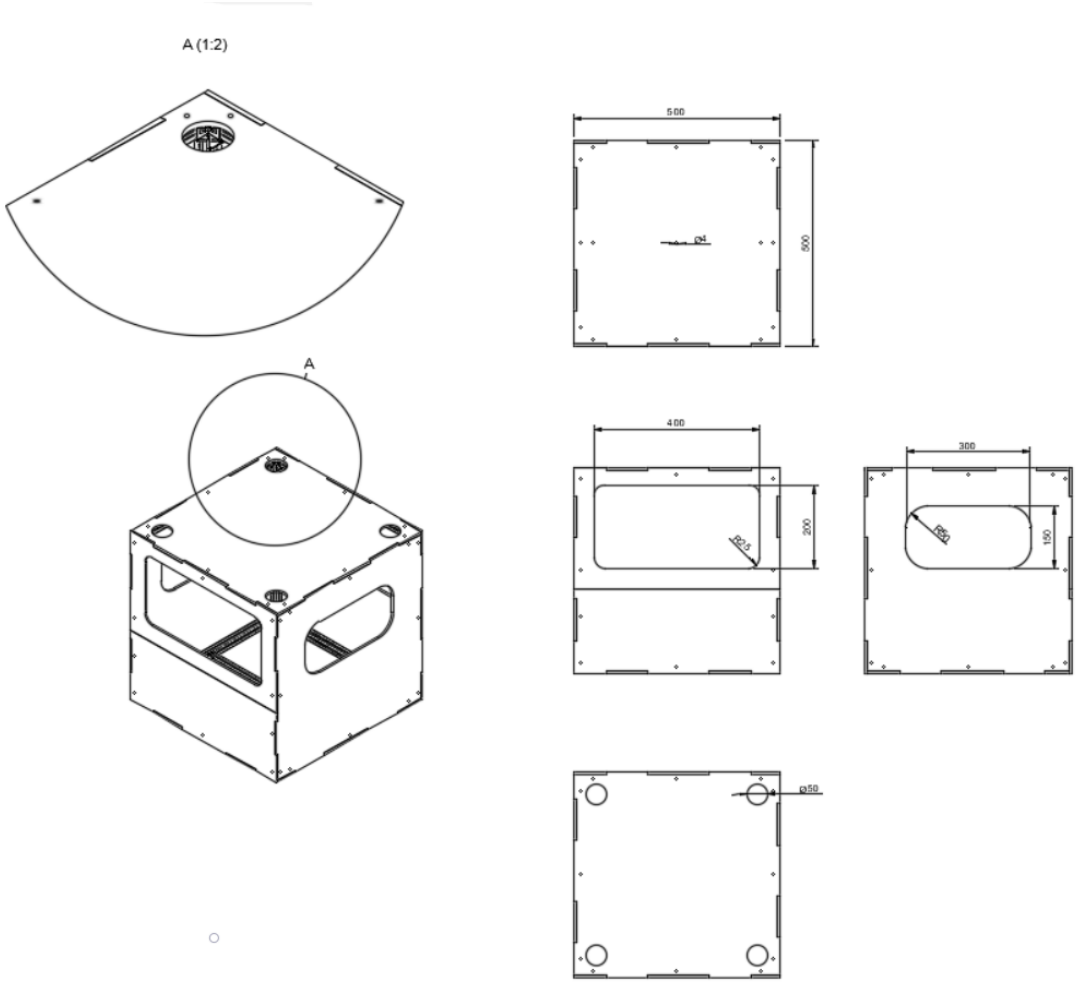


Figure 39: Frame with panels, technical drawing.

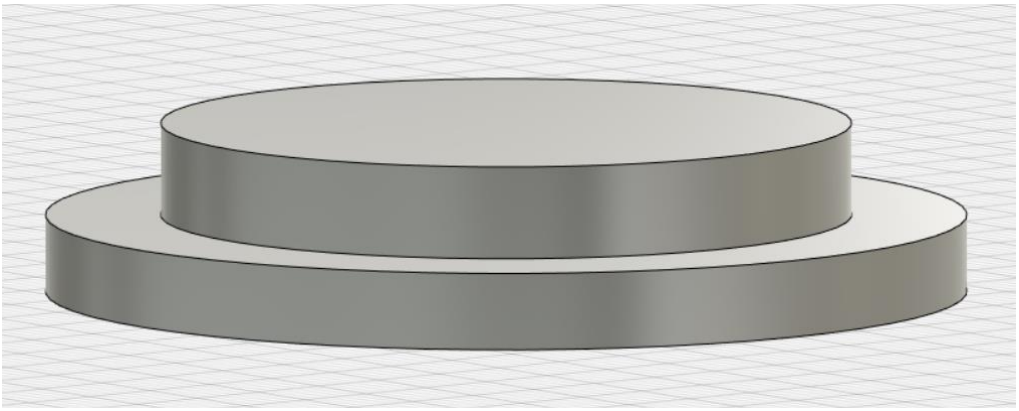


Figure 40: Foot, CAD drawing.

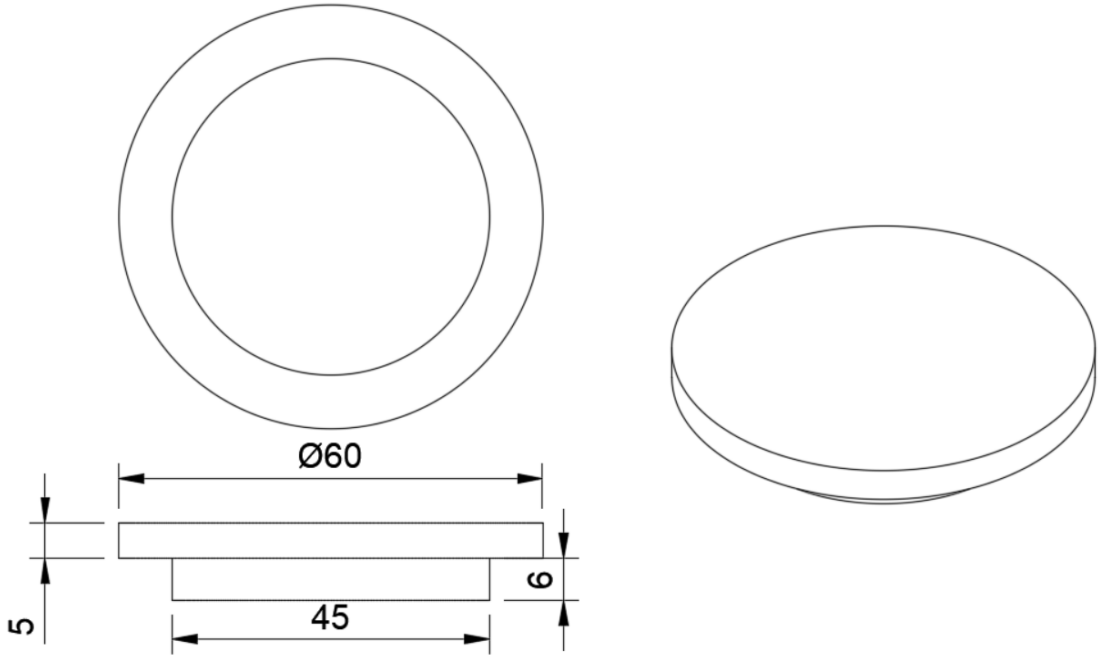


Figure 41: Foot technical drawing.

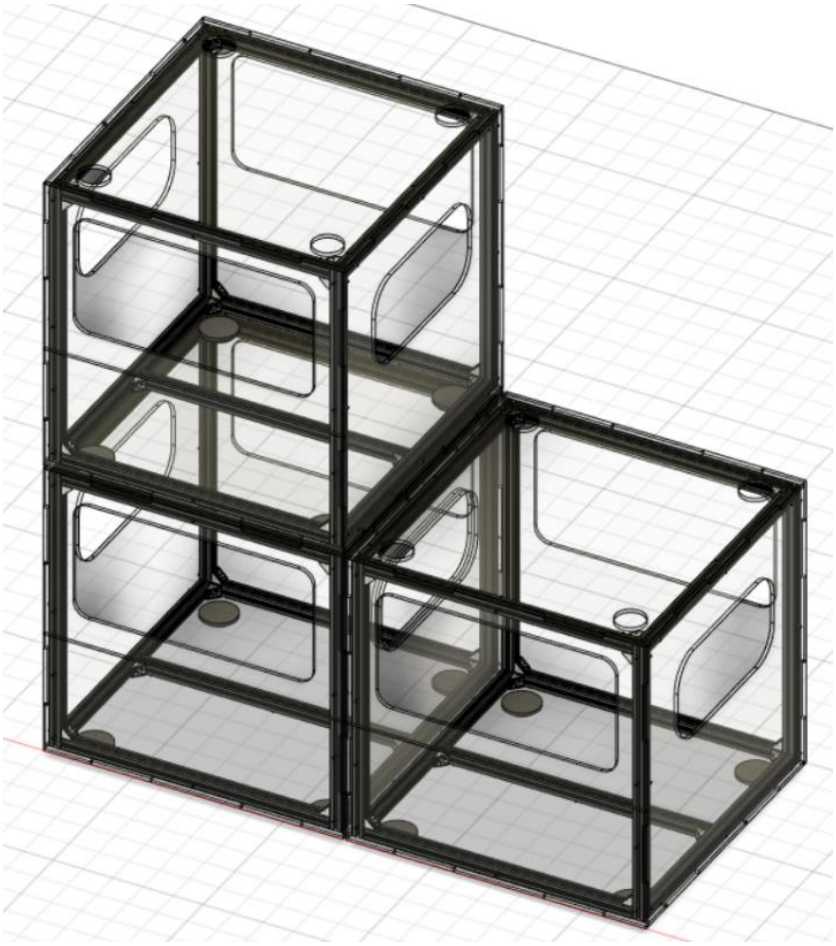


Figure 42: Three cubes, CAD drawing.

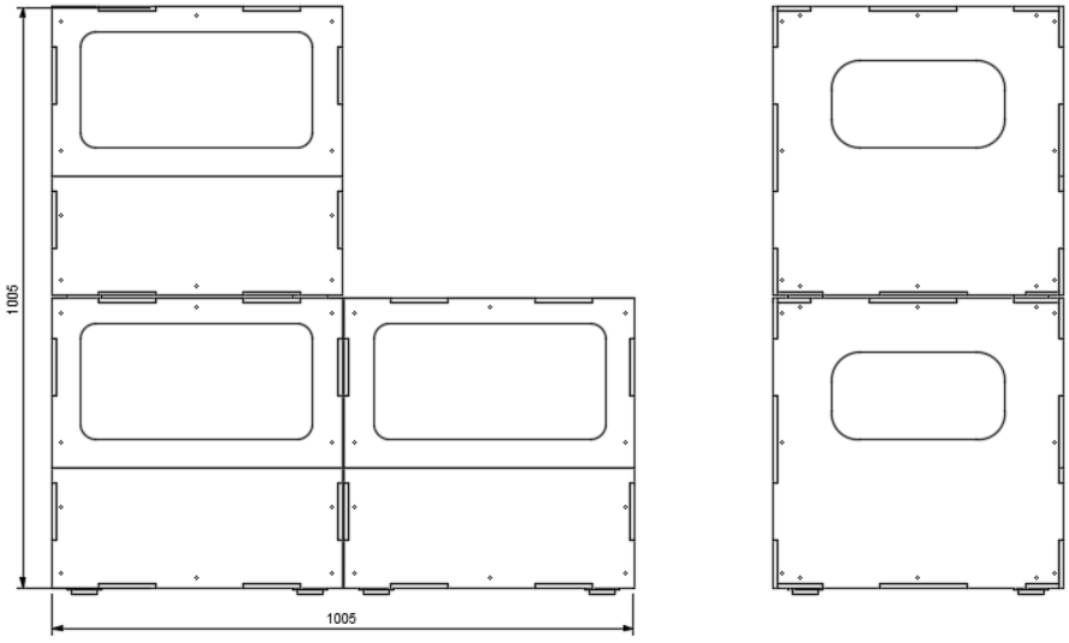


Figure 43: Three cubes, technical drawing.

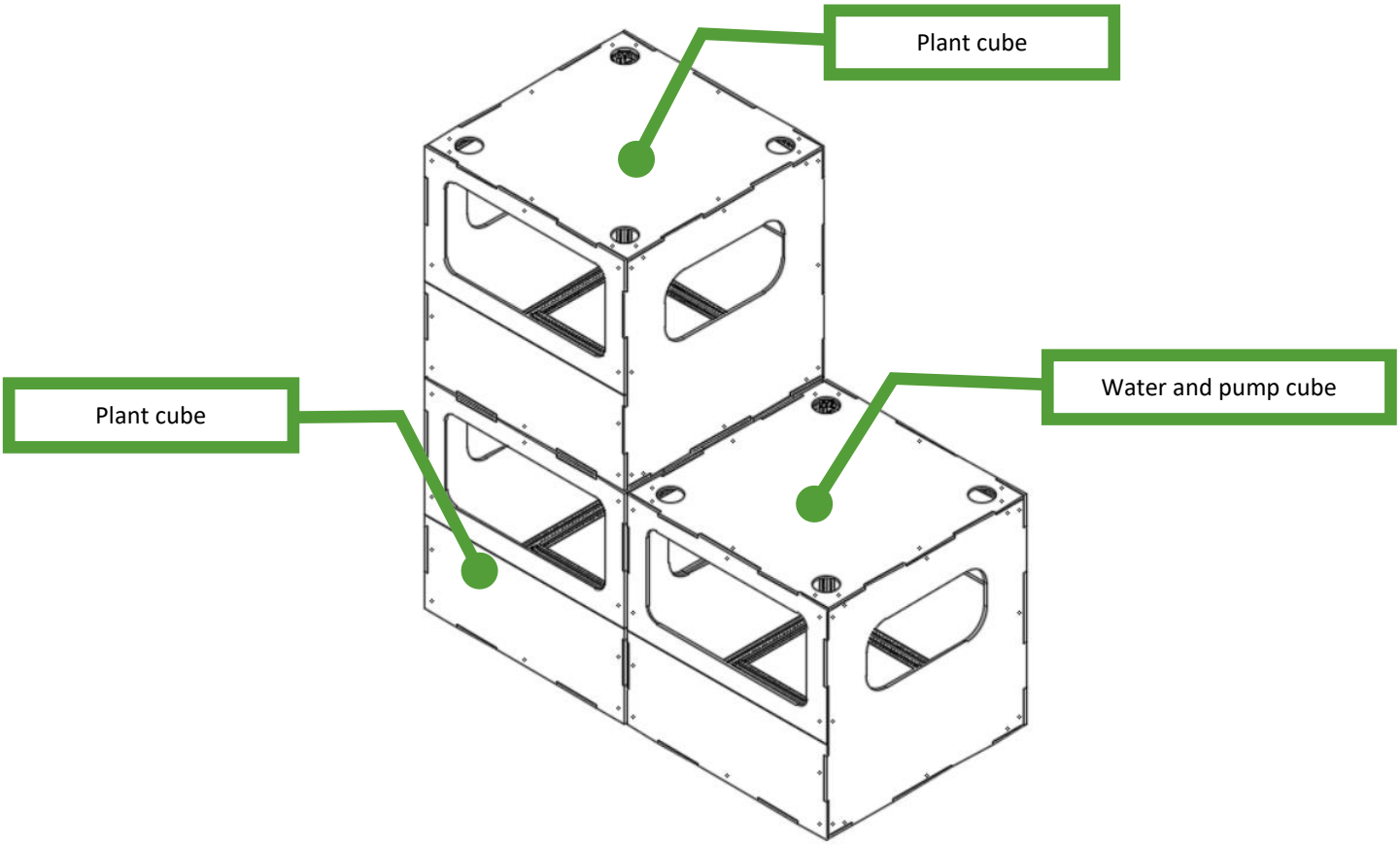


Figure 44: Functions of the three cubes, technical drawing.

Step 2: Purchasing the materials

Materials were purchased from different sellers, considering the price, quality, and shipping times. For a detailed view, refer to the Bill of Materials (BOM).

Step 3: Building

The building involved different techniques:

- Laser cutting
- 3D printing
- Analog fabrication (as opposed to digital fabrication)

a. Preparing the aluminum profiles

The t-slotted aluminum profiles were purchased with a length of 2 m. Therefore, cutting them to the right lengths with a bend saw was necessary.

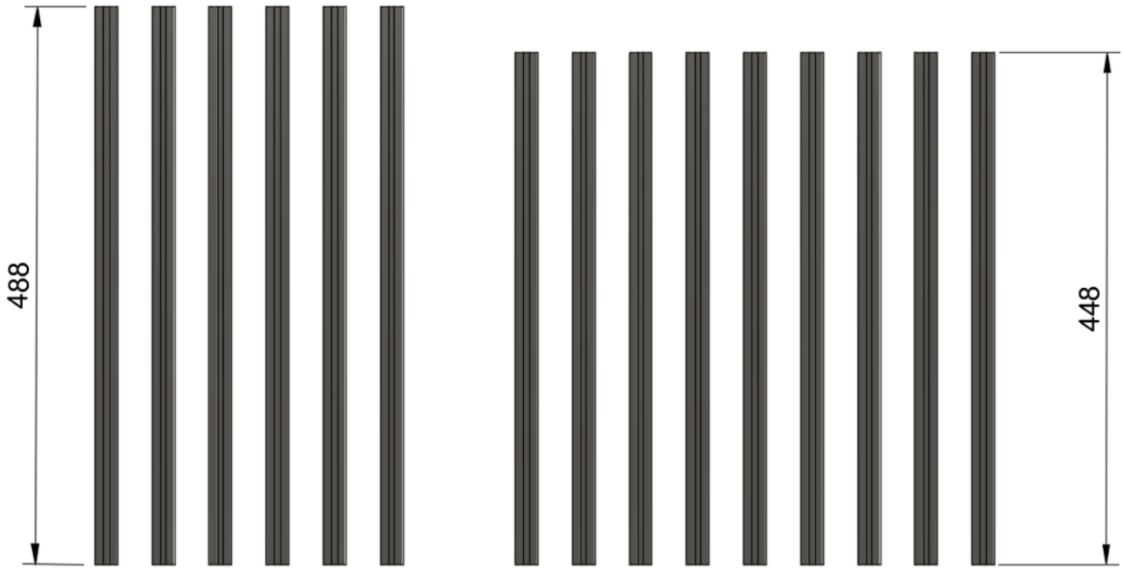


Figure 45: Guideline for sawing the T-slotted aluminum profiles.

Figure 46: Sawing the T-slotted aluminum profiles.

b. *Laser cutting the panels*

For the panels, acrylic sheets of 600 x 600 mm, and 6 mm thickness were used.

DXF files were prepared from the CAD design[5].

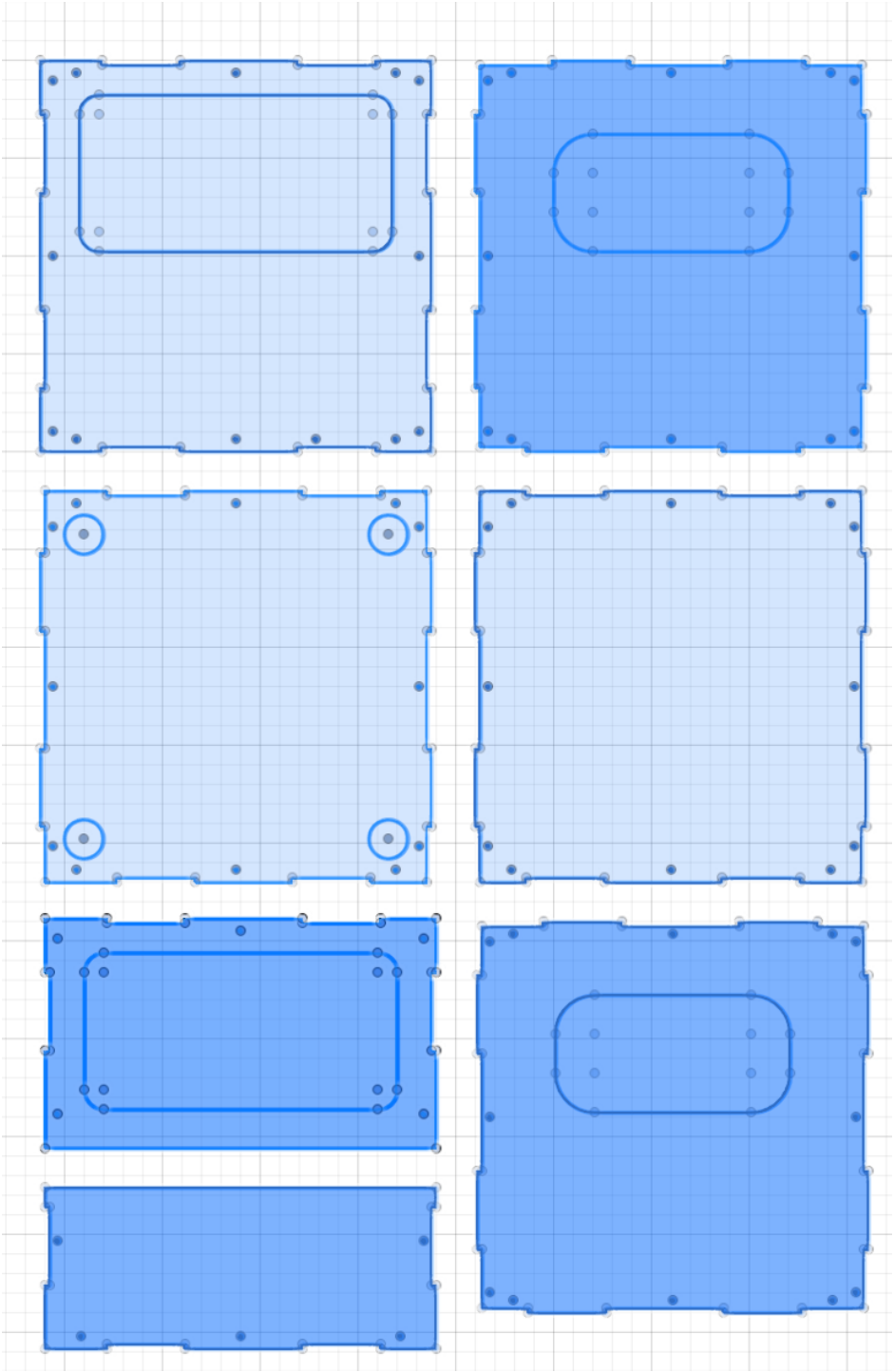


Figure 47: Sketches used to save the DXF files.

[5] The process varies depending on the CAD software. Please, use the DXF files provided or follow tutorials online in the case of scaling.

Visicut[6] was used to produce the g-code.

Figure 48: Visicut interface.

Laser Duo was used to laser cut the panels. For Laser Duo, the settings used were[7]:

- Power: 80
- Speed: 2,5

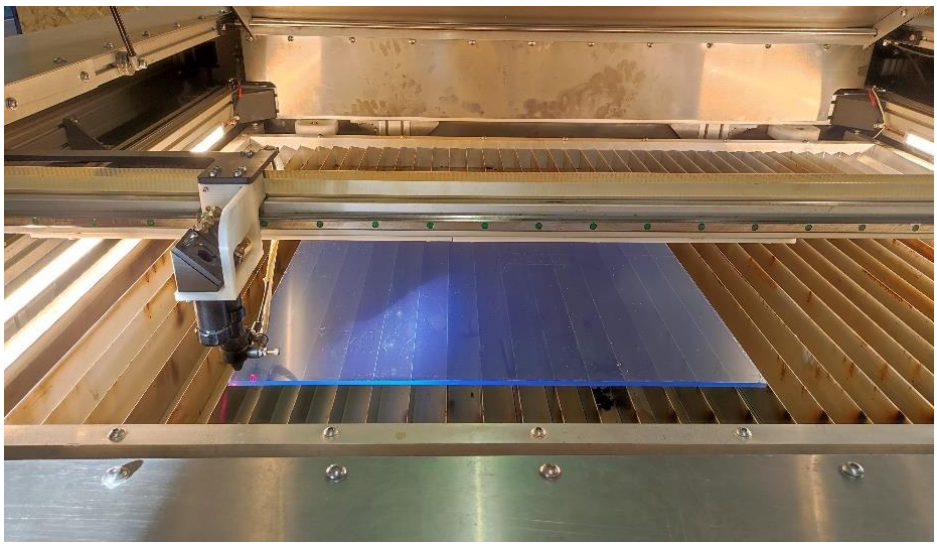


Figure 49: Preparing the laser cutter.

[6] Visicut is an open source g-code generator for laser cutters. It is free to download here: https://visicut.org/.
[7] Please, note that the settings vary depending on the laser cutter. It is suggested to run some tests with the material before cutting the design.

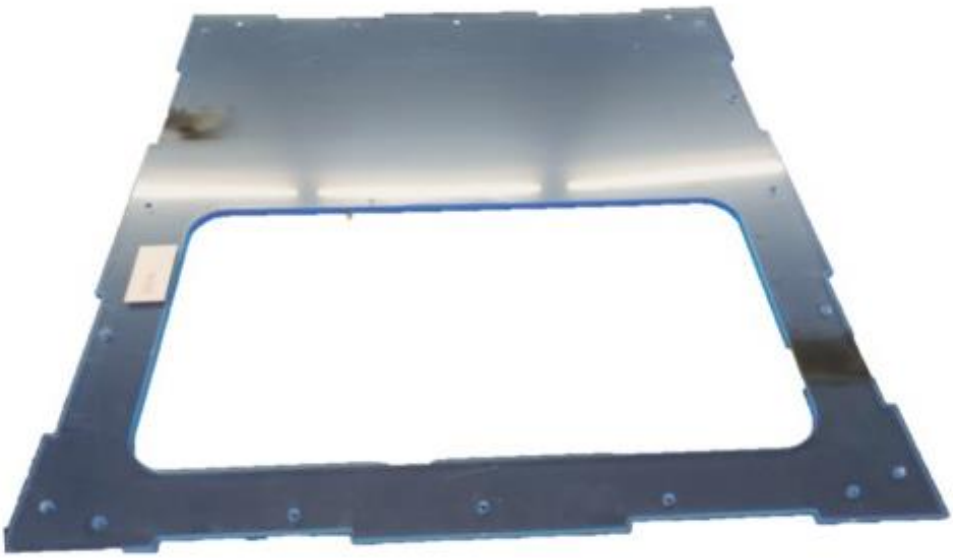


Figure 50: A laser cut panel.

c. Mounting the frame

The cubebs were prepared by fastening the t-slotted aluminum profiles. For one cube, the following materials were used:

- 4 x aluminum profiles 488 mm
- 9 x aluminum profiles 448 mm
- 36 x T-nut slot 5 M4
- 36 x screws DIN 7380 M4 8

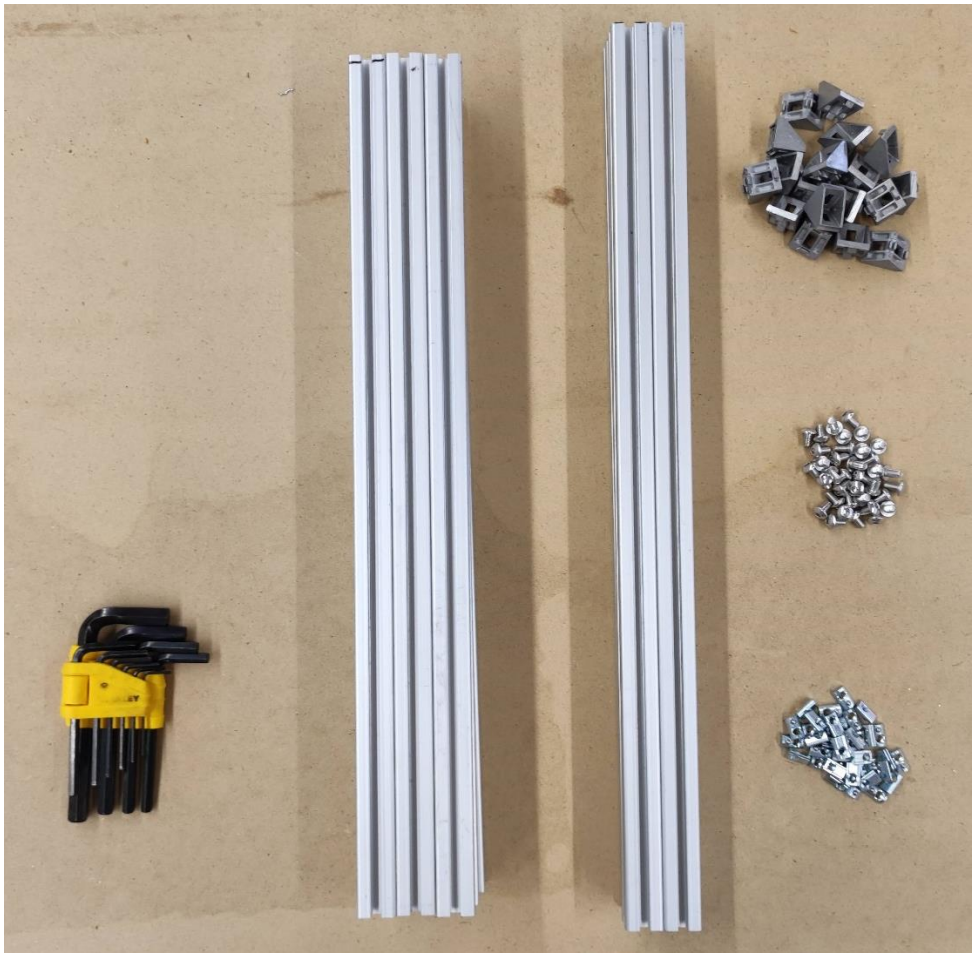


Figure 51: Parts used for the frame of one cube.

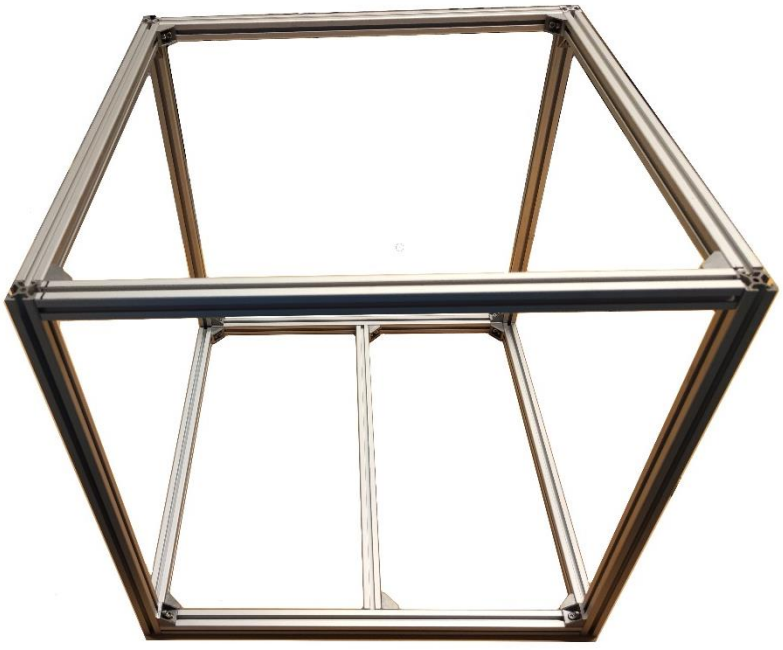


Figure 52: Assembled frame.

d. Mounting the panels

The panels were mounted using (for one cube):

- 41 x T-nut slot 5 M4
- 41 x screws DIN 7380 M4 10

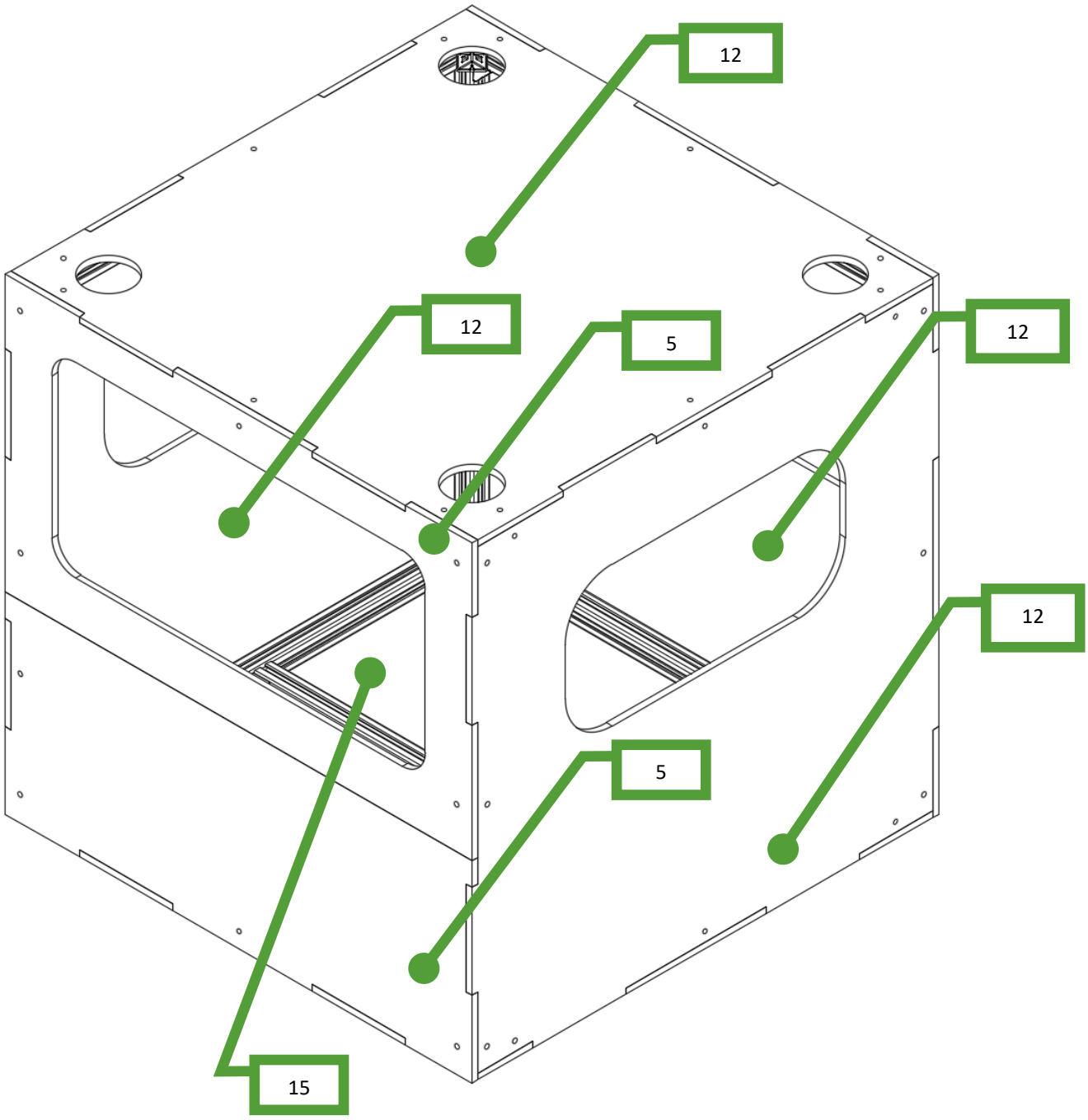


Figure 53: Number of screws for each panel.

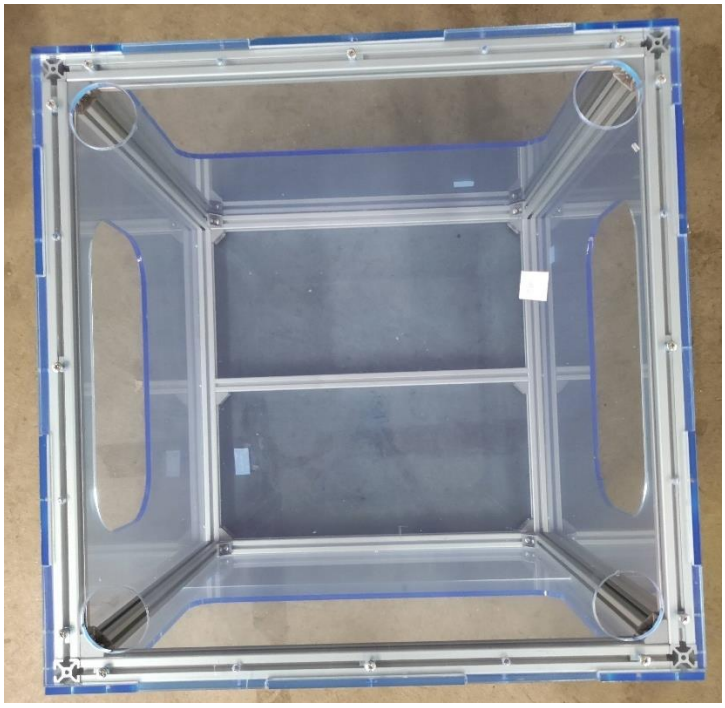


Figure 54: Fastened panels.

e. Printing and gluing the feet

After being 3D printed, the feet were glued to the bottom of the cubes using extra strong glue.

Figure 55: 3D printing the feet.

Figure 56: Feet attached to the base of the cube.

f. Placing the growing lights

Growth lights were attached to the top panel using the tape provided with the lights. One cube contains two strips.

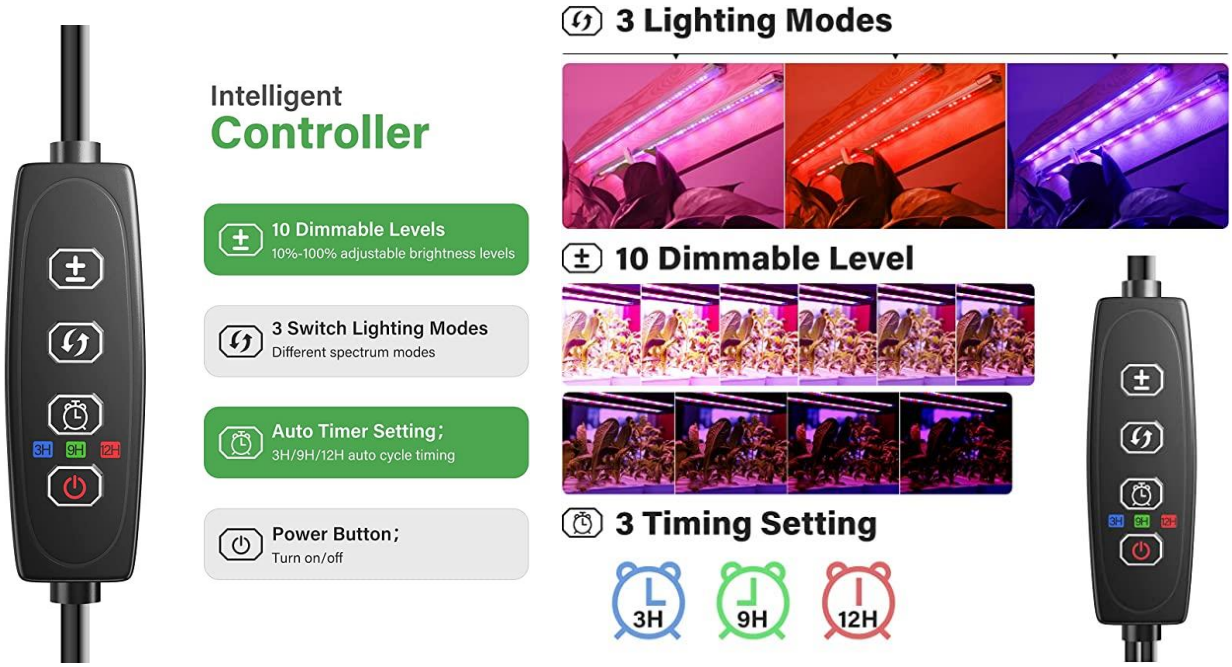
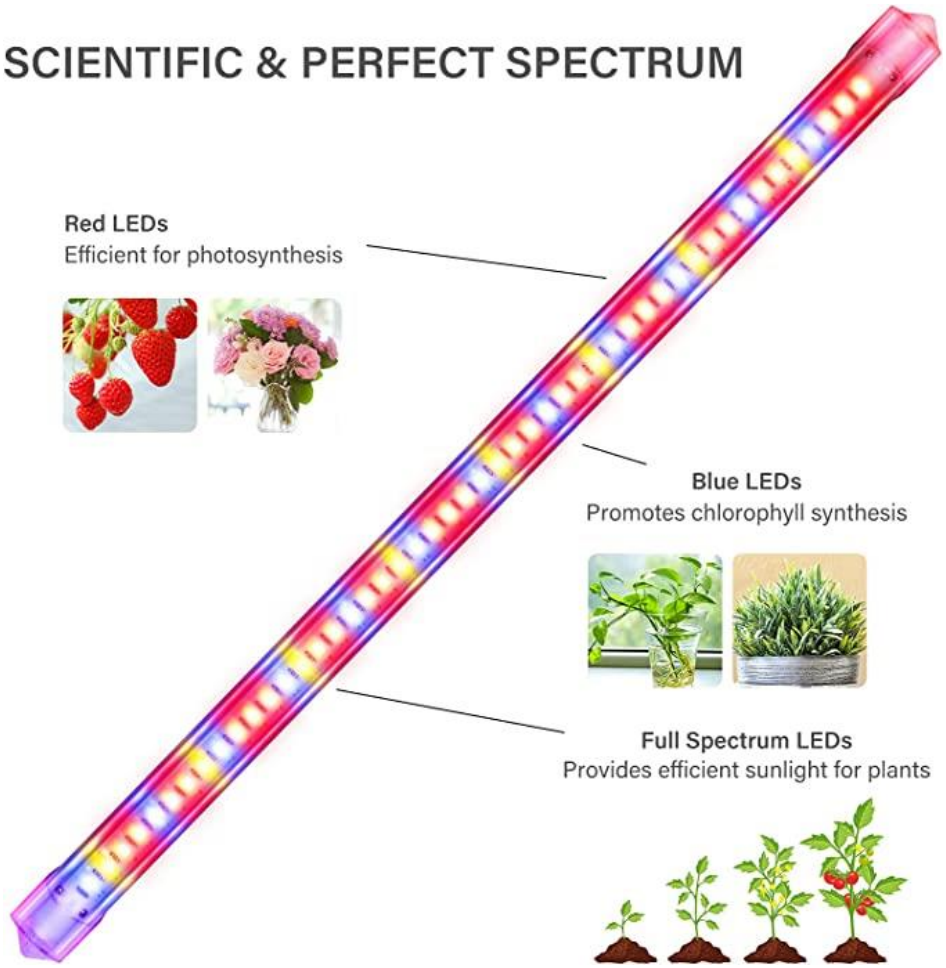


Figure 57: Explanation of the options for the LED growth lights for the indoor prototype (Source: https://www.amazon.de/-/en/Spectrum-Dimmable-Levels-Hydroponics-Succulent/dp/B0957X5RW1/ref=sr_1_5?keywords=wachstumsleuchte%2Bled%2Bstreifen&qid=1654179579&sprefix=growing%2Blight%2Bled%2B%2Caps%2C92&sr=8-5&th=1).



Box contents:

1 x LED two-head growth light strip, 1 x charging head, 1 x instructions, 1 x 3 metre double-sided tap and cable ties

Timer setting function

3 timing modes: 3/9/12H. This timing function is a 24-hour cycle timing. If you want the plant lighting to be switched on for 3 hours daily from 7 to 10 o'clock. You only need to turn it on at 7 am in the morning and set it for 3 hours. With continuous power supply, the cycle works and is invalid after switching off.

High quality LED chips

Each strip with 48 highly efficient LED chips has a lifespan of 5000 hours. You can use the plant lights many times for your plants. It is easy and safe to use.

Multi-Purpose Plant Grow Light Lamp

Accelerate the ripening of fruits, promote plant growth and colouring of succulents, improve flower quality and extend flowering time. Suitable for different plant lighting requirements.

Figure 58: Description of the LED growth lights for the indoor prototype (Source: https://www.amazon.de/-/en/Spectrum-Dimmable-Levels-Hydroponics-Succulent/dp/B0957X5RW1/ref=sr_1_5?keywords=wachstumsleuchte%2Bled%2Bstreifen&qid=1654179579&sprefix=growing%2Blight%2Bled%2B%2Caps%2C92&sr=8-5&th=1).

- Full spectrum LED plant lamp: 2-strip LED plant light (each 16.1 inches) contains 96 LED chips with excellent heat dissipation, which provide perfect full spectrum light for indoor plants. As for LED power consumption, this plant grows with less watts. It is a perfect investment if you grow small plants.
- 3 spectrum modes and 10 brightness levels: the grow lamp with 3 spectrum modes. Different spectral modes are suitable for the light needs of different plants. 10 adjustable brightness levels to meet the lighting requirements of each plant in different growth stages.
- Auto cycle timing: the LED growth light timing function has 3H/9H/12H. And it is 24H cycle timing. It can be turned on and off automatically every day according to your settings. When the display is turned off, the timing function is off. It is very useful and practical when you are busy or travelling.
- Easy installation: the grow light bar comes with 3 metres of double-sided adhesive tape and cable ties that are suitable for different devices and surfaces and stick perfectly to the shelves. You can easily adjust it to your interior.
- Wide application: perfect for indoor plant shelves or cabinets, widely used for germination, seedlings, seed start, potted plants, succulents, catcus. Especially if the plant needs extra light in rain, cloudy or dark indoor conditions.

Widely used full spectrum LED grow lamps for indoor plants

Red light x 56 chips: Contribute to photosynthesis, germination, flowering and results.

Blue light x 24 chips: Help plants with chlorophyll synthesis absorb more energy for better germination.

Yellow light x 16 chips: Provide sun-like light for plants, let plants grow like in nature.

These plant lights are ideal for your plant tents, plant shelves, seedling cultivation, succulents, hydroponic rooms, greenhouses, etc.

Wide range of uses:

For hydroponics and seedlings, for plant rack and gardening, for succulents, indoor plants, for greenhouses

The length of the grow light strip is 16.1 inches. Large cover for your plants that need enough light to grow. Simply place your plants in the middle of the two light strips to get even light from both sides.

Note:

- Recommended height for plants: 0.5-1 metre (19-39 inches) and 12-16 hours a day can completely replace the sun.

Figure 59: Instructions for the growing light (Source: https://www.amazon.de/-/en/Spectrum-Dimmable-Levels-Hydroponics-Succulent/dp/B0957X5RW1/ref=sr_1_5?keywords=wachstumsleuchte%2Bled%2Bstreifen&qid=1654179579&sprefix=growing%2Blight%2Bled%2B%2Caps%2C92&sr=8-5&th=1).

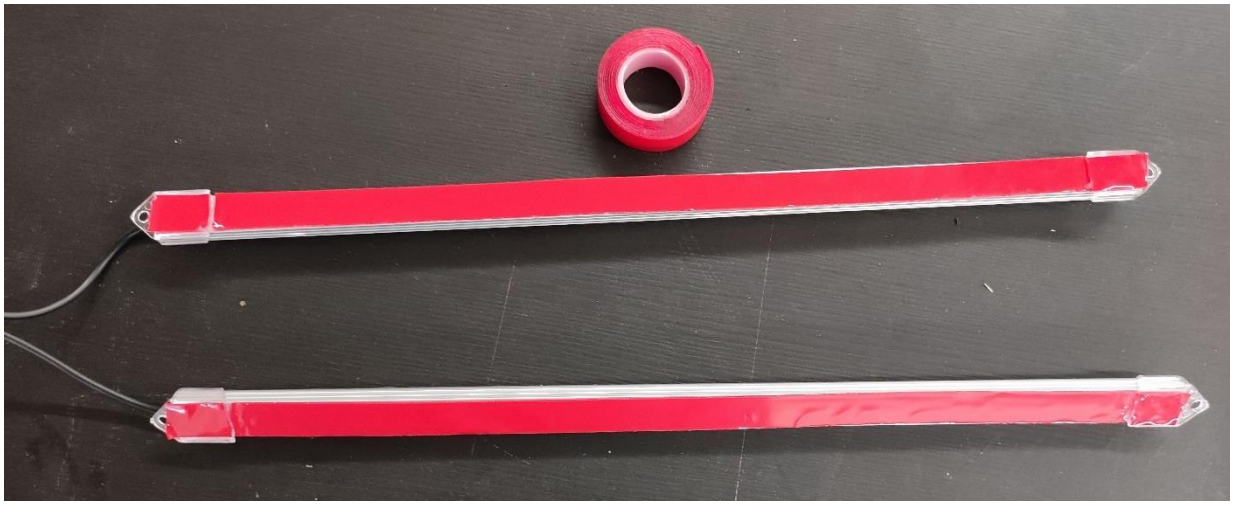


Figure 60: Preparation of the LED growth lights.

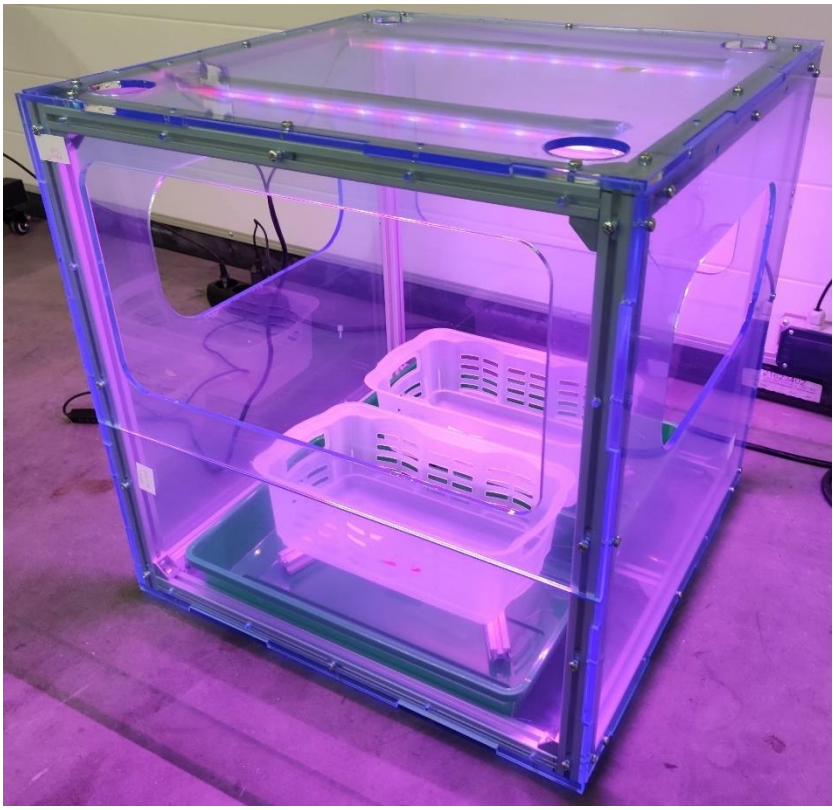


Figure 61: Testing the growing lights.

g. Watering system

A 5 L container was used to store the water. To the water was added liquid fertilizer.

A programmable pump was used to ensure watering.

Figure 62: Pump description
(Source: https://www.amazon.de/Irrigation-Automatic-Greenhouse-Sprinkler-Watering/dp/B07C6979DK/ref=sr_1_1_sspa?keywords=bew%C3%A4sserungssystem%2Bpumpe&qid=1654179501&sprefix=watering%2Bsys%2Caps%2C103&sr=8-1-spons&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUFKOTk3UkdCNk1GR0smZW5jcnlwdGVkSWQ9QTA4MTA3NzJTVTFKMlZRSDJDVTMmZW5jcnlwdGVkQWRJZD1BMDI4OTg1OTNOMzZLUlVGVThNNlImd2lkZ2V0TmFtZT1zcF9hdGYmYWN0aW9uPWNsaWNrUmVkaXJlY3QmZG9Ob3RMb2dDbGljaz10cnVl&th=1).

Step 4: Planting

The pots were filled with coconut fibers, and each was placed into a saucer (to collect drainage water). The reason for this setup is the decision to use the "nutrient film technique"[8].

Figure 63: Schematics of the used technique
(Source: https://naturezedge.com/how-to-start-a-hydroponic-vegetable-garden).

The seedlings were planted in the coconut fibers. The pipes were brought to the pots.

Figure 64: Transplanted lettuce.

[8] More information: https://naturezedge.com/how-to-start-a-hydroponic-vegetable-garden

Figure 65: Setup of the indoor prototype for the workshop.

Figure 66: Indoor setup with active lights.

THE WORKSHOP

On the 4th, 5th, and 6th of July took place the Vertical Farming Workshop, organized by AGYA in Gut Karlshöhe.

Two vertical farming prototypes (indoor and outdoor) were presented during the workshop. The participants were actively engaged and had the opportunity to transplant seedlings for both the outdoor and indoor versions in a "hands-on" session. Furthermore, the participants were encouraged to think about the potential and benefits of vertical farming as well as the possible challenges that must be faced when realizing such projects. The participants also had the opportunity to learn more about 3D printing and exchange on the possibilities of implementing such an advancing technology for their projects.

USEFUL LINKS

https://www.fabcity.hamburg/agriculture/

https://www.gut-karlshoehe.de/

https://agya.info/

https://visicut.org/

https://naturezedge.com/how-to-start-a-hydroponic-vegetable-garden

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