Restore4Life

RESTORING WETLANDS FOR A SUSTAINABLE FUTURE

TREATMENT WETLANDS

TEACHING PROTOCOL

GRADE LEVEL: Secondary school, Educators

LESSON STRUCTURE:
1 School lesson (45 min) for the introduction ("Engage")
2 Lessons (90 min) for the implementation of the wetland model – ideally outdoors ("Explore")
1 Lesson (30-45 min) for linking problems & solutions ("Explain")
1 Lessons (30-45 min) for observing the system in action ("Elaborate")
1 Lesson (45 min) for reflection ("Evaluate")

INTRODUCTION:

Treatment wetlands are an environmentally-friendly solution for wastewater treatment, inspired by natural processes. The Workshop introduces students to the principles and functions of treatment wetlands in general and vertical flow wetlands in particular, emphasizing their importance in sustainable water management.

LEARNING OBJECTIVES:

1. Understand that treatment wetlands are a nature-inspired technology that treats wastewater using natural principles;
2. Identify natural purifying principles (filtration, bacterial degradation, and plant uptake);
3. Understand the structure and function of treatment wetlands in general and vertical flow wetlands in particular;
4. Build and maintain a vertical flow wetland model while gaining insight into the work of scientists and engineers.
5. Critically analyze the ecological impacts and sustainability of treatment wetlands in different environments.
6. Understand the importance of water quality for different purposes (drinking, irrigation, industry, environment, etc.)

KEYWORDS: treatment wetlands, wastewater treatment, eco-friendly solutions, sustainability; vertical flow wetlands, natural principles, filtration, bacterial degradation, plant uptake, ecological impact

TEACHING FRAMEWORK BASED ON THE 5E INSTRUCTIONAL MODEL

1. ENGAGE - Sparking curiosity

AIM: To spark curiosity and activate prior knowledge about the various uses of water, the impact of pollution on water sources, and the importance of treating used water before it is safely returned to the environment.

GUIDING QUESTIONS

- Why water treatment is essential for people and ecosystems?
- How can we clean the water by using nature?
- What happens if polluted water is not treated?

TEACHER SUPPORT

1. Hold up two glasses of water: one with clean tap water and one with dirty or muddy water.
   - Ask: “Is this water clean? Would you drink it? Could we release it into a river safely?”
   - Discuss why water treatment is essential for people and ecosystems.
2. Introduce three types of water:
   - Treated water (safe for the environment and reuse).
   - Greywater (usable for non-drinking purposes like watering plants).
   - Polluted water, e.g. household wastewater (unsafe for humans, animals, and plants).
3. Present a real-world scenario. Show a photo or video to elicit engagement and ask students:
   - “How can we clean this water using nature?”
   - “What happens if polluted water isn’t treated?”
4. Students should reflect in their journals on the importance of water treatment.

Connect issues to students’ lives: effects on recreation, impacts on wildlife, community health implications, economic consequences, etc.

Use ***Restore4Life online interactive visualization*** for this topic.

MATERIALS NEEDED: Photos of polluted and clean water; two glasses of water (clean and dirty).

2. EXPLORE – Hands-on learning activity

AIM: The Vertical Treatment Wetland Demonstrator is designed to teach students about natural water purification using engineered wetland processes. It shows how vertical flow wetlands effectively treat wastewater and nutrient-rich runoff through natural physical, chemical, and biological methods. This model highlights sustainable, low-energy and low-maintenance water management systems.

GUIDING QUESTIONS

- What are main pollutants in household wastewater and greywater?
- Which parameters shall be measured to assess water quality?

ACTIVITY: BUILD A VERTICAL FLOW WETLAND MODEL

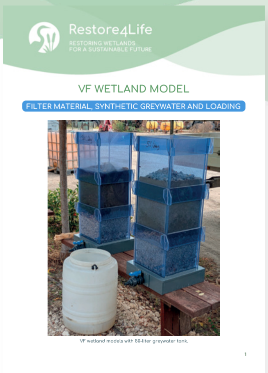
1. Build two filter columns according to the technical description
2. Select a location for the filter columns where the treated greywater can be drained easily
3. Provide materials to students: transparent container, gravel, LECA, plants, plastic faucets, and other supplies;
   - Two filter columns (according to the technical description)
   - Filter material (according to the description of the implementation)
   - Products to mix synthetic greywater (according to the description of the implementation)
   - Additional materials like container for greywater, small buckets, shovels, a scale, marker, etc.
4. Divide students into teams and guide them through building the model:
   - Filling of VF wetland models with gravel/sand (according to the description of the implementation)
   - Mixing of synthetic greywater (according to the description of the implementation)
5. Load filled VF wetland models with clean water to rinse fines out of the filter
6. Load VF wetland models with the anticipated amount of greywater; to load the models realistically, the loading should ideally be done in batches, i.e., in the morning, at lunch time and in the late afternoon)
7. After several consecutive days of loading, analyse samples of the inflow greywater for main pollutants such as COD and ammonia nitrogen.

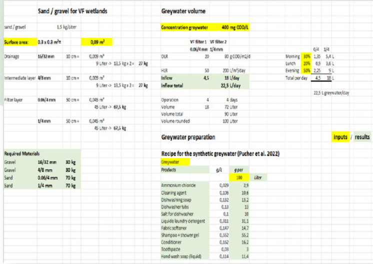
TEACHER SUPPORT General introduction to the Vertical Flow wetland models is given in file Intro-to-VF-pilots_Langergraber.pdf.

1. Technical description of filter column (VF-wetland-model_Technical-documentation.pdf)
2. Description of the implementation: filter material, synthetic greywater and loading of the model (VF-wetland-model_Materials-greywater-loading.pdf)
3. MS Excel® sheet for calculations (VF-wetland-model_Calculations.xlsx)

All descriptions provided are for filter columns with a surface area of 30 cm x 30 cm. In the case other dimension shall be used, the calculations can be easily adapted using the MS Excel® file (#3) by changing the respective parameters as described in #2, the description of implementation.

The implementation of the VF wetland models is described without using wetland plants. Plants can be added for a more realistic model of a VF wetland. However, as main removal processes are carried out by microorganism (mainly bacteria), the treatment performance of the VF wetland models is the same with and without plants.





3. EXPLAIN – Making sense of the experiences

AIM: This stage aims to help students interpret their observations by exploring how soil, sand, and gravel filter particles, how bacteria remove pollutants, and the role of plants in a VF wetland. It connects students' findings with the underlying principles of how the model works.

GUIDING QUESTIONS

- How do soil, sand and gravel filter particles?
- How do bacteria remove pollutants?
- What are the effects of plants in a VF wetland?

KEYWORDS: filtration, bacteria, microbes, natural processes.

TEACHER SUPPORT

Use the ***Restore4Life online interactive visualization*** for Treatment Wetland topic to visually explain the processes occurring in both natural and treatment wetlands.

Facilitate a discussion:

- How is this similar to what happens in natural wetlands?
- Why do we need treatment wetlands in urban and/or rural areas?

4. EXTEND / ELABORATE – Expanding understanding

AIM: Building on students' observations and knowledge gained from the experiment, this stage aims to empower students to apply their knowledge by identifying factors that affect the efficiency of the VF wetland model, understanding what changes are needed for real wastewaters, and exploring how to adapt the model for real-world applications.

GUIDING QUESTIONS

- What factors most strongly influence the efficiency of the VF wetland model?
- What needs to be changed when using the VF wetland model for real wastewater?
- How could we adapt the VF wetland model for a real case application?

TEACHER SUPPORT

Show examples of treatment wetlands from different parts of the world.

- Highlight variations based on climate, local resources, and pollution levels.
- Discuss the role of engineers in designing these systems for specific needs.

MATERIALS NEEDED: Examples of treatment wetlands worldwide.

5. EVALUATE – Assessing learning

AIM: This stage helps students consolidate their knowledge and test their understanding of treatment wetlands as a sustainable, cost-effective wastewater solution that also supports biodiversity and ecosystem services. By applying their learning to local environmental challenges, students develop critical thinking skills and a deeper appreciation for nature-based solutions.

GUIDING QUESTIONS

- What challenges did we encounter and how did we overcome them?
- How has this investigation changed our view of wetlands and their capability to treat polluted water?
- What new questions have emerged from our investigation?

ACTIVITY: Teams create a poster or infographic that includes a diagram of the treatment wetland and a short explanation of its purpose and how it works.

TEACHER SUPPORT

- How has your understanding of wetlands and nature-based water treatment changed?
- What surprised you most about treatment wetlands?
- Compare treatment wetlands with natural wetlands: discuss similarities and differences.
- Could this kind of system replace conventional wastewater treatment plants?
- How could our investigation methods be improved?
- Analyze local water pollution issues and propose solutions using treatment wetlands.
- If possible, keep tracking weekly changes in the plants, water quality, and maintenance of the system.

MATERIALS NEEDED: Poster materials, markers, paper.

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VF WETLAND MODEL

FILTER COLUMN – TECHNICAL DOCUMENTATION

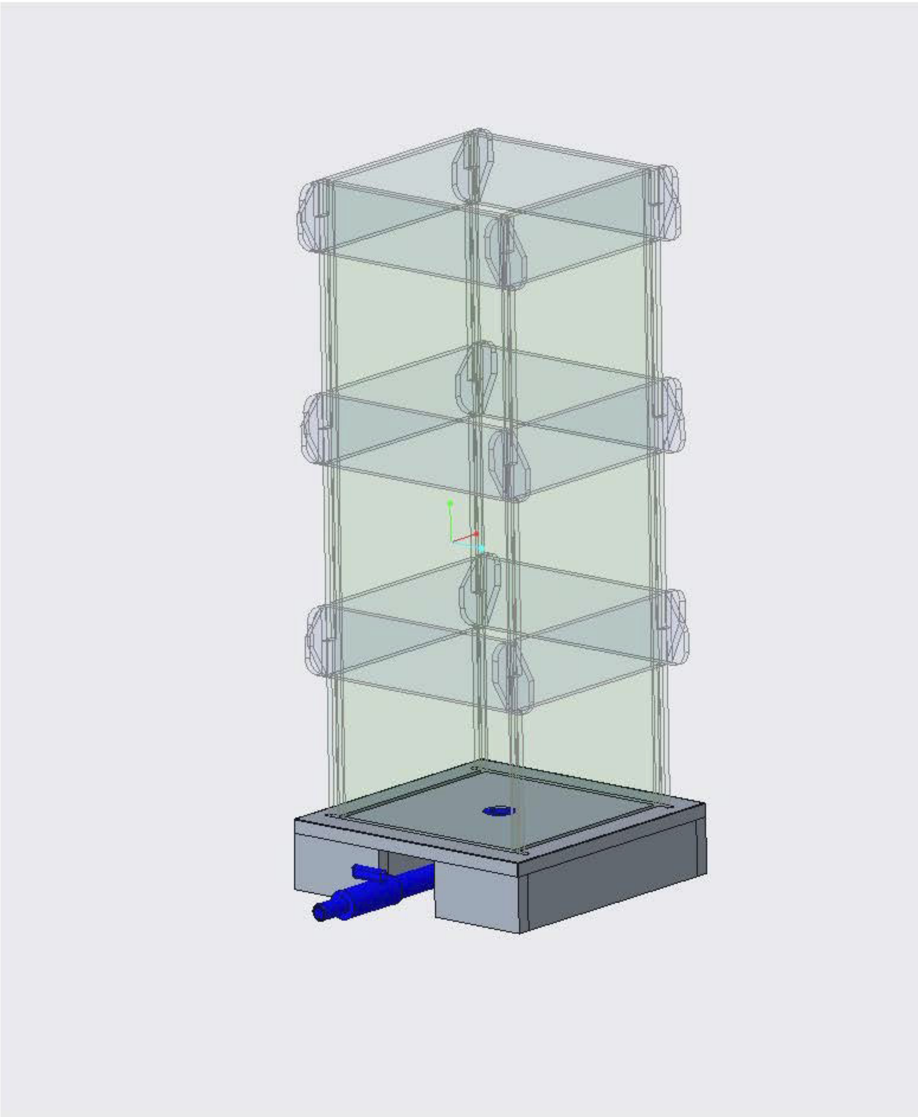


TABLE OF CONTENT

DESCRIPTION OF THE FILTER COLUMN

The upper container part is made of a tongue-and-groove construction, waterproofed with aquarium adhesive, using transparent PVC-U (Gamma Kunststofftechnik GmbH, 2025) with a triple plug reinforcement made of the same material.

The lower base and drainage part consist of a gray 20 mm PVC-U substructure, joined with PVC-U adhesive, featuring a lockable PVC-U drainage fitting and hose connection piece.

The upper and lower parts are connected to each other in a watertight manner using aquarium adhesive (Förch Dichtkleber MS-P, 2025) via a tongue-and-groove system. The drainage fitting was screwed and glued watertight using individual PVC fitting components.

MANUFACTURING OF PVC-U COMPONENTS

All PVC-U parts were cut 4according to the attached drawings on a table saw equipped with a blade suitable for PVC-U [Figure 1, shaped on an edge sanding machine, and the radii were sanded while the edges were deburred. The grooves for the tongue-and-groove connections were milled in three stages using a roughing end mill (Important: spiral chip groove!) [Figure 2, Figure 3] and subsequently deburred.

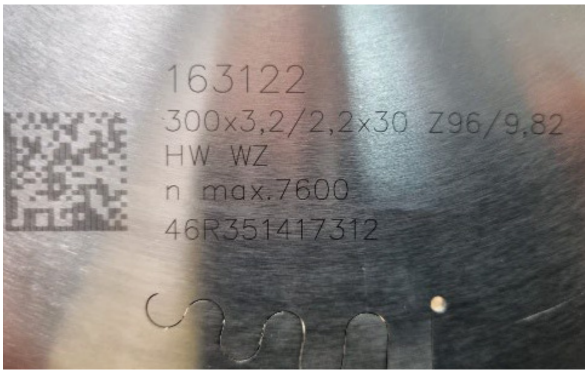


Figure 1: Selection of circular saw blade

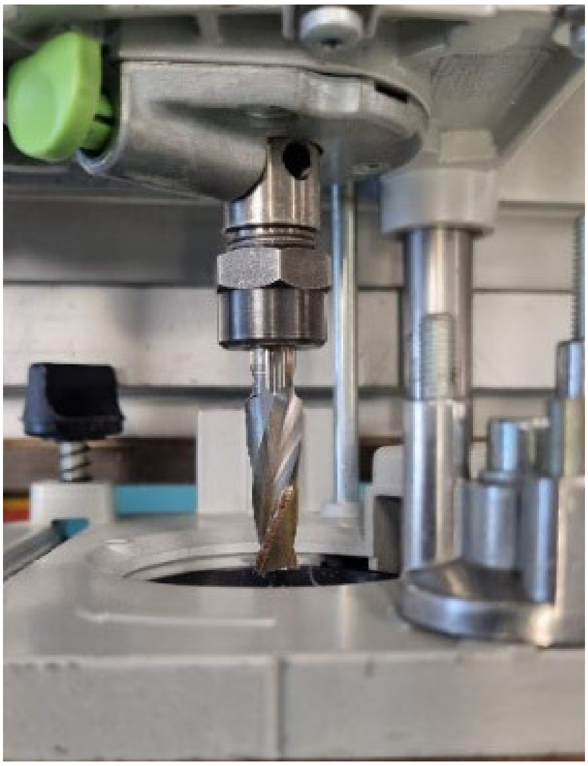


Figure 2: Router with roughing end mill

Figure 3: End mill with spiral chip groove

ADAPTING THE DRAINAGE FITTING COMPONENTS

The individual standard parts (HT-Connect GmbH & Co. KG, 2025) had to be partially adapted to fit within the only 8 cm high base.

A PVC-U tank fitting [Figure 5] was shortened by 10 mm and provided at the upper end with two 5 mm deep and ø6 mm blind holes spaced according to the teeth of an angle grinder key [Figure 6]. These serve to screw the tank fitting into the PVC-U elbow. The elbow [(1) 8] subsequently acts as a nut to tighten the tank fitting, while the original nut of the tank fitting is removed and discarded.

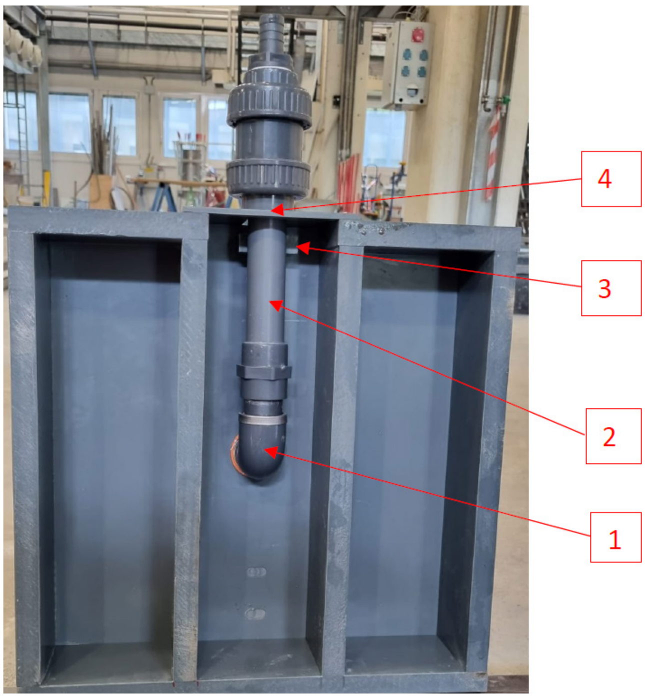


Figure 4: Bottom view of base/drainage fitting

Figure 5: Original standard part

Figure 6: Adapted standard part-holes for angle grinder key

To ensure that the PVC-U tank fitting does not protrude above the base level of the container, a ø46 mm blind hole, 6 mm deep, is created in the base plate using a Forstner drill. This hole must be made before the ø33 mm through-hole, as the Forstner drill lacks a center guide due to the absence of a material core [Figure 7].

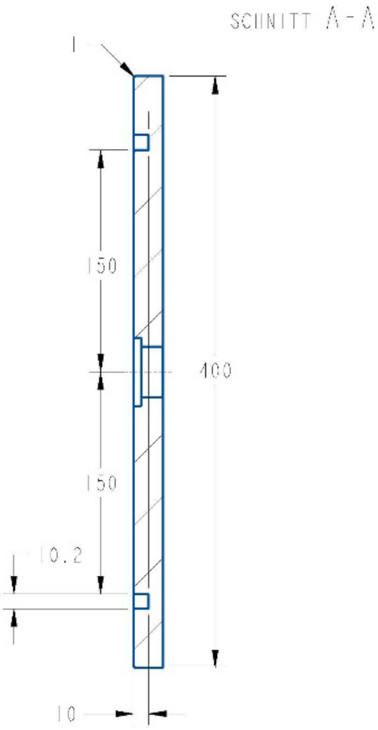


Figure 7: Detail of tank fitting

Figure 8: Pan head screw with flange according to ISO 7380-2, A2

The length of the drain pipe [(2) in Figure 4] depends on the specific position of the drain hole and the shut-off valve, which must be positioned with its connection outside the support plate [(4) in Figure 4]

The support plate, which is centrally attached to the outlet side of the base with four M4 x 20 pan head screws with flange (ISO 7380-2, A2) [Figure 8], serves to absorb any unintended, sudden torques caused by impacts on the drainage fitting from above or the sides. The counterpart to this is a PVC-U block glued to the underside of the base with dimensions h = 27 mm, b = 20 mm, l = 50 mm [(3) in Figure 4].

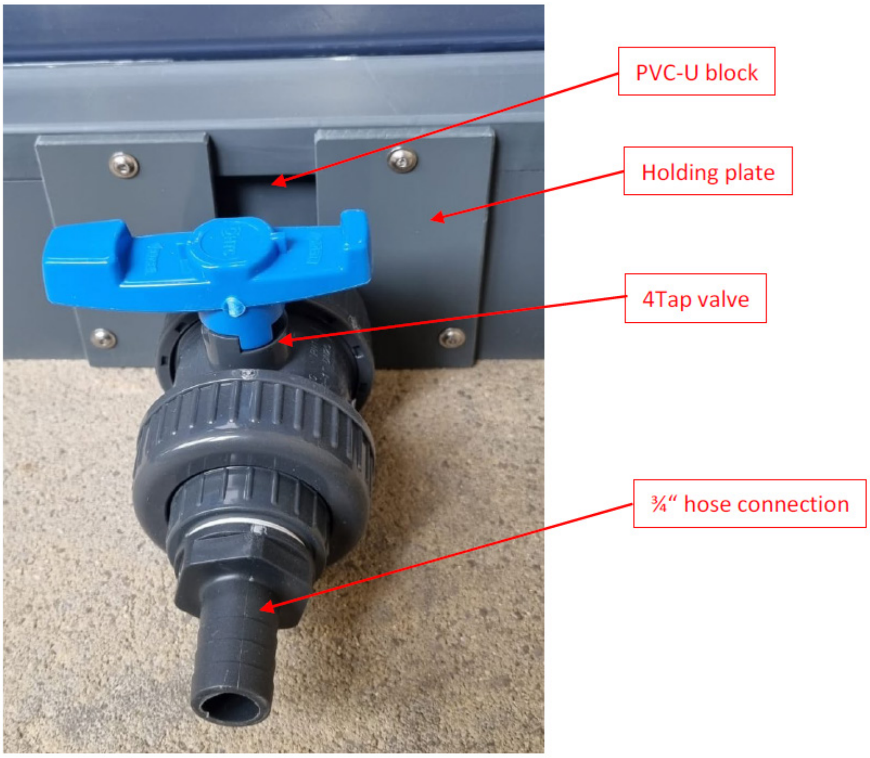


Figure 9: Drainage fitting with support plate and glued PVC-U block

ASSEMBLY OF DRAINAGE FITTING

1. Attach the tank fitting with seals and elbow to the base plate.
2. Screw the connections (adhesive fittings) tightly using sufficient PTFE sealing tape.
3. Cut the PVC-U pipe to length and glue it with PVC-U adhesive (recommended: Tangit) (Henkel AG & Co. KGaA, 2025) according to the manufacturer's instructions.
4. Then glue the PVC-U block [Figure 9] over the pipe under the base plate using PVC-U adhesive.
5. Mount the holding plate [Figure 9] using M4 threaded holes (threads at least 20 mm deep) cut according to the holes in the support plate, and secure it with the pan head screws.
6. Complete the drainage fitting by attaching the tap valve [Figure 9] and sealing the ¾" hose connection piece [Figure 9] to the tap valve with PTFE sealing tape.

ASSEMBLING THE CONTAINER BODY

The four different transparent PVC-U side panels, shaped according to the manufacturing drawings, are laid flat on a soft surface, cleaned, and glued tightly with aquarium adhesive (Förch Dichtkleber MS-P, 2025) according to the manufacturer's instructions. Care must be taken to ensure that the underside of the individual parts forms a flat surface and that sufficient adhesive is applied. The container is then stood upright and braced with the PVC-U reinforcements. Ensure the side panels are aligned parallel; if necessary, suitable clamps may be used as tensioning aids. Leave any excess adhesive untouched and carefully remove it with a utility knife after curing.

After curing, align the container while lying flat, clean the four inner edges thoroughly, and seal the fillet joints with an 8 mm wide bead of aquarium adhesive [Figure 10].

Position the container upright and secure the plug reinforcements by applying an 8 mm fillet joint to the outer reinforcement grooves [Figure 11].

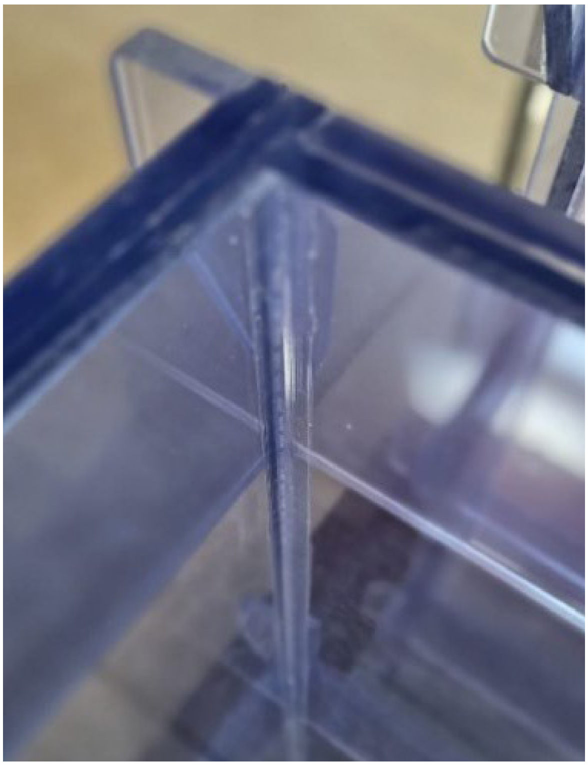


Figure 10: Fillet joint with aquarium adhesive

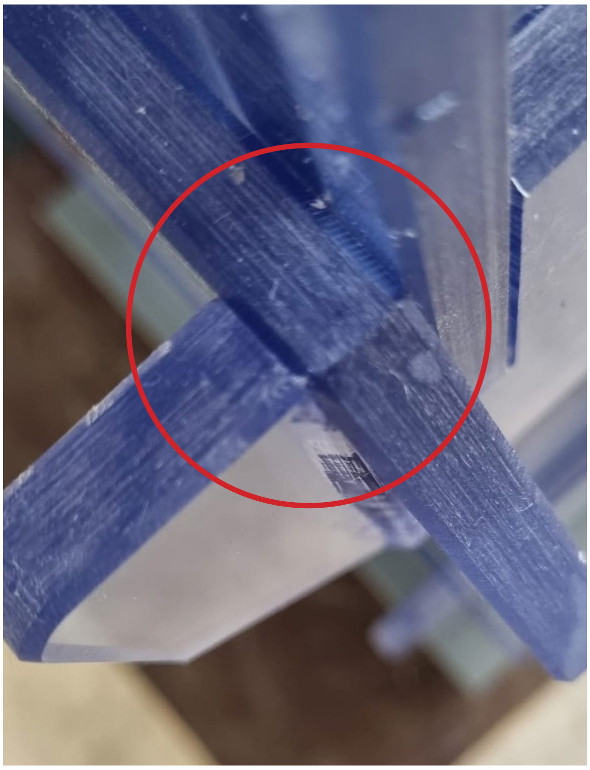


Figure 11: Fillet joint to secure plug-in elements

CONNECTING THE CONTAINER BODY TO THE BASE

Place the fully assembled base on a flat surface, clean the milled groove thoroughly, sand it, and clean it again. Then lay the container body flat, and remove the inner fillet joint at the lower end over a length of 1 cm. Clean, sand, and clean again.

Next, carefully apply aquarium adhesive (Förch Dichtkleber MS-P, 2025) to all three sides of the groove on the base without gaps, place the container body on top, and gently tap it into place with a plastic hammer until the desired position is reached. Then spread the excess adhesive inside and outside into a fillet joint (additional adhesive may need to be applied).

Figure 12: Competed container

DRAINING GRID

To prevent clogging of the drainage fitting, a stainless-steel perforated sheet (Frankstahl Rohr- und Stahlhandelsges.m.b.H, 2025) with dimensions 295 mm x 295 mm x 1.5 mm, round offset 3-5, 1.4301 EN 10088-2, is loosely placed on the container floor [Figure 13].

Figure 13: Loosely placed stainless steel perforated grid

Figure 14: Removable valve lever

DRAINING LIQUIDS FROM THE CONTAINER

To drain liquids, a standard ¾" hose (not included with the container) of sufficient length should be attached to the hose connection of the drain valve using a hose clamp. Then, the blue valve lever [Figure 14] should be attached and turned counter-clockwise to open.

IMPORTANT NOTES

- The valve lever [Figure 14] is removable (pull upwards). If the container is placed in a public area, the lever should be removed to prevent accidental emptying of the container.
- Containers should always be positioned so that the drain valve faces a wall to avoid breaking the PVC-U parts due to impacts from shoes or other objects.
- Containers may be damaged during transport, so they should be inspected for damage before installation. In general, avoid strong impacts on the PVC-U components, especially in the area of the protruding corners of the reinforcement plastics.
- Filter materials should be added carefully, avoiding large drop heights.
- The containers have been subjected to a leak test; however, it is recommended to perform another leak test after reinstallation, as transport may cause new leaks.

POTENTIAL HAZARDS

- If the container bursts due to sudden breakage, injuries from sharp-edged fragments cannot be ruled out.
- Liquids escaping from a broken container may cause short circuits if they come into contact with live electrical conductors.
- Strong mechanical stress may cause leaks or breakage of the container.
- Children and adolescents must be supervised when handling the containers.

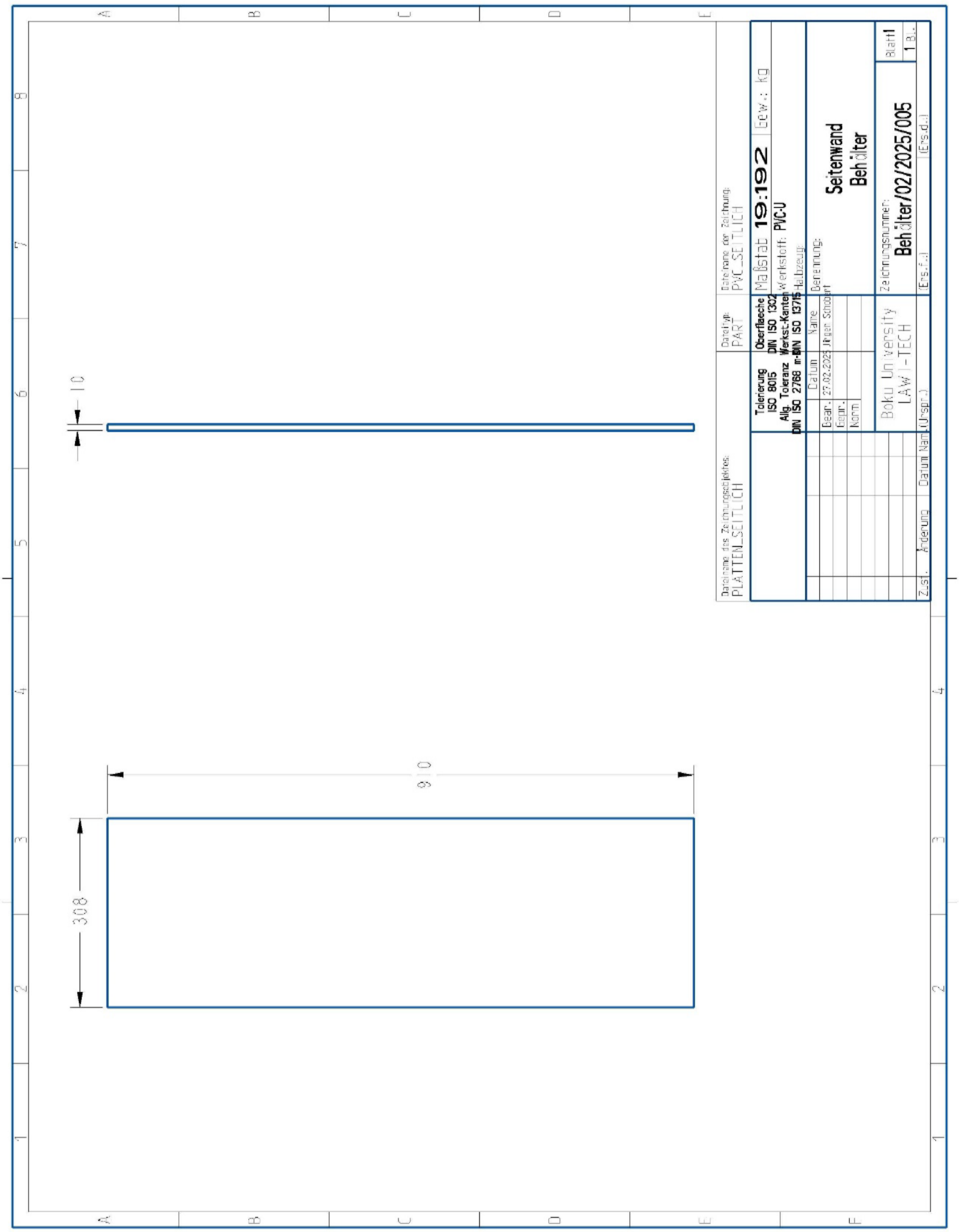
CLEANING

The containers should be cleaned with standard dishwashing detergent. Abrasive or caustic cleaning agents should be avoided.

COST OVERVIEW

The following table gives an overview on the materials costs. Material costs for one container has been about 870 EUR.

Material	**Firma**	**Kosten**	
PVC-U gesamt	Gamma Kunststoffe	€ 701,25	
Ablaufgarnitur	PVC-Welt	€ 53,40	
Kleinmaterial	Förch	€ 80,00	
Lochblech	Frankstahl	€ 34,32	
	per Container	€ 868,99	pro Behälter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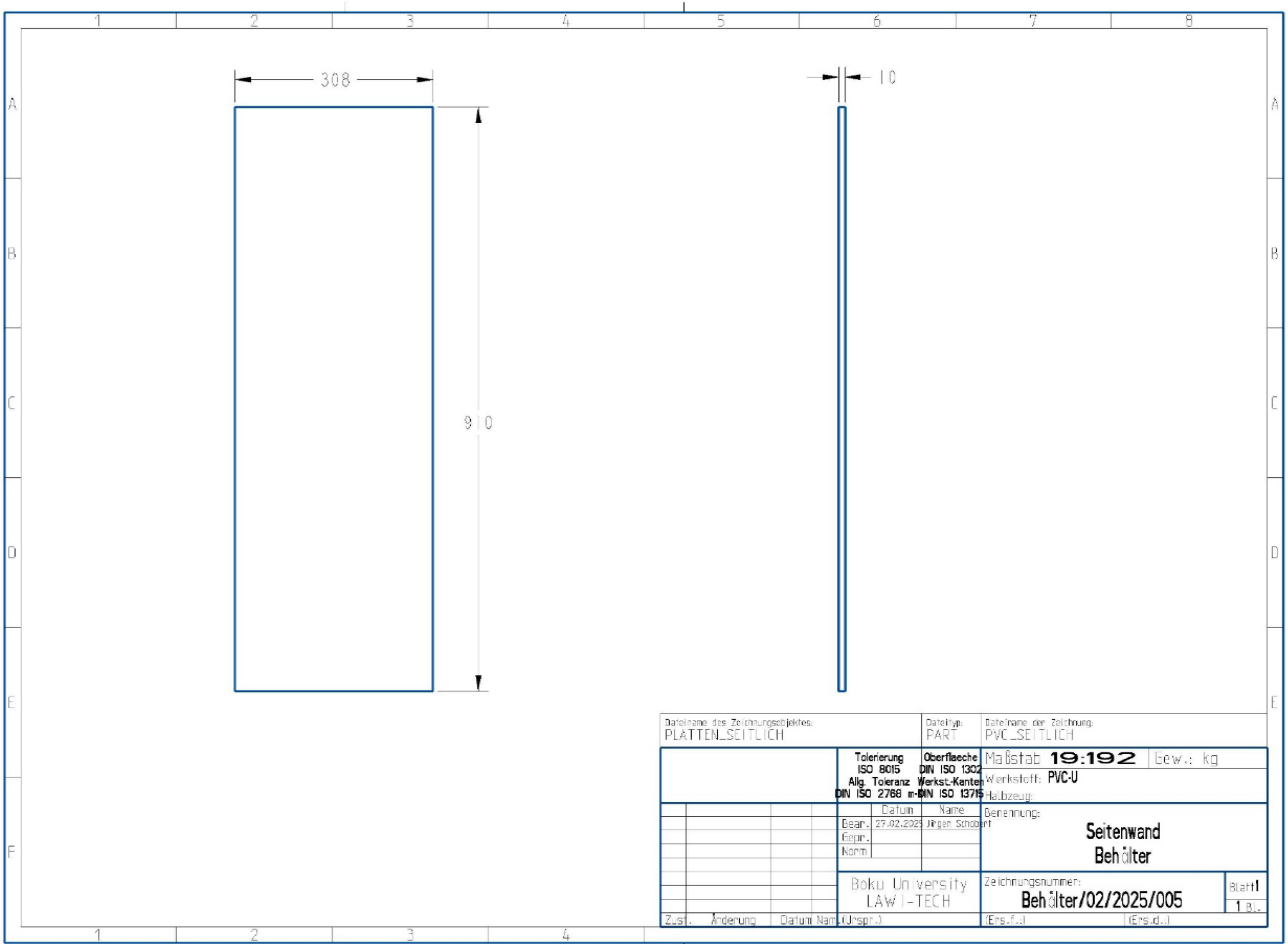

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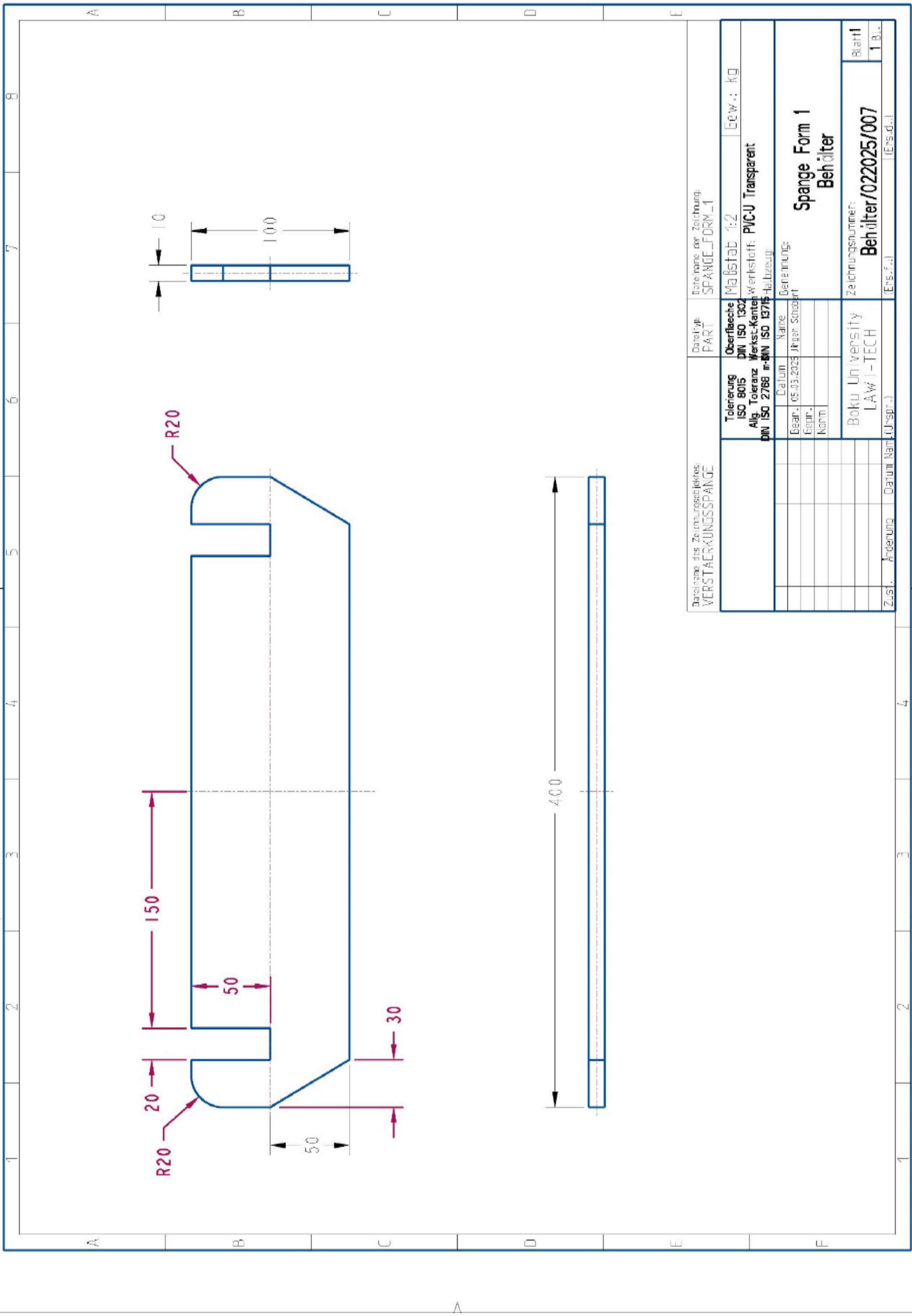
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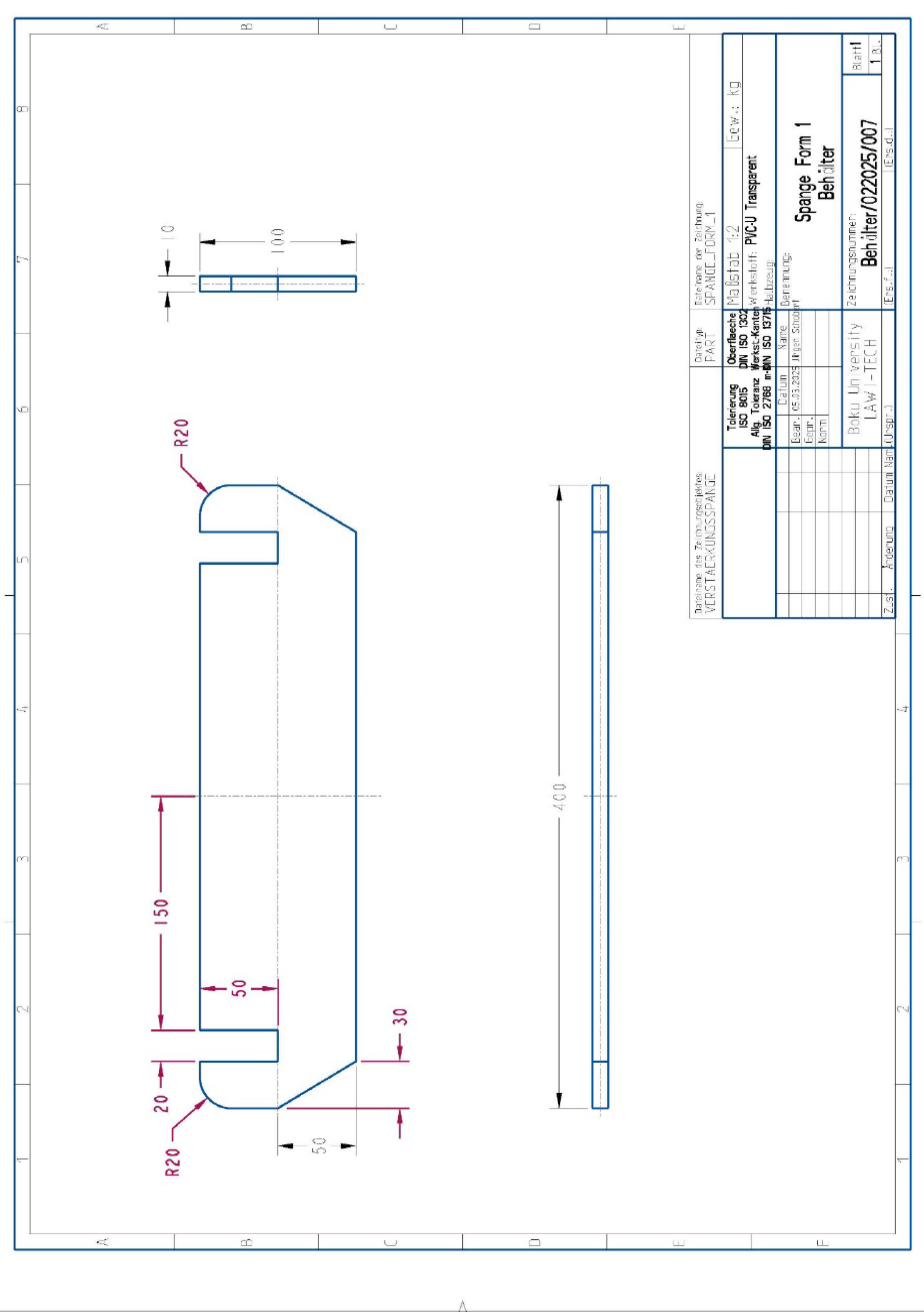

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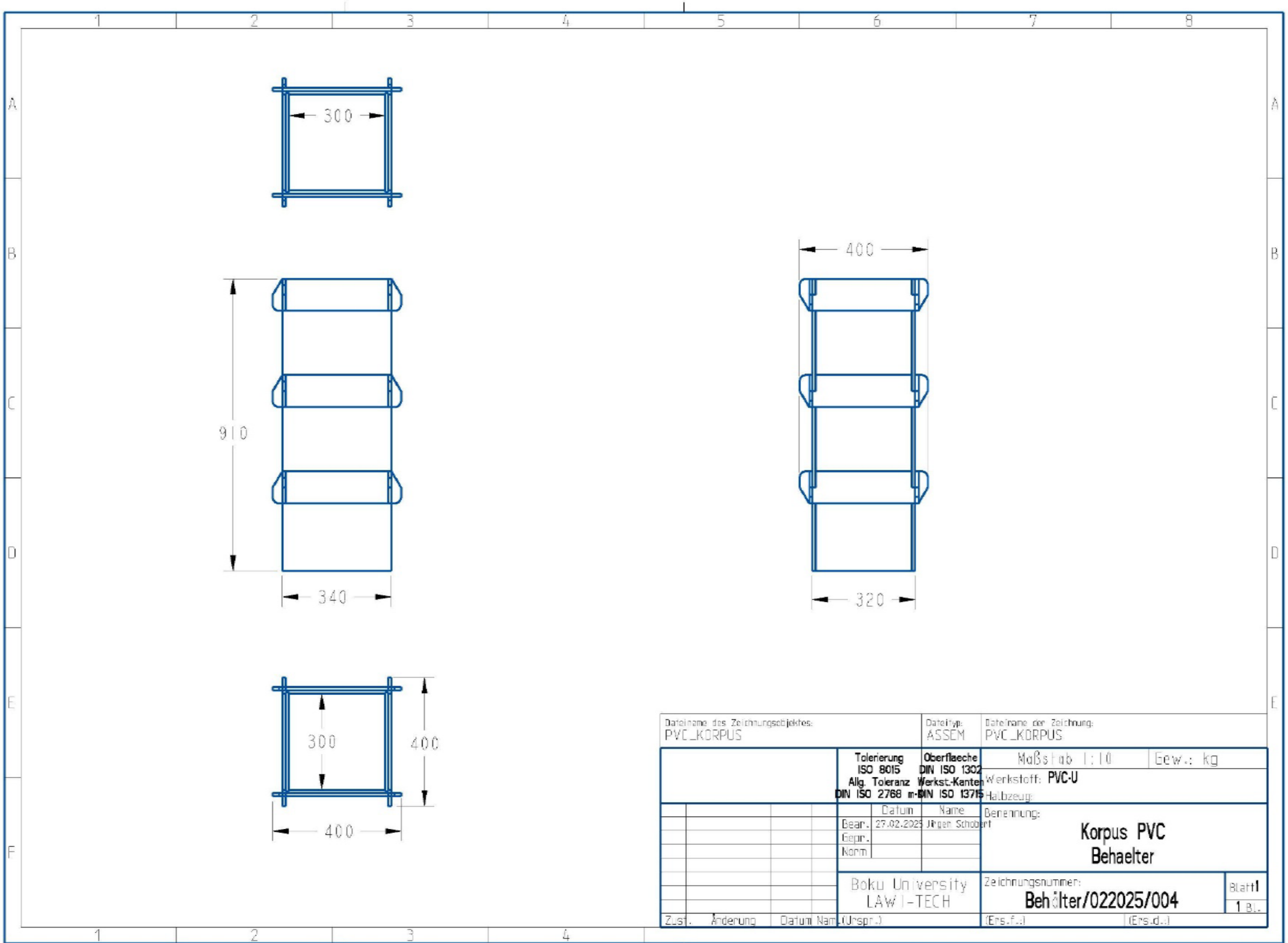
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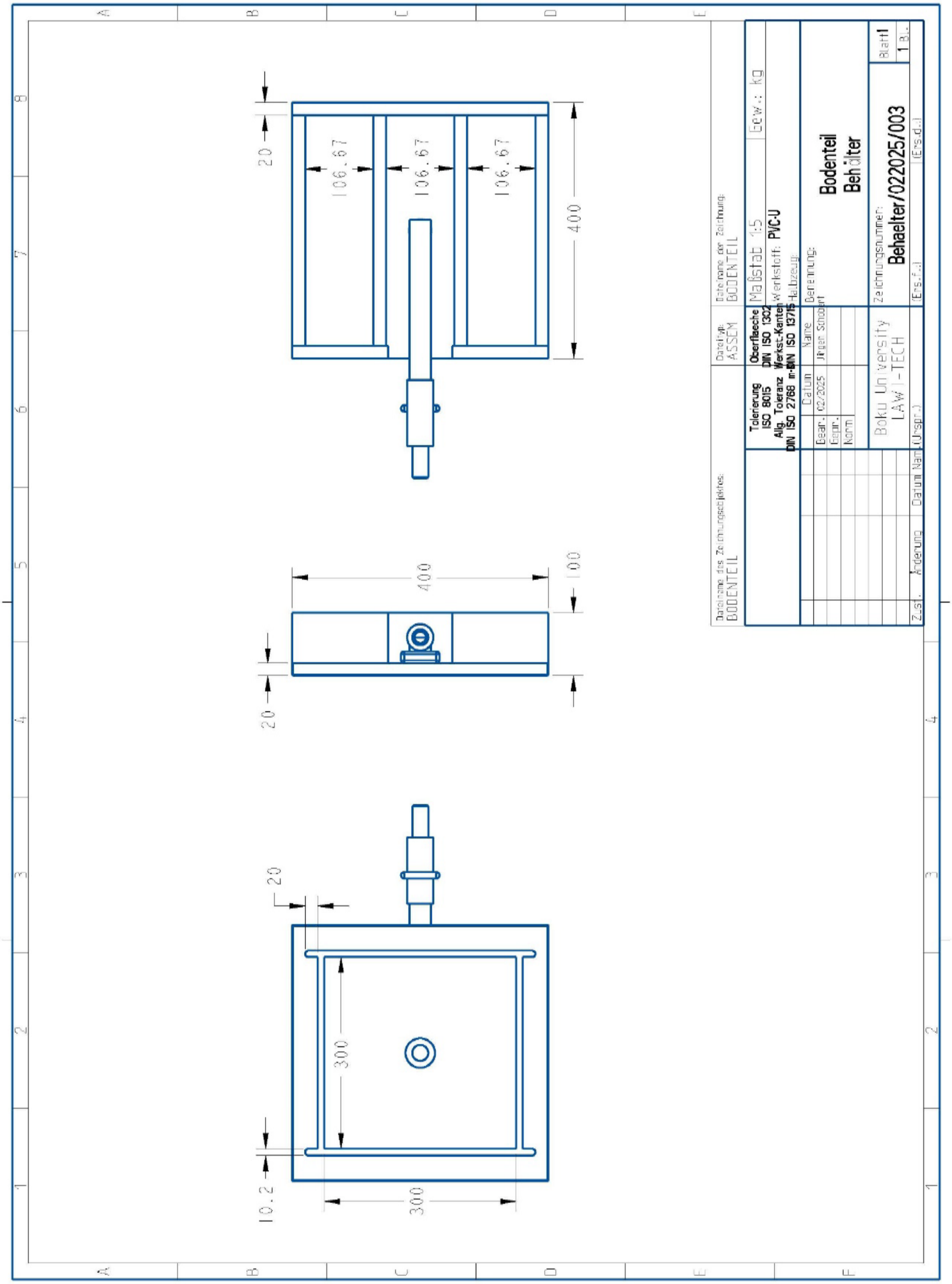

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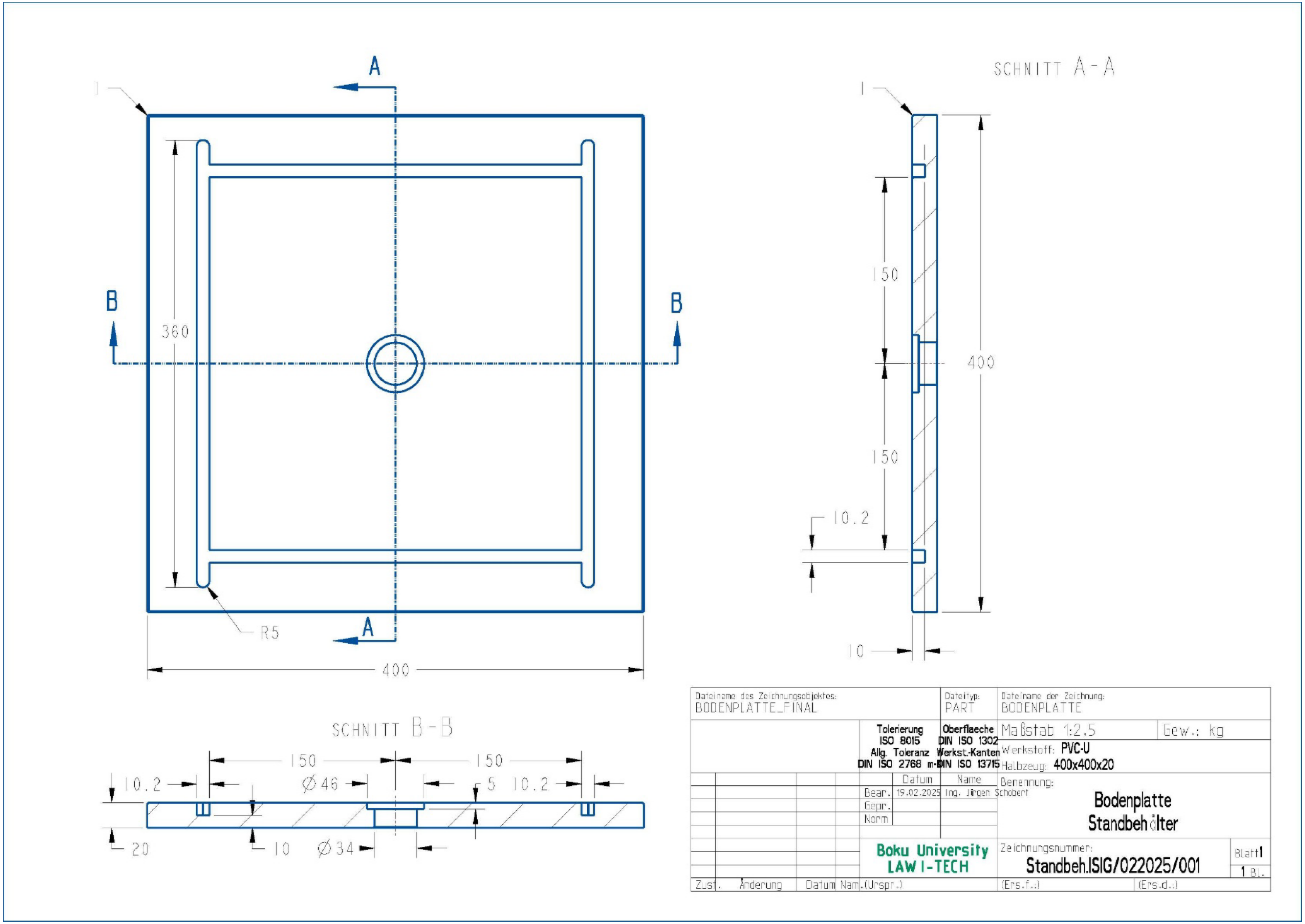

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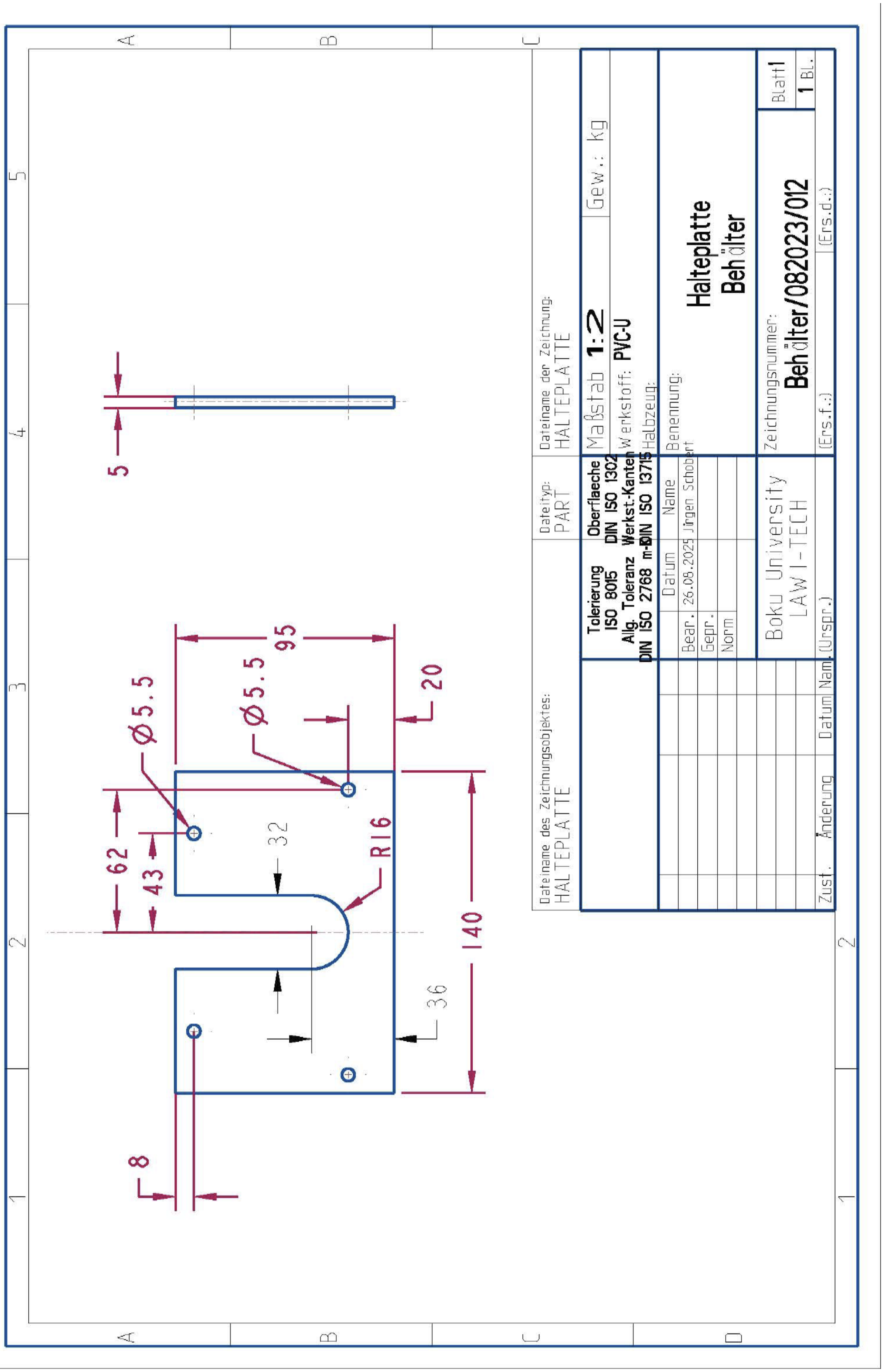

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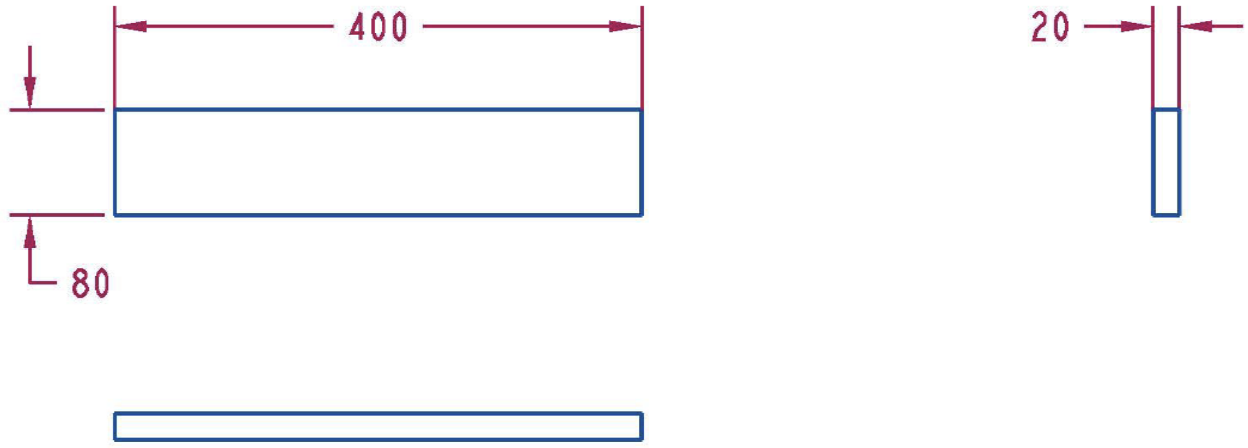

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Boku University
LAWI-TECH

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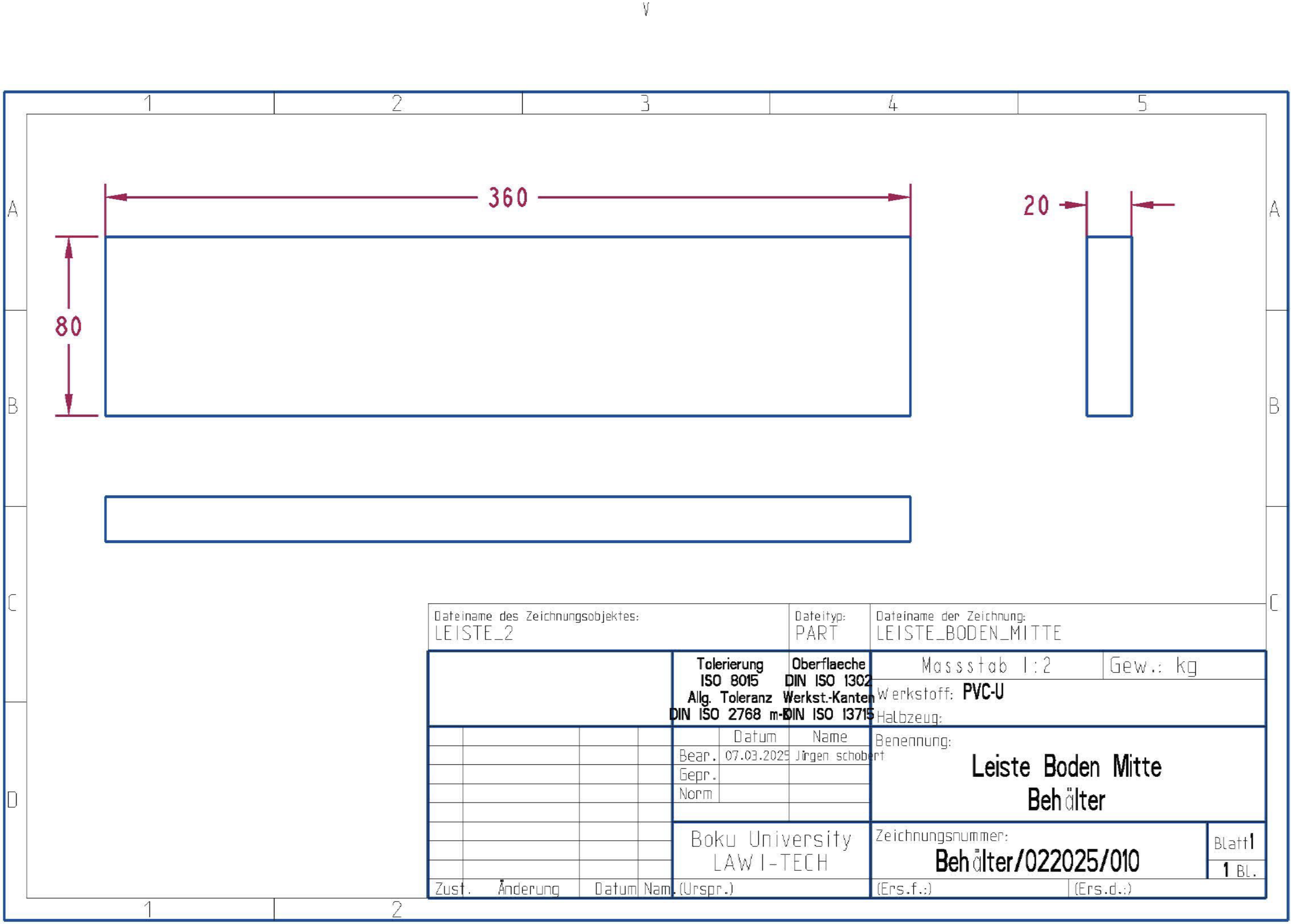

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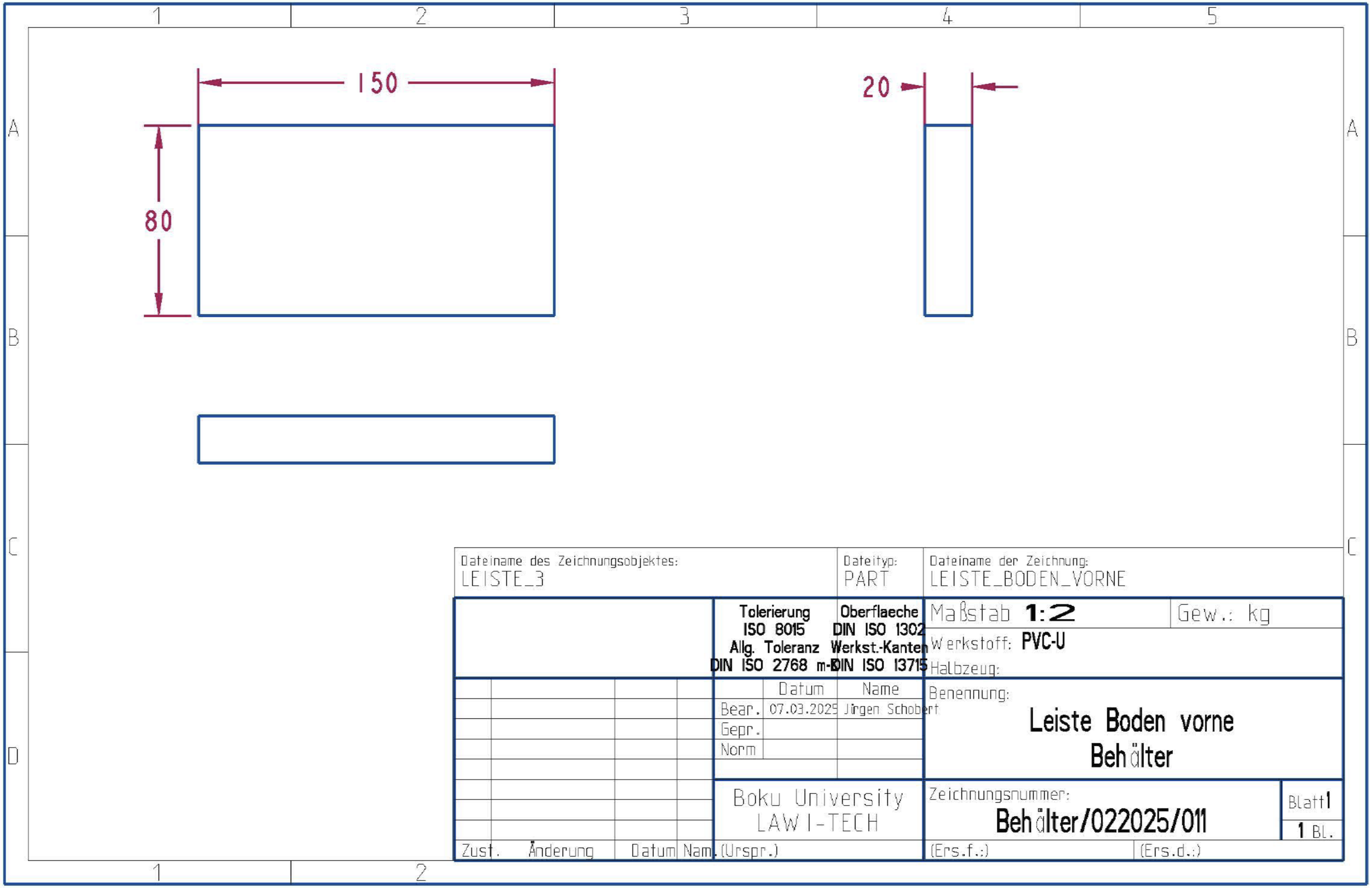
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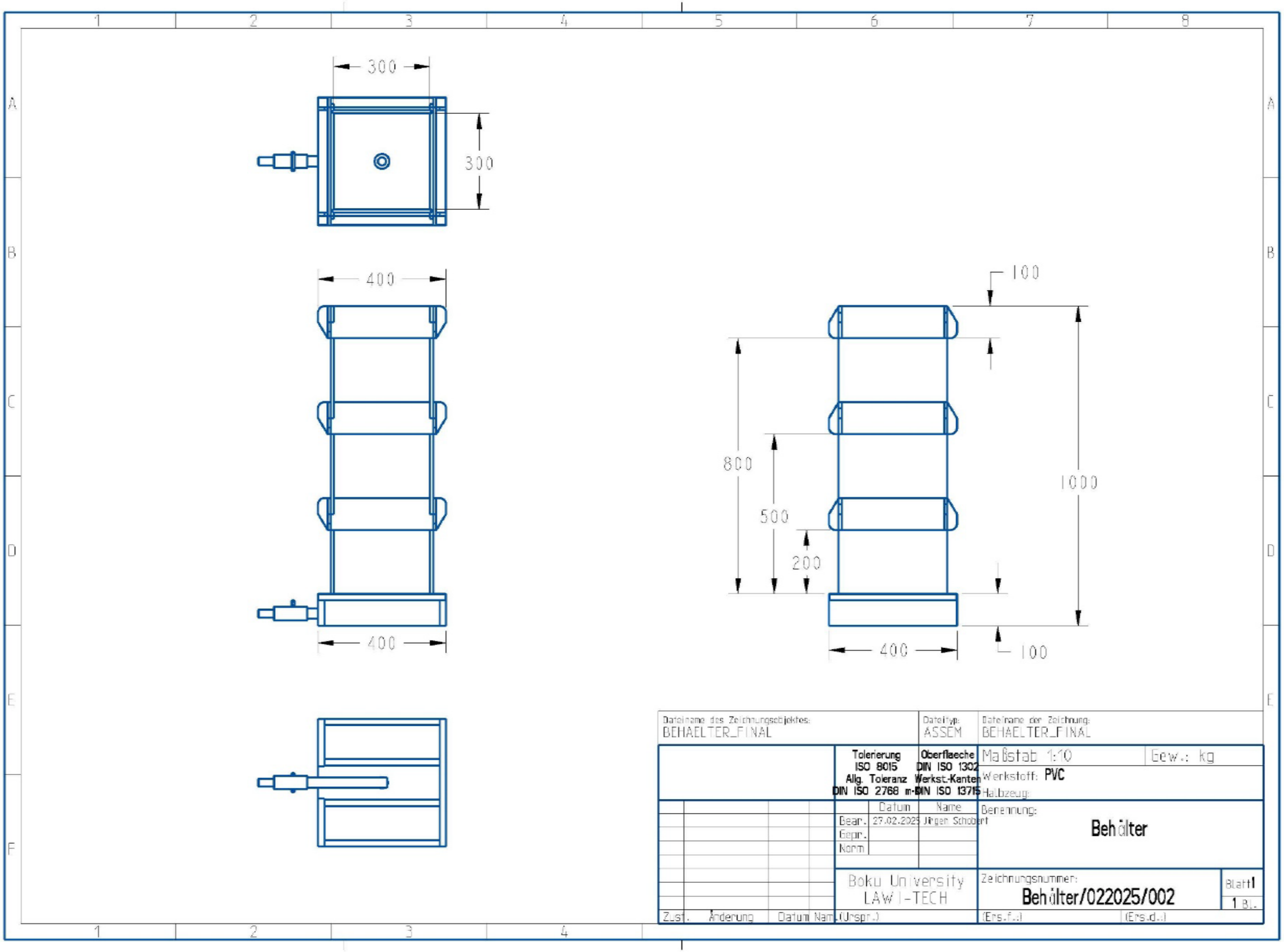
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LIST OF FIGURES

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Restore4Life

RESTORING WETLANDS
FOR A SUSTAINABLE FUTURE

VF WETLAND MODEL

FILTER MATERIAL, SYNTHETIC GREYWATER AND LOADING

VF wetland models with 50-liter greywater tank.

TABLE OF CONTENT

INTRODUCTION:

Treatment wetlands are man-made systems that are designed to mimic many of the conditions and/or processes that occur in natural wetlands with specific task to provide a water treatment function. Vertical flow (VF) wetlands, wastewater is intermittently fed in pulses on the surface of the filter and percolates vertically through it. In the interval between two loadings, air re-enters the pores and aerates the filter, so that mainly aerobic degradation processes occur. Effective primary treatment is required to remove particulate matter to prevent clogging of the filter. Using VF wetlands, stringent requirements regarding effluent quality can be met, i.e., also the removal of ammonium as required in some countries (Dotro et al., 2017; Langergraber et al., 2019).

With the VF wetland pilots, we want to showcase the functioning of treatment wetlands in general and VF wetlands in particular in schools. For this purpose,

- pilot systems with different filter media are used to demonstrate the effect of the filter medium on the treatment performance, and
- then pilots are loaded artificial/synthetic greywater for hygienic reasons.

This document shows the steps required for implementing the VF pilots on site.
The design and construction of the filter columns is described in the document **"VF Wetland Module - Filter Column – Technical Documentation"** (Schober, 2025).

All calculations presented here, are carried out for a filter column with a surface area of 30 cm x 30 cm, i.e., 0.09 m². by using the **MSExcel®-file VF-wetland-model_Materials.xlsx** provided, these calculations can be easily adapted.

FILTER MATERIAL

SELECTION OF FILTER MATERIAL

As described above, the influence of the filter material of the main layer on the treatment performance of VF wetlands shall be shown by building 2 VF wetland models using different filter media.

Table 1 gives an overview on the filter media required for the 2 VF wetland models. The coarser the filter media applied in "VF model 2", the larger the difference in the treatment performance. If no coarse sand is available also gravel (4 - 8 mm) can be used as main filter layer. Coarse gravel should be put on top of the sand layer to prevent erosion at the surface when loading the filter. Table 2 shows maximal applicable organic loading rates for different filter media of the main layer.

Table 1: Filter media for the 2 VF wetland models

Layer	**Depth**	**VF model 1**	**VF model 2**
Top	-	Coarse gravel	Coarse gravel
Main filter layer	50 cm	Fine sand (0.06 - 4 mm, washed)	Coarse sand (1 - 4 mm or 2 - 3 mm) or Gravel (4 - 8 mm)
Intermediate layer	10 cm	Gravel (4 - 8 mm)	Gravel (4 - 8 mm)
Drainage layer	10 cm	Coarse gravel (16 - 32 mm)	Coarse gravel (16-32 mm)

Table 2: Organic loading rate (in g COD/m²/d) for different filter media of the main layer

Filter material	**Sand (0.06 - 4 mm)**	**Coarse sand (1 - 4 mm)**	**Gravel (4 - 8 mm)**
Organic loading rate	max. 20	max. 80	max. 120

Using the MSExcel®-file VF-wetland-model_Materials.xlsx, the amount of the material for the 2 VF wetland models can be calculated by entering the surface area of the filter column in m² in the yellow cell (Figure 1). For calculated amount of sand/gravel is summarized in Table 3.

Table 3: Required sand/gravel for filling 2 VF wetland models with surface area of 0.09 m² each.

Material	**Amount (kg)**	**Description**
Coarse gravel (16 - 32 mm)	30	Drainage layer (VF model 1+2)
Gravel (4 - 8 mm)	30	Intermediate layer (VF model 1+2)
Sand (0.06 - 4 mm)	70	Main filter layer Gravel (VF model 1)
Coarse sand (1 - 4 mm)	70	Main filter layer Gravel (VF model 2)

	Sand / gravel for VF wetlands								
sand / gravel	1,5	kg/Liter							
Surface area:	**0.3 x 0.3 m²=**			**0,09**	**m²**				
Drainage	**16/32 mm**	10	cm =	0,009	m³				
				9	Liter ->	13,5	kg x 2 =	**27**	**kg**
Intermediate layer	**4/8 mm**	10	cm =	0,009	m³				
				9	Liter ->	13,5	kg x 2 =	**27**	**kg**
Filter layer	**0.06/4 mm**	50	cm =	0,045	m³				
				45	Liter ->	**67,5**	**kg**		
	1/4 mm	50	cm =	0,045	m³				
				45	Liter ->	**67,5**	**kg**		
Required Materials									
Gravel	**16/32 mm**	**30**	**kg**						
Gravel	**4/8 mm**	**30**	**kg**						
Sand	**0.06/4 mm**	**70**	**kg**						
Sand	**1/4 mm**	**70**	**kg**						

Figure 1: Screenshot from MSExcel®-file VF-wetland-model_Materials.xlsx for calculating the amount of sand and gravel for filling the VF wetland models.

FILLING OF THE VF WETLAND MODELS

The filter columns are filled from bottom to top. Figure 2 to Figure 9 show the process of filling the filter columns. The coarse gravel placed on top of the main layer to prevent erosion can be seen in Figure 9.

Figure 2: Placing the empty filter columns

Figure 3: Marking the height of the filter layers with a marker

Figure 4: Filling of drainage layer

Figure 5: Filter columns with drainage layer

Figure 6: Filling of intermediate layer

Figure 7: Filling of main layer

Figure 8: Filling of main layer (left column) and making a flat filter surface (right column)

Figure 9: Filled filter column with coarse gravel on top

SYNTHETIC GREYWATER

Synthetic greywater is used to provide a liquid that is free of microbial contamination so that it can be also used by pupils in schools without harm.

For mixing synthetic greywater, products used in a household's daily life have to be mixed. By using the recipe of Pucher et al. (2022), synthetic greywater with influent concentration of around 400 mg COD/L and 10 mg NH_4-N/L can be produced.

Table 4 shows the recipe for synthetic greywater with original data on g product per liter and the calculated values for 100-liter greywater. In the MSExcel®-file VF-wetland-model_Materials.xlsx, the amount of greywater that shall be produced can be entered in the yellow cell and the amount of products required is calculated (Figure 10).

Figure 11 shows the mixing of a concentrated greywater solution in a small bucket. The greywater tank is filled with drinking water (Figure 12) before the concentrated greywater solution is poured in the tank (Figure 13). Finally, the synthetic greywater needs to be mixed in the tank (Figure 14)

Table 4: Recipe for synthetic greywater according to Pucher et al. (2022)

Product	**g/L**	**g/100 L**
Ammonium chloride	0.029	2.9
Cleaning agent	0.106	10.6
Dishwashing soap	0.132	13.2
Dishwasher tabs	0.13	13
Salt for dishwasher	0.1	10
Liquide laundry detergent	0.311	31.1
Fabric softener	0.147	14.7
Shampoo + shower gel	0.552	55.2
Conditioner	0.162	16.2
Toothpaste	0.03	3
Hand wash soap (liquid)	0.114	11.4

Greywater preparation

Recipe for the synthetic greywater (Pucher et al. 2022)

Greywater

Products	***g/L***	***g per***	
		100	***Liter***
Ammonium chloride	0,029	2,9	
Cleaning agent	0,106	10,6	
Dishwashing soap	0,132	13,2	
Dishwasher tabs	0,13	13	
Salt for dishwasher	0,1	10	
Liquide laundry detergent	0,311	31,1	
Fabric softener	0,147	14,7	
Shampoo + shower gel	0,552	55,2	
Conditioner	0,162	16,2	
Toothpaste	0,03	3	
Hand wash soap (liquid)	0,114	11,4	

Figure 10: Screenshot from MSExcel®-file VF-wetland-model_Materials.xlsx for calculating the amount of products for mixing the synthetic greywater

Figure 11: Mixing of products to a concentrated greywater solution in a small bucket

Figure 12: Filling of the 50-liter greywater tank with drinking water

Figure 13: Pouring of concentrated greywater solution in greywater tank

Figure 14: Mixing of the synthetic greywater

LOADING OF THE FILTER COLUMNS

For calculating the amount of synthetic greywater that can be loaded each day the maximum applicable Organic loading rate (Table 2) has to be considered. For the calculations shown in Table 5, a filter surface area of 0.09 m² and a COD concentration of the synthetic greywater of 400 mg/L are used. Calculations can be easily amended by changing the respective cells in the MSExcel®-file VF-wetland-model_Materials.xlsx (Figure 13). The distribution of the loadings on a day can be calculated in the MSExcel®-file (right part of Figure 13). It is advised to provide loadings as close to reality, i.e., loadings should be applied when greywater is produced in a household. Usually more greywater is produced in the morning and evening.

Table 5: Recipe for synthetic greywater according to Pucher et al. (2022)

Parameter	**Unit**	**VF model 1**	**VF model 2**
Filter material main layer		Fine sand (0.06 - 4 mm, washed)	Coarse sand (1 - 4 mm)
Organic loading rate	g COD/m²/d	20	80
Hydraulic loading rate	L/m²/d = mm/d	50	200
Volume of greywater	L/d	4.5	18

Greywater volume

Concentration greywater		**400**	**mg COD/L**
	VF filter 1	**VF filter 2**	
	0.06/4 mm	**1/4 mm**	
OLR	20	80	g COD/m2/d
HLR	50	200	L/m²/day
Inflow	**4,5**	**18**	**L/day**
Inflow total		**22,5**	**L/day**
Operation	4	4	days
Volume	18	72	Liter
Volume total		90	Liter
Volume rounded		100	Liter

		0/4	1/4	
Morning	30%	1,35	5,4	L
Lunch	20%	0,9	3,6	L
Evening	50%	2,25	9	L
Total per day		4,5	18	L
		22,5	L greywater/day	

Figure 15: Screenshot from MSExcel®-file VF-wetland-model_Materials.xlsx for calculating the loading of the VF wetland models.

Figure 16 shows the filled filter columns with a 50-liter greywater tank. Before the first loading with greywater, the VF wetland models should be loaded at least once with clean water to fill the pores with water and the wash out fines from the filter material (Figure 17). After this the VF wetland models can be loaded according to the anticipated regime (right part of Figure 13). The amount needed for a single loading is taken from the greywater tank using e.g., a small bucket (Figure 18).

Figure 16: Filled filter columns with 50-liter greywater tank. The left column is filled with coarse sand and can be loaded with 20 liter per day, the right column with fine sand and can be loaded with 5 liter per day.

Figure 17: First loading with clean water.

Figure 18: Taking amount for single loading from 50-liter greywater tank.

TESTING THE REMOVAL EFFICIENCY

For testing the removal efficiency, samples should be taken only a few days (better on week) after the VF wetland models have been regularly loaded.

Table 6 shows expected and measured inflow and outflow concentrations of the VF wetland models that have been taken after only 2 days of consecutive loading of the models. The CDO of the synthetic greywater was less than expected, the NH4-N concentration as expected. Outflow COD concentrations are similar in both filters indicating that removal is mainly via filtration/adsorption and not biological degradation. When applying synthetic greywater, establishing the microbial biofilm takes longer compared to systems where real wastewater loaded. The measured NH4-N outflow concentration in VF model 1 (fine sand) was significantly lower compared to VF model 2 (coarse sand). However, also here the difference can be mainly attributed to higher adsorption capacity of the finer filter material.

Table 6: Expected and measured inflow and outflow concentrations of the VF wetland models

	Synthetic greywater		**Outflow VF model 1 (0.06 - 4 mm)**		**Outflow VF model 2 (1 - 4 mm)**	
Parameter	*Expected*	Measured	*Expected*	Measured	*Expected*	Measured
COD (mg/L)	*400*	**305**	*< 20*	**106**	*50*	**107**
NH_4-N (mg/L)	*10*	**14.8**	*< 0.1*	**0.04**	*> 1*	**5.2**

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