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Integrated Planning and Implementation of a Blue-Green Architecture Project by Applying a Design-Build Teaching Approach

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Abstract: Blue-green architecture (BGA) describes buildings and open spaces that combine nature-based and technical systems of vegetation and urban water management. This creates positive effects on the urban climate, public health, biodiversity, and water balance. In this study, a design strategy for BGA is applied and evaluated on a practical project. The project consists of an interdisciplinary course in which students of architecture and landscape architecture designed and implemented a BGA for a school garden in Munich, Germany. The students worked in an interdisciplinary planning team in which they took on different roles and responsibilities (blue/green/integration). As a result, the design was put into practice by their own hands and a nature-based system was built. The greywater from the school garden is now treated in a constructed wetland and, in combination with rainwater, feeds into a redesigned pond. Biodiversity was increased and a contribution to the environmental education of the pupils was made. The students demonstrated high learning success. Finally, the design strategy for BGA was positively evaluated using a design-based research approach and additional points were added for future applications.

Keywords: blue-green infrastructure; prototyping; nature-based solutions; landscape architecture; greywater; integrated planning; design strategy

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1. Introduction

Urbanization, continuous sealing of soils, and the impacts of climate change are global trends that require a paradigm shift in urban development and urban transformation [1]. Buildings, as well as private and public outdoor spaces, are facing high pressure to meet the resulting structural, social, and climatic requirements [2]. The increase in extreme weather events leads to a complex interaction of water surplus (caused by stronger and more frequent heavy rainfall) and summer drought [3]. The overheating of urban areas in summer is intensified by the urban heat island effect (UHI) [4]. The disadvantages of the UHI were already proven for Munich in the 1980s [5]. Therefore, climate adaptation strategies call for a change in the built environment towards more resilient systems [6]. Nature-based solutions (e.g., roof and façade greening, open water bodies, constructed wetlands) in combination with technical solutions (e.g., public water supply, underground water storage, smart irrigation systems) are particularly effective in terms of urban microclimate, stormwater management, and climate adaption [7,8]. Networks connecting these natural-based and technical solutions are called blue-green infrastructure (BGI) [9,10]. As urban climate adaptation is a highly topical issue, BGI is also of great relevance for the planning disciplines [2,11,12].

BGI connects urban vegetation and water management to a synergetic network. The concept can also be applied on a smaller scale, in which case it is referred to as 'blue-green architecture' (BGA) and focuses on one or several related buildings, the corresponding water flows and greening systems (roof, façade, garden) roughly up to the property boundary [10].

To ensure multifunctional solutions for the complex requirements of such BGI and BGA networks, the planning and design takes place in interdisciplinary teams [13,14]. The disciplines involved include architecture, landscape architecture, urban water management, and urban planning. The interaction of the planning disciplines is a particular challenge in the implementation of BGI and BGA. Due to the different objectives of the disciplines, it is almost unavoidable that conflicts of interest arise between water-related and vegetation-related planning aspects. Therefore, a well-structured planning process connects the specific objectives and fields of action of the disciplines effectively to each other. This ensures that spatial and functional solutions are developed that meet the respective disciplinary requirements [10].

This study is based on an integrated design strategy for BGA that was developed in a previous research project [14]. A BGA project (the so-called Impulse Project Stuttgart) was examined and the results in terms of the integrated design process were abstracted. To date, the design strategy for BGA has not been tested in practice and an evaluation of the applicability is missing. Here, we describe the application of the integrated design strategy in an interdisciplinary course in which students of architecture and landscape architecture designed and implemented a BGA project. The project started with the task of realizing a greywater treatment system for a school garden in Munich, Germany. Greywater is defined as slightly polluted wastewater (free of feces), which is produced, for example, when showering, washing hands, or in the kitchen [15]. The research area is located in the north of the city in an allotment settlement in the immediate vicinity of a huge park, the English Garden. The garden plot has a special situation in terms of building law, resulting in the fact that there is a drinking water connection, but no sewage system.

The planning task was taken as an opportunity to apply the design strategy for BGA in practice. The application in the context of a university course gives the opportunity to provide students with the competence to manage and realize integrated planning processes that focus on the interaction of water and vegetation in the field of buildings and landscape. This research-based teaching approach follows the structure of the prescribed design strategy for BGA and serves as the methodological framework of the presented study. This results in three aims for this study: (1) The design and implementation of a blue-green architecture (built result). (2) A learning outcome for the students in terms of blue-green integrated planning. (3) Evaluation of the design strategy for strengths and weaknesses. The lessons learned were in turn incorporated into the further development of the design strategy for BGA (Figure 1).

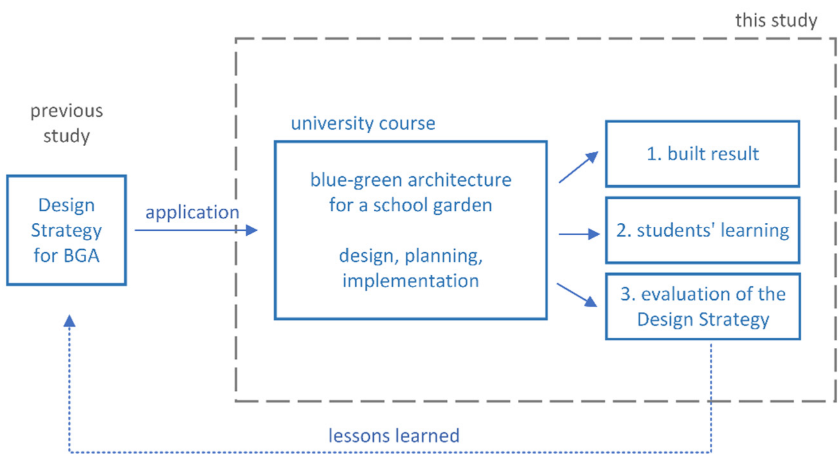


Figure 1. Design of the presented study.

The underlying planning task of is this study was a suitable case for an application and validation. The school garden for which the nature-based greywater treatment system was to be developed is used for teaching purposes and has a school kitchen in the classroom hut with a drinking water connection. However, there is no connection to the public sewage system, which is why the kitchen wastewater has to remain on the property. The teacher responsible for the school garden initiated the project with the aim of creating a natural system for water treatment, e.g., green wall, constructed wetland, or green roof (cf. [16]).

In this study, we focus on the following research questions that relate to the objectives according to the numbering:

1. Can the design strategy for BGA be used to create a functional and aesthetic system that meets the users' requirements?
2. Do the students experience a learning success through the research-based and practical teaching method?
3. What conclusions can be drawn from the design and planning process to improve the design strategy for BGA?

2. Methods

The study is based on a combination of several methods, which are described in more detail below. The design and planning process was based on the design strategy for BGA (Section 2.1.). The course followed a research-based and practical teaching method, also known as design-build (Section 2.2). Starting with the design, through the implementation to the evaluation of the applied design strategy, the overall research method can be described as design-based research (DBR). DBR is one in which the design serves to solve complex problems [17,18]. Reimann (2011) [19] describes the methodology and its characteristics, as well as its application in education:

> "In order to establish the claim that certain aspects of a design are necessary to bring about learning, and are not only contingent, one may employ the logic of control-group designs. However, DBR is conducted in real educational settings where this is hardly practically possible. Instead, DBR invokes the logic of process-oriented explanations. In the process approach, the phenomenon under study is not phrased in terms of variables and their relations, but in terms of events and their order. Researchers are not primarily looking at how quantitative attributes co-vary or change their value over time, but study the event sequence directly, and the 'forces' that move the sequence forward." [19]

There are numerous examples of such an design-build approach, especially in architectural teaching [20,21]. Through the scientific evaluation and systematic analysis of the gained knowledge, "Practice-based Design Research" is conducted, which is particularly useful in the design disciplines [22].

2.1. Design Strategy for Blue-Green Architecture

The aim of integrated blue-green planning is to consider water-related (blue) and vegetation-related (green) aspects right from the beginning of the design process and to integrate them in the decision-making process. This two-sided approach intends to ensure that synergies are created in terms of environmental, social, and spatial impacts (e.g., microclimate, heavy rainfall prevention, water management) [10]. Various blue-green integrated projects have already been implemented [23]. Examples are the Bishan-Ang Mo Kio Park in Singapore or the Uptown Water Circle in Normal, Illinois, US [24,25]. Systematic design approaches that balance water demand and water availability are not documented. For this purpose, a design strategy for BGA was developed in a previous study (Figure 2) [14]. The design strategy is applied exemplarily in this study for the planning, design, and implementation of a BGA.

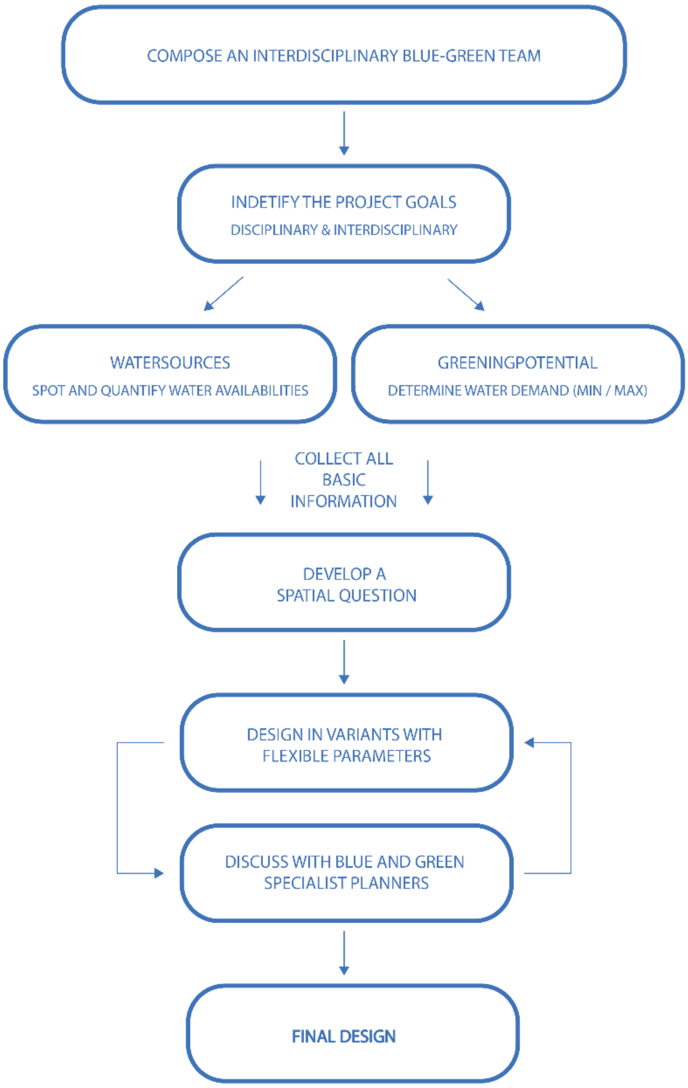


Figure 2. Integrated design strategy for blue-green architecture [14]. The integrated planning approach has been developed in a previous design-based research project. The different steps are described in detail in the indicated reference. The design strategy for BGA is applied for the first time in this study. The design process for the BGA project is guided by this approach in order to achieve a balanced weighting of blue and green aspects.

The design strategy is a guideline for interdisciplinary planning teams and describes specific steps from the goal setting of the intended project to the final design. The planning process for the blue-green architecture in the school garden is based on the described steps and will also be evaluated on the basis of these guidelines (Figure 2).

2.2. Research-Based and Practical Teaching Approach

The design and implementation of the BGA project was part of a university course that followed a research-based teaching approach. This approach creates a high level of interaction between research and teaching, resulting in high synergies for both fields. The sustainable development of design projects plays an increasing role in the professional practice of architects and landscape architects. Therefore, students should already be prepared for this in lectures [26,27]. Design projects are an integral part of teaching in architecture and landscape architecture [28]. The students develop designs that usually address spatial issues in a very concrete and realistic way [29]. The constant revision and further development of the architectural and landscape architectural plans in consultation with the lecturers leads to a steadily growing understanding of problems and solutions [30]. 1:1 projects, which involve the implementation of one's own planning, are still underrepresented [20,31]. For students of architecture and landscape architecture, it is particularly important to have application-oriented courses during their university studies [32,33]. The direct transfer into practical implementation deepens what has been learned through physical experience. Furthermore, students receive feedback on the practicability of their design and have the chance to correct any incorrect assumptions they may have been made during the planning phase [27]. Interdisciplinary courses that teach a holistic approach of sustainable architecture and that are closely related to current research therefore have high learning outcomes [26]. In the best case, there is a close exchange between research and teaching and mutual enrichment takes place [34].

The course reported in this paper was entitled "Prototyping blue-green systems" and was open to students of landscape architecture (M.A.) and architecture (B.A.). The seminar was held in the summer semester of 2021 and covered a period of 16 weeks. It was structured in three phases. The first part provided the necessary basics. It included a theoretical introduction to blue-green systems and integrated planning, as well as a site visit to the school garden. Within four weeks, a design was developed, which then moved into phase two, the prototyping. In this phase, the focus was on the detailed planning of individual elements and the prefabrication of some components. The third part of the course was the implementation on site. Over six construction days, the design was realised by the participants' own hands supported by the pupils of the school. The students wrote protocols of the construction process in which they recorded their own insights into the design and implementation process. The three phases of the course were accompanied by supervision and consultations of the lecturer. Additionally, interim presentations and meetings were held with the school teacher who represented the client.

3. Design and Implementation

3.1. Planning and Design

The structure of the integrated planning was conducted step by step according to the described design strategy (Figure 2). The planning and design process was documented with recordings of the meetings and protocols. It is described in detail below to make the decision-making process comprehensible.

3.1.1. Composition of the Planning Team

Eight students who had registered for the course formed the planning team. Since the students had backgrounds in architecture and landscape architecture, the role of water specialist planning had to be assigned internally. Table 1 shows the division of the students into three groups (blue/integration/green) and the corresponding responsibilities.

Table 1. Students were divided into three interdisciplinary groups. The three groups are shown here in their composition (LA = landscape architecture, A = architecture) and the responsibilities in the overall planning team. The division was specified by the lecturer in order to provide the students with an orientation for their tasks.

Blue Group	Integration Group	Green Group
1: LA student 2: LA student 3: A student	1: LA student 2: A student	1: LA student 2: LA student 3: A student
water sources water qualities and quantities water storages water treatment	conceptualization communication consistent design costs	green design water needs irrigation plant selection

The groups worked on their topics independently and met regularly to exchange their results. This division enabled an equal weighting of the topics and issues resulting from the subject-specific blue-green challenges. The integration group merged the findings and was responsible for the spatial concept, a consistent design, and compliance with the cost framework.

3.1.2. Identification of Framework Conditions and Project Goals

The framework conditions were determined during a site visit. The students prepared the visit to the school garden together in one group and collected questions addressed to the responsible teacher. On site, it turned out relatively quickly that the system would be built in close spatial proximity to the classroom hut with the kitchen and thus also to the grey water source. Therefore, the hut and its surrounding area were surveyed (Figure 3). This identification of a suitable building site had a significant influence on the further work of all groups, because the functional considerations could be put into a spatial relation.

Figure 3. All three groups survey the construction site near the classroom hut during the first site visit.

Later, the students divided into their three groups to collect the framework conditions separately according to responsibilities. The following three subchapters describing the framework conditions are therefore results that were obtained in parallel. In this case, the listing starts with the integration group to give an overview of the planning task and then continues with the blue and green aspects. In some cases, there were overlaps in the subjects of the groups, which were coordinated in bilateral discussions. The interfaces are named in the text.

Integration Group: Definition of Planning Task and Project Goals

The role of the integrating group was to bring all the different demands together and to create a unified concept. The students interviewed the responsible teacher to obtain a detailed profile of the requirements for the project. It was already known from the initial planning preparations that the central task would be to create a nature-based greywater treatment system for the kitchen wastewater. The specifications for the system were defined more precisely during the consultation with the responsible teacher:

- The garden is a utility garden whose cultivation is integrated into classes. The entire landscaping of the ground takes place in cooperation with the children. Maintenance and care tasks include new planting, watering, pruning, and grafting of fruit trees. In addition, there are individual projects such as the construction of insect hotels, beehives, and small huts, e.g., for observing bird broods.

- The pupils also cultivate potatoes and grow cereals. They process the grain by hand into flour, which they use to bake bread in the kitchen.
- Not all areas need to be irrigated. If necessary, water is taken from wells by hand with watering cans. The wells provide sufficient water. There is no shortage even during drought.
- The main time of use of the kitchen sink is at lunchtime, when cooking takes place in the hut. The greywater therefore contains fats, small amounts of food residues, and organic soaps. Up to now, the greywater has been collected in buckets and left to drain unfiltered on the property. The use of the garden will increase in the coming year, as in addition to the school lessons (April–November), an after-school group will be present in the afternoon all year round. Therefore, the current greywater disposal is not a sustainable solution and a nature-based treatment is desired.
- The rainwater from the roof surfaces drips from the gutters into catch stones and runs from there into two pond basins. Much of it seeps away on its way. The water is not taken out of the basins. It evaporates or infiltrates.
- There are several ponds on the site. The small pond south of the hut is hardly looked after (Figure 4). Once a year, the leaves are removed and in spring water is replenished from the well. It serves as a spawning ground for grass frogs. During longer dry periods, the water level decreases significantly, which has an unfavorable effect on the frog population.
- The planned greywater treatment should be as low-maintenance as possible and not cause high running costs. A long lifetime would be welcome.
- In connection with the creation of a disposal solution for the greywater from the kitchen, another washbasin is planned to be installed. This will be available outdoors as a basin for washing hands.
- The total costs for the project are limited to € 4500. These are exclusively material costs. The work is carried out by pupils and students.

Figure 4. The pond in close proximity to the hut has not been well maintained so far. The area to the left of the entrance was identified as a suitable building site.

These remarks, together with the survey of the planning area and a photo documentation of the site, were available to all three groups as a basis for their work.

Blue Group: Water Situation on Site and Quantity Determination for Water Treatment

Building on the integrated design strategy described in Figure 2, the blue group started by recording the overall water situation on site and quantification of water availabilities.

The focus was on two main sources, rainwater (run-off from the roof of the classroom hut) and greywater from the kitchen sink in the hut's kitchen together with the greywater from the planned outdoor washbasin (cf. 3.2.1). A third source of water on the property would be groundwater, but this is not included in the considerations in order to leave the resource worth protecting untouched as far as possible.

Since no fresh water is used for irrigation and the withdrawal for cooking can be neglected, the amount of greywater produced is roughly equivalent to the overall fresh water consumption. The amount of fresh water used in the kitchen could be estimated from the consumption data of the tap water supply and the teacher's report. In recent years, the consumption has been between 6000 and 8000 L per year. Due to the intensified use of the garden (see 4.2.1), it is assumed that an additional 3000 L of water will be consumed throughout the year. Therefore, in the future a grey water volume of roughly 10,000 L per year can be assumed.

No lessons (and no after-school care) take place on weekends and school holidays which means that the kitchen is not used. Thus, the distribution of water consumption and the generation of greywater is not equal throughout the year.

In addition, the garden is only attended to a reduced extent from the beginning of December to the end of March. No horticulture lessons take place during this time, but the after-school care is present from lunchtime onwards. Therefore, the greywater volume is not distributed equally over the school days, but is reduced accordingly in the winter months (Table 2).

Table 2. Distribution of greywater volume over twelve months relative to school days and usage pattern.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
school days/month *	18	17	19	13	17	15	21	0	14	19	19	16
greywater in l/month	287	271	303	979	1280	1129	1581	0	1054	1430	1430	255
greywater in l/school day	16	16	16	75	75	75	75	0	75	75	75	16

* on the basis of a monthly average from 2012 to 2022.

The calculation of the greywater volume is based on the following premises:

- Water consumption horticultural classes (according to previous consumption data) April–November: 7000 L;
- Water consumption after-school care (estimated) January–December: 3000 L;
- The distribution of the total consumption (10,000 L) corresponds to 37% for the months December–March and 63% for the months April–November.

The distribution of greywater volume shows that especially during the summer holidays, very little to no greywater is produced. Generally, greywater is classified as a continuous supply compared to other water resources such as rainwater. Due to the fluctuations in the use of the garden, we have a special case here. The school wishes to have a nature-based system for greywater treatment. In order to ensure functionality, long dry phases are to be avoided. The additional feed of rainwater is therefore being considered. Furthermore, the additional flushing with rainwater (less polluted than greywater) has the benefit of diluting the greywater and reducing the contaminant loading in the substrate. The roof area close to the greywater source was considered for supply to the greywater treatment system (Figure 5).

The quantities of the available rainwater were calculated using average monthly weather data for Munich [35]. The monthly values were multiplied by the surface of the roof area (23.3 m^2). For rainwater runoff, the coefficient of discharge 1.0 was applied, as the water accumulation in the event of heavy rainfall is considered to most relevant [36]. Together with the generated greywater, this results in the average total monthly water volumes (Table 3).

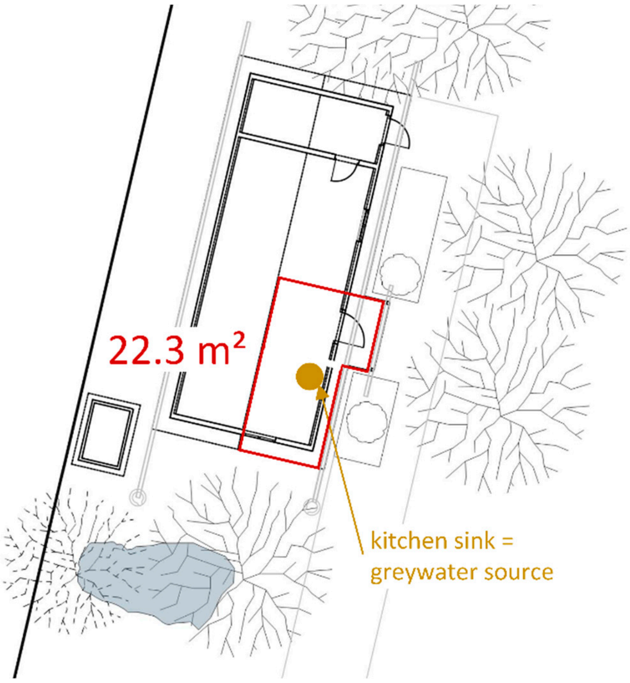


Figure 5. The roof area of 22.3 m^2 close to the greywater source was considered for rainwater harvesting. The rainwater gutters would have to be connected to the system individually.

Table 3. Monthly total water volume from the roof drainage above the kitchen and the greywater from the kitchen and outdoor washbasin. Since the weather data are average values, there can be significant fluctuations from year to year which are not represented here.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
precipitation in l/m^2/month	67	57	75	73	110	109	110	100	86	71	69	73
roof drainage in l/month	1561	1328	1748	1701	2563	2540	2563	2330	2004	1654	1608	1701
greywater in l/month *	287	271	303	979	1280	1129	1581	0	1054	1430	1430	255
water inflow filter/month	1848	1599	2051	2680	3843	3669	4144	2330	3058	3084	3038	1956

* According to Table 2.

The results of the water volume calculation are shown graphically in Figure 6. The water volumes of rainwater and greywater are summarized. From the proportion of the two values, it can be seen that on a monthly average there is a clear dilution of the more polluted greywater by the less polluted rainwater. This reduces the surface load on the filtration bed.

The values of rainwater and greywater were analyzed for their suitability for a nature-based greywater treatment in form of a constructed wetland. The area to the left of the entrance to the classroom hut was identified as a suitable position (through interfacing with other groups). The proximity to the kitchen sink and the existing pond as natural storage presented an advantage in that no long distances had to be bridged with pipes. As the availability of rainwater is subject to high fluctuations, a storage tank should be provided that can be available for additional water supply for the constructed wetland during dry periods. Additionally, during heavy rainfall, a lot of precipitation could be retained. This storage should be placed between the downpipes of the roof and the filtration bed.

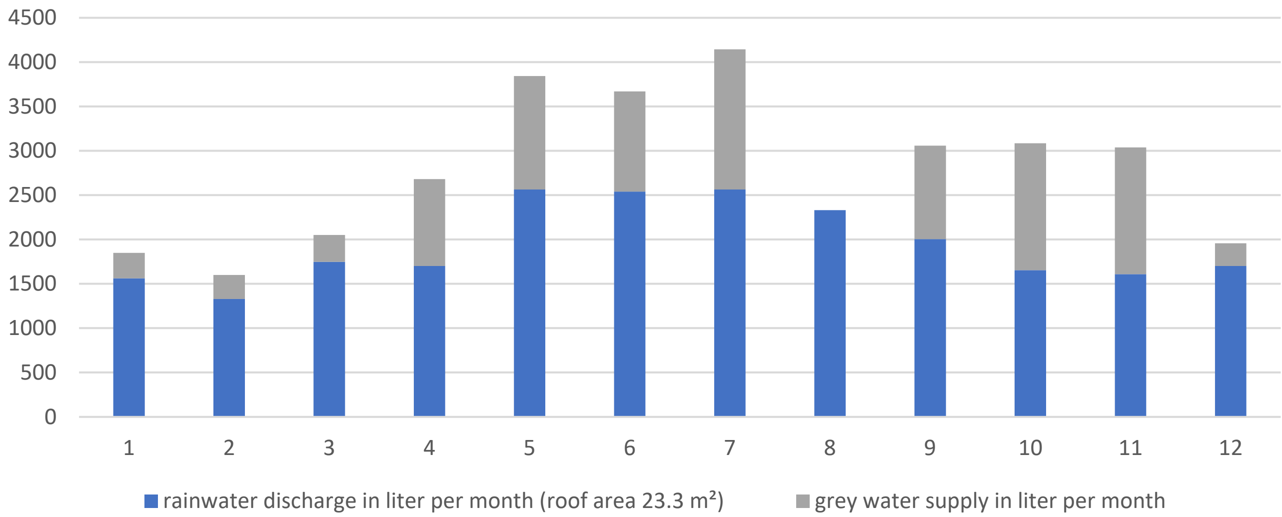


Figure 6. Average monthly water volume from the roof drainage above the kitchen (rainwater) and greywater from kitchen sink and outdoor washbasin.

Since no nature-based greywater treatment on a similar small scale is known, the capacity of the system was estimated. Data from the Impulse Project in Stuttgart, Germany, and from constructed wetland roofs served as comparative values [37,38]. The parameters relevant for the treatment are different in several points in the Impulse Project. These include the nature of the greywater (kitchen vs. showers) and the depth of the filtration bed. The planting of the constructed wetland (interface with green group) also has an effect on treatment performance.

In the Impulse Project, approximately 400 L of greywater from showers and hand basins are distributed daily over 5 m^2 of filtration bed. The filtration bed has a depth of around one meter (except for the loading equipment on top and insulation underneath). This results in a monthly surface load of 2400 L/m^2.

For the filtration bed in this project, an area of 2.0 m^2 and a height of 50 cm are used as initial guide values. For a plant in these dimensions, a monthly maximum loading is assumed to be 4000 L. This results in a surface load of 2000 L/m^2, but from greywater and rainwater (less pollution). In most months, the value is significantly lower, from which it is concluded that the filter performance of the constructed wetland in the envisaged size and under the described conditions should be sufficient.

Green Group: Existing Vegetation and Greening Potential

The tasks of the green group consisted of recording the existing vegetation and a potential need for irrigation. This analysis makes it possible to improve the situation on the ground by creating unused synergies for water availability. In a further step, potentials for additional greening were identified and ideas for design were mapped. The group started with a survey of the garden's vegetation. They focused on the area around the classroom hut and collected their observations: overall, the property has a very high degree of greenery and the soil is almost completely unsealed. The woody plants are predominantly native species and in good, well-maintained condition. The tree population causes a high degree of shading, especially in the area of the classroom hut. For documentation, the students made an inventory of the vegetation. The existing woody plants are shown in Figure 7. Due to the soil conditions (largely unsealed soil with 40 cm topsoil, gravel below) and the groundwater level (1.5 to 1.8 m), the (deeper-rooted) woody plants in particular are well supplied with water (as determined in interfacing with the blue group).

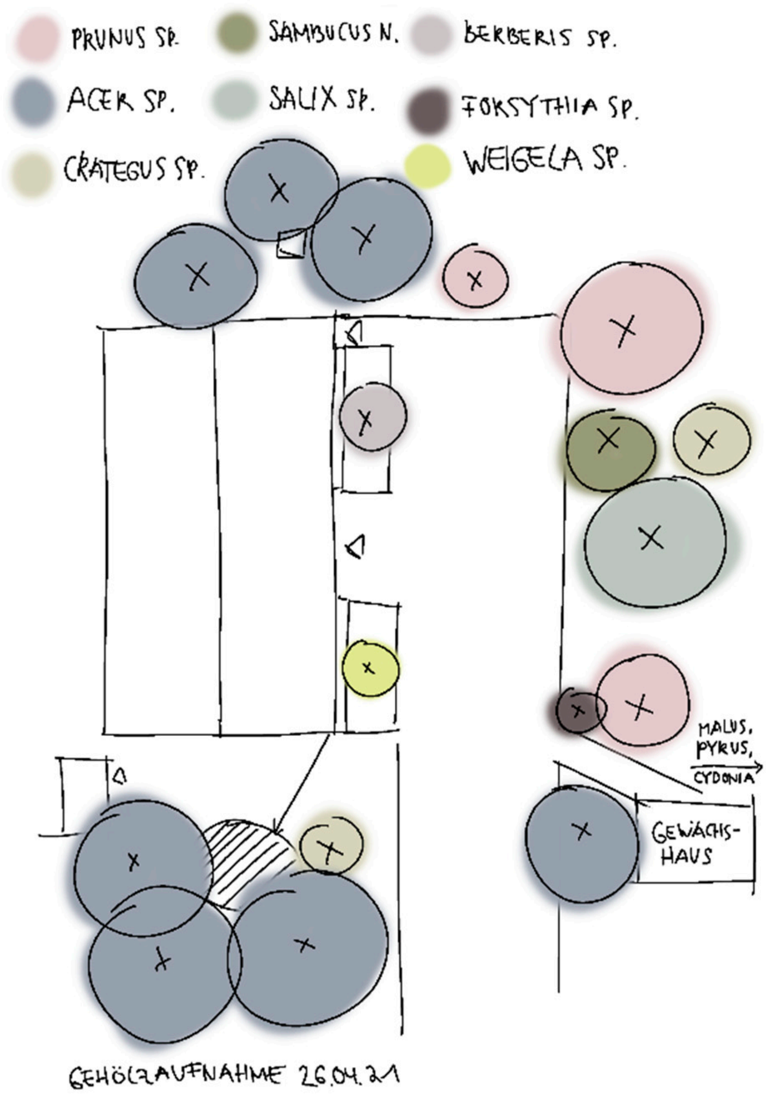


Figure 7. Students' documentation of tree population in proximity to the planning area. The sketch is not north-oriented.

The students of the green group collected their impressions and considerations on a digital white board and gathered all ideas for landscape design there (Figure 8). The whole garden is larger than shown in Figures 7 and 8. To the east of the classroom hut are the fields and greenhouses that are cultivated during lessons. The design of the garden is closely linked to its use. The green group set itself the goal of fitting future measures into the existing structure and of integrating selective enhancements. Potentials for additional greening are derived from the observations on site. In order to give the pupils even more experience of nature and to bring them into contact with different greening concepts, strengthening biodiversity and creating vertical greening were defined as specific objectives. These two aspects were to be incorporated into the planned BGA.

The group conducted extensive research on the topic of marsh plants for greywater treatment [38–43]. The planting of greywater filters mostly focuses on reed rhizomes. The ability of reeds to release oxygen into water and soil enhances the microbial decomposition of organic matter [43]. However, there are other plants that can be used which have a positive influence on the appearance and biodiversity through flowering species (Table 4).

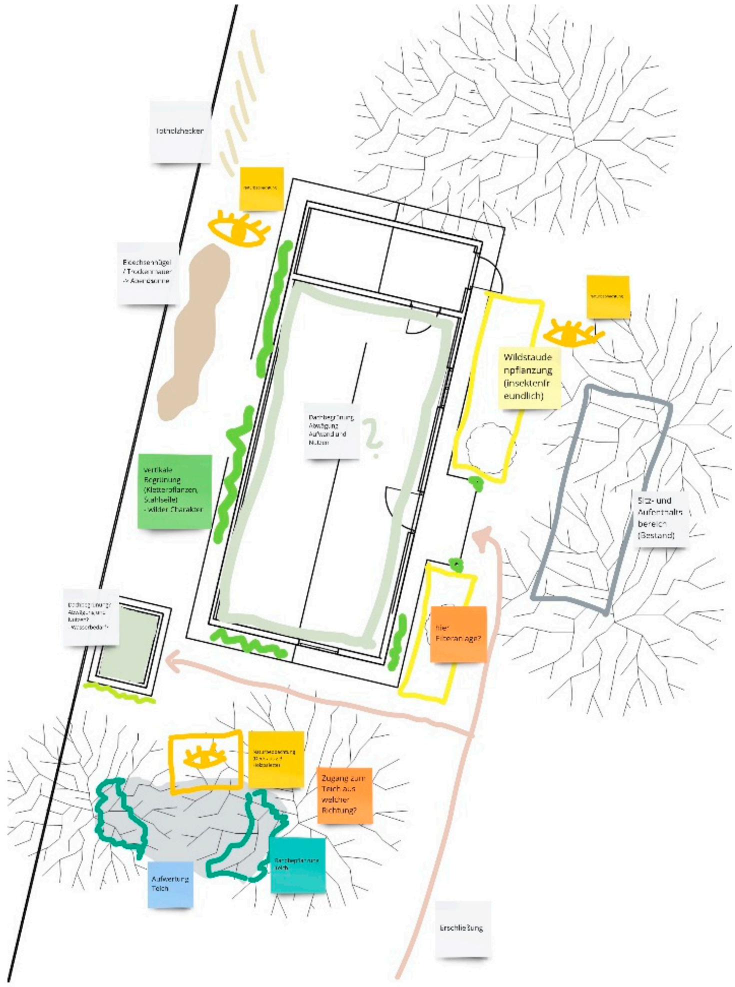


Figure 8. Snapshot of the students' white board while mapping the greening potentials and further ideas to improve quality of experience.

Table 4. List of potentially suitable native marsh plants for greywater treatment as compiled by the green group.

	Habitat	Growth Height	Filtration Effect	Hydrologic Balance	Specific Characteristics	Planting Distance
Schoenoplectus lacustris	humus- and nutrient-rich muddy soil; sunny to semi-shady	80–300 cm	available	average daily ET * = 6.9 mm; water depth from 10–80 cm	suitable neighbours include Iris pseudacorus or Phragmites australis	60 cm planting distance, 2 to 4 pieces per m^2
Phragmites australis	permanently moist to wet, fresh to marshy soil; sunny to semi-shady	150–400 cm	available	average daily ET * = 7.8–9.2 mm; water depth from 10–40cm	autumn colouring	35 cm planting distance, 8 to 10 pieces per m^2
Carex acutiformis	wet soils with high humus and nutrient content; sunny to semi-shady	50–120 cm	available; performance comparable to reed	high water requirement; ET * rate in medium range compared to other species; water depth 0–20 cm	reposition plants; highly adaptable to different types of wastewater	50 cm planting distance
Juncus effusus	nutrient-rich moist to wet soils, low in lime; sunny to semi-shady	70–80 cm	available	up to 10 cm water depth with no problems	evergreen tussocks with long stolons	

Table 4. *Cont.*

	Habitat	Growth Height	Filtration Effect	Hydrologic Balance	Specific Characteristics	Planting Distance
Lythrum salicaria	moist soil flooded by water; sunny to semi-shady	60–80 cm	available	waterside up to 30 cm water depth	insect feed; pink–purple flowers July to September	4 pieces per m^2
Mentha aquatica	moist to muddy soils; sunny to semi-shady	40–60 cm	high nitrogen consumption rate; antiseptic	waterside up to 30 cm water depth	insect feed; pink–purple blooms in June; typical minty smell	35 cm planting distance, 8 to 10 pieces per m^2

* ET = evapotranspiration.

3.1.3. Development of Spatial Question and Adjustment of Project Goals

In the sense of BGA, the framework conditions were analyzed in terms of water availability and water demand [10]. The blue and green group first defined their subject-specific objectives and then incorporated them into the overall planning. This approach ensured that all requirements, from both the blue and green sides, were addressed. Table 5 shows the objectives of the blue and green group.

Table 5. After recording the framework conditions, the groups defined subject-specific objectives. These refer to the conditions on site and the planning task set. The blue and green objectives formed the basis for the spatial question.

Blue Group	Green Group
treatment of greywater for discharge into the small pond	preservation of the 'overgrown' character of the site
year-round operational	selective design enhancement (waterfront planting for the pond, flowerbeds at the entrance, vertical greening)
electricity-free design (gravity driven water flow)	enriching biodiversity
no use of chemicals for water purification	establishing a stable and self-sustaining vegetation
prevention of freezing in winter	environmental education, experience/observation of nature

The greywater on the site requires treatment and is also a resource that has not yet been used. The water demand for the vegetation in the garden is basically covered, but there is still potential for improvement. The fields are irrigated with groundwater, which is in principle a resource worth protecting [44]. A simple infiltration of the greywater would have contributed to groundwater recharge, but it would have remained a 'blue' solution without synergy with the 'green' side. The pond, which functions as an ecosystem for tree frogs, also needs to be refilled with groundwater annually. Here, potential synergies with the generated greywater were identified: The greywater can be fed into the pond in treated form, thus ensuring that the water level remains constant throughout the year which allows for biodiversity enrichment (flora and fauna) as well as more chances for nature observation by the pupils. This resulting synergy of 'blue' and 'green' improvements became the common objective and thus also the central feature of the BGA design.

The integrating group took up these blue and green objectives and formulated additional requirements for the BGA design, which also have an impact on the spatial question. The system should be built in such a way that it results in a practical division of space in which the walkways are not disturbed. It should be a safe system. Children are protected from direct contact with untreated sewage. Likewise, sensitive parts of the system will be protected from the children. The entire system will be designed to be durable, cost-effective and easy to maintain. It needs to work all year round and therefore also be protected from frost. Maintenance must be easy. Therefore, inexpensive, easily purchasable and replaceable parts are used. Everything should be comprehensible and understandable for the children. In this way, the system serves environmental education. The important parts and connections are exposed and visible. This makes the 'path of the water' recognizable (using no underground pipes). Everything should be aesthetically designed so that it fits the informal and rural character of the place. The design will adapt to the place. No 'technical monstrosity' will be created. The objectives created huge interfaces between the groups. Therefore, the first draft was created in a collaborative effort of the whole planning team.

3.1.4. Design

Based on the objectives developed by the groups and the overall team, a first design proposal for the construction area was developed (Figure 9). At this point, many technical and design details were still unresolved. An initial site plan shows the intended interventions. The initial plans were to enlarge and redesign the existing pond and flatten the shore zone to create a vegetated swamp area that provides a spawning site for grass frogs. Strengthening the pond would create a habitat for frogs, newts, and dragonflies. It serves as a watering place for birds, bees and other insects. The pond is intended to be a quiet place that differs from the hustle and bustle around the hut. Therefore, the design concept of the pond planting creates zones and serves as a shield towards the hut. To the south, on the other hand, the greenery is placed in such a way that the children have access to the water. An observation place with seating (e.g., with an old tree stump) will be set up.

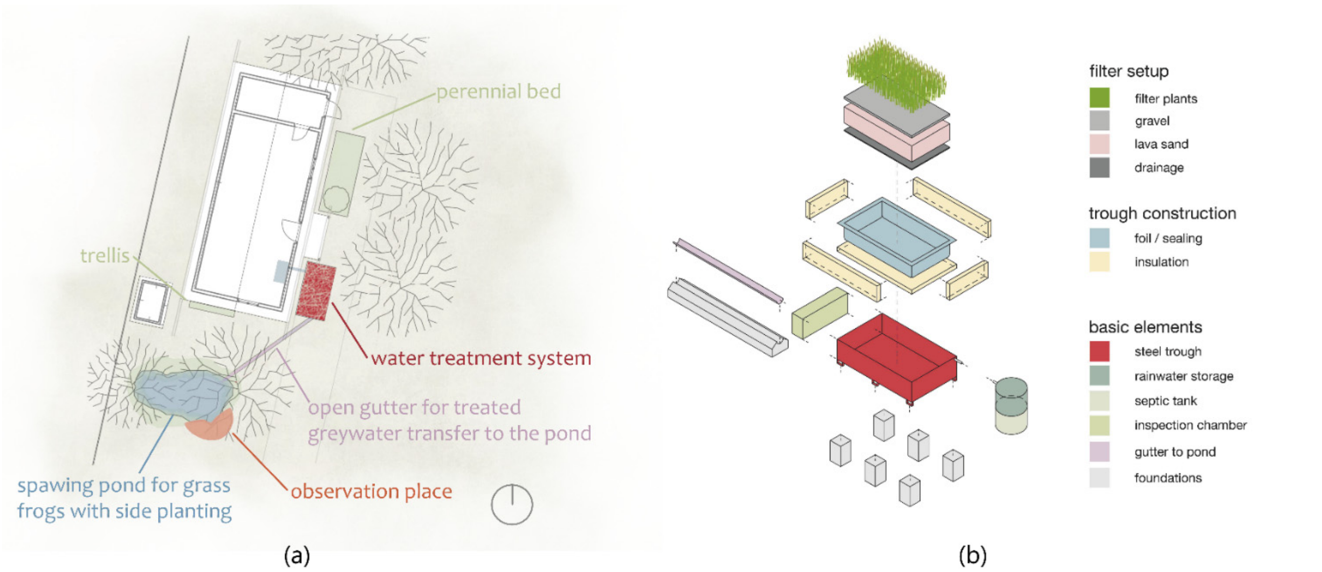


Figure 9. Preliminary design proposal of the students. (**a**) The single components were defined and brought into a spatial context. (**b**) The students' axonometry shows the design of the filtration bed. The structure is based on other small greywater treatment plants (examples for comparable structures: [37,41,45]).

The perennial bed to the right of the entrance of the hut will be replanted. Plants that are currently in the bed on the left and have to give way there because of the water treatment will be moved here. The small tree will also be preserved and given a new location in the garden. This measure also strengthens biodiversity. Flowering species such as great masterwort, lady's mantle, and wood strawberry are nectar sources for bees. A trellis for climbing plants at the hut should complete the design as a vertical element.

The central element of the greywater treatment system is a steel trough. Different variants were considered: the reuse of an old oil tank, plastic basins, and custom-built infrastructure. A steel tank measuring 210 × 130 × 55 cm (length/width/height) turned out to be the most cost-effective and, at the same time, aesthetically pleasing solution and the most suitable for the application. This trough would contain the constructed wetland. With regard to the structure, substrate, insulation, and loading, the knowledge about small, mobile constructed wetlands gained from the Impulse Project in Stuttgart provided a valuable planning guide [37]. Structures of other similar plants were also used for comparison [37,41,42].

The identification of the suitable trough and the construction of the greywater treatment was carried out in cooperation between the integrating and blue groups. Since the constructed wetland would have a considerable weight, point foundations were planned. Six centimters of insulation on the inside of the trough would prevent freezing in winter to keep the microorganisms alive during the cold season. Lava sand was chosen as a filter substrate. The green group's planting plan was to be followed by using flowering and filtering marsh plants.

For the blue group, it became a challenge to develop the system in such a way that the height between the sink drain and the upper edge of the pond water would be used as effectively as possible. In total, only about 70 cm of height was at disposal, of which the main part (about 45 cm) should be available for the filtration bed. The deeper the filter structure, the better the cleaning performance. Therefore, only about 25 cm of height difference remained for connecting pipes, pre-cleaning, filter loading, and water transfer to the pond.

The exact loading technique had not yet been determined. The plan was to create a septic tank for mechanical pre-cleaning and to flush the greywater onto the filtration bed at intervals in order to achieve distribution over the entire surface. A tilting mechanism was envisaged for this purpose. An inspection chamber was foreseen in the area of the filter outlet. All groups provided rough cost estimations for the building material in order to determine whether the entire system would remain within the set framework of € 4500.

At this stage, the concept was presented to the teacher (who acted as the client) to obtain approval for all suggestions and the planned interventions on site. The feedback was positive on all points and therefore the planning could go into the next round.

3.1.5. Revision, Adaption, and Final Design

In further planning, technical details were solved. The groups worked separately in many parts and discussed the problems at the interfaces in regular meetings. The blue group planned a timber framework that would support the septic tank and the rainwater storage. The septic tank consists of three chambers: a sieve filters the coarse solids out of the wastewater. The second and third chambers are arranged in such a way that mechanical grease separation occurs. The tilting mechanism for loading the filtration bed was not implemented as planned. Initial experiments showed that an even distribution of the greywater on the substrate became possible also without interval loading. A simplification of the construction was preferred here to make the system more robust also against playing children. The inspection shaft could be omitted as well. The backwater it would create in the constructed wetland would have no advantages for the design. The timber frame and the corresponding components were prefabricated in the workshop (Figure 10) and later brought to the construction site.

The filtration bed was slightly modified after consultation with specialist planners from the water industry. In order to maximize filtration depth, the insulation on the underside is placed between the trough and soil rather than inside the trough. It is wrapped with wire to keep rodents out. The side insulation remains in the trough. It is sealed with foil. The drainage layer consists of 15 cm of gravel. The lava sand is placed on top and no more gravel layer is placed above it.

An important point was to ensure year-round operation. Therefore, it was planned to remove the septic tank in winter. Otherwise, it could freeze and burst. Since the use of the garden is limited in the winter half-year and no cooking occurs during this time, the greywater is also less polluted. Therefore, there are no solids and the septic tank is not needed. It can be removed and the greywater can feed directly into the filtration bed. An occasional inflow of water from hand washing would also be very beneficial for the filtration bed in winter to prevent freezing through.

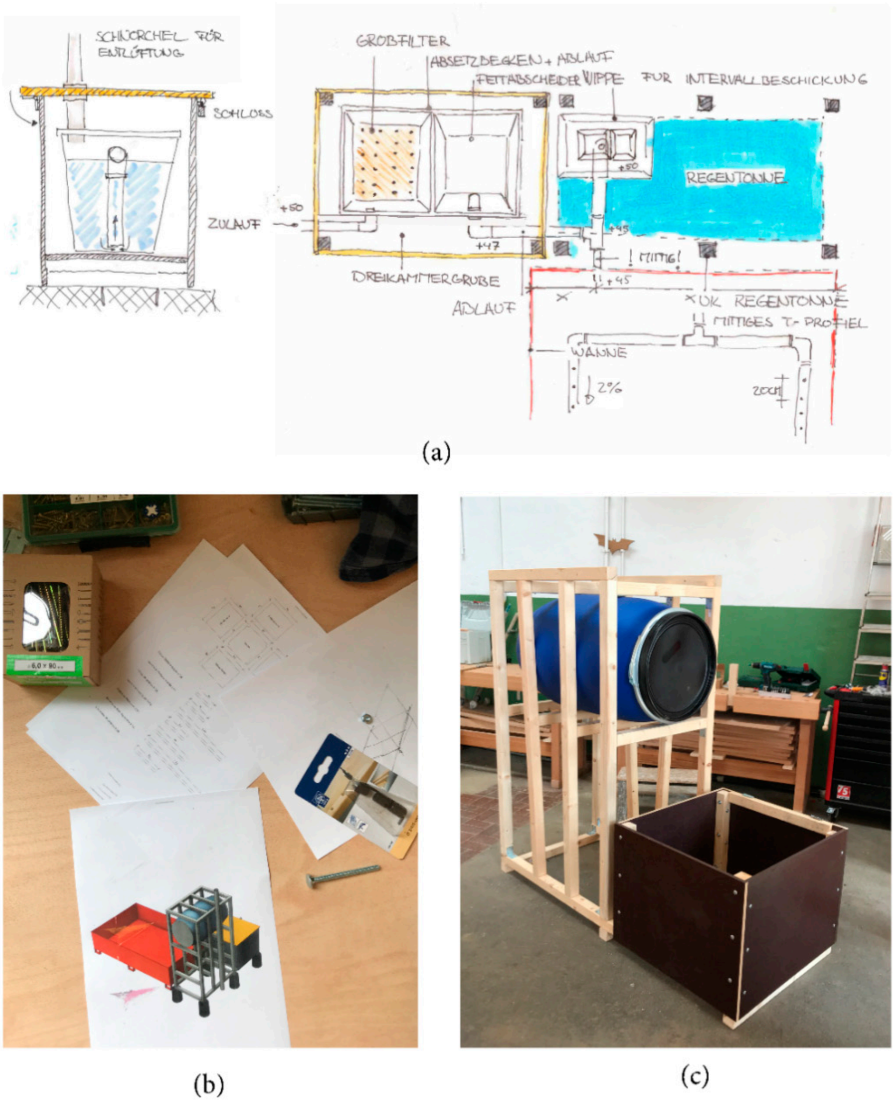


Figure 10. Documentation of the development of technical components for the BGA project. (**a**) Considerations for septic tank design and filter loading. These students' sketches do not show the final design, but an intermediate step in the planning. (**b**) Based on CAD drawings and 3D models, the assembly of the components was prepared. (**c**) The timber framework is pre-fabricated in the workshop.

The integrating group developed a consistent design concept for the greywater treatment plant. The components were differentiated by color: In addition to the blue rainwater tank and red steel trough, the septic tank was painted yellow. This made each functional element recognizable as belonging together and made it playfully understandable for the children. The planning of the gutter between the constructed wetland and the pond turned out to be difficult. Suitable stones for an open channel were not commercially available. Deeper channels had the disadvantage that they could become a tripping hazard. Therefore, covering the channel with a grid in order to make the walkway trip-free was considered. Finally, a suitable solution emerged: with appropriate molded shells, suitable (relatively flat) trough stones could be cast in concrete on one's own. This way, the water remained on the surface and the children could see how the gutter fills up with water after washing the dishes.

The green group developed planting concepts for the filtration bed, the pond, and the perennial bed. According to the previously compiled list and the required planting distances, they chose *Phragmites australis*, *Mentha aquatica*, and *Lythrum salicaria* for the constructed wetland. For the marsh zone of the pond, the species selected were *Caltha palustris*, *Primula rosea*, *Lythrum salicaria*, *Mentha aquatica*, and *Juncus effusus*. The plant selection for the perennial wildflower bed included *Astrantia major*, *Alchemilla mollis*, *Galium odoratum*, and *Fragaria vesca*. The green group revised their overall concept insofar as the climbing vegetation (*Clematis*) was no longer placed on the wall of the hut, but directly on the wooden construction around the rainwater barrel and septic tank. This created a synergy of technical construction and vertical greening.

The final design is shown in Figure 11.

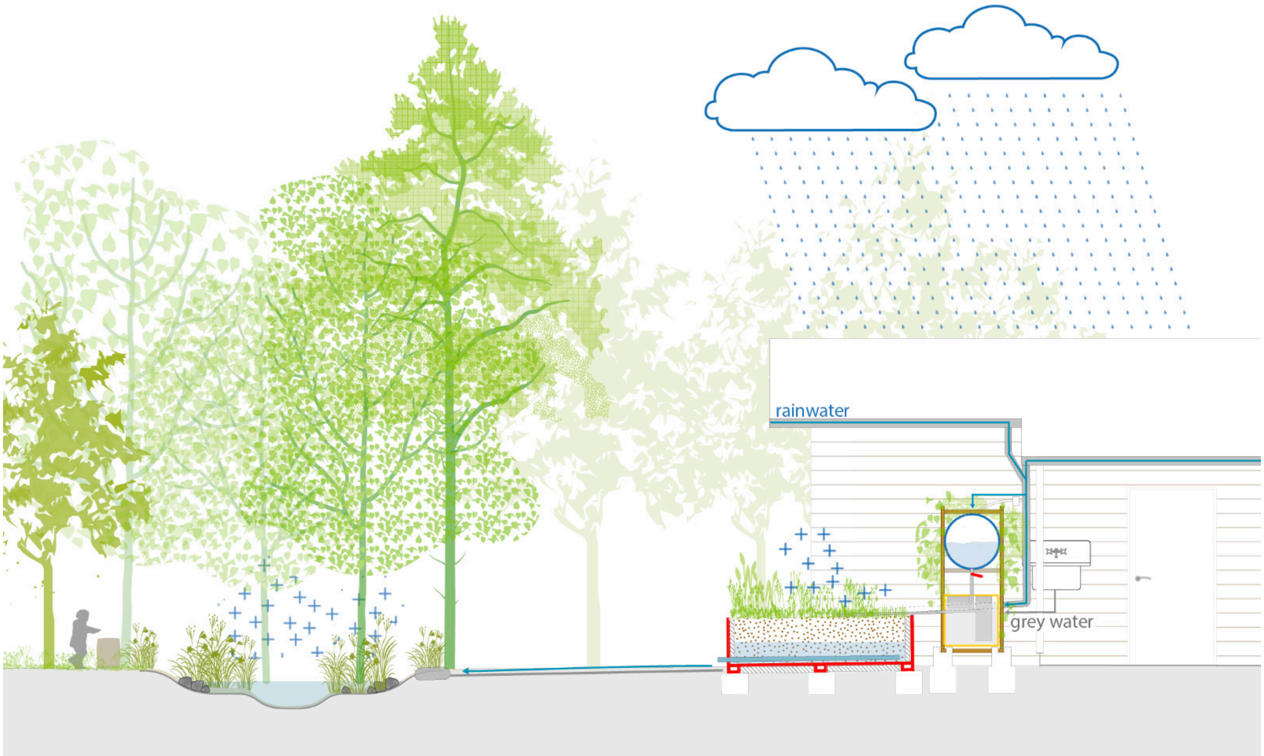


Figure 11. Final design of the blue-green greywater treatment system. The greywater from the kitchen sink (not shown in the picture) and the outdoor sink (on the right) is pre-cleaned in the septic tank (yellow). The roof runoff flows via the rainwater storage tank (blue) to the filtration bed and is fed directly in case of heavy rainfall. The timber frame that supports the septic tank and the rainwater storage tank is overgrown with climbers. The insulated filtration bed is filled with lava sand and grown with flowering marsh plants. The treated water is directed to the frog pond via an open gutter. The pond is planted in the shore area and has a nature observation place for the pupils.

With these changes and improvements in the design, the construction work on the site could begin. During the design process and the revisions and adjustments of the detailed planning, the costs were continuously tracked. Most of the structural elements were based on simple solutions using inexpensive components. High positions were especially the steel trough, the special substrate (lava sand), timber, and concrete.

3.2. Implementation

The students realized the design in practice on their own. The intention of this practical teaching concept was to create a holistic learning experience for the students. The approach aimed to enable the students, through the implementation of their own design, to identify planning errors and to achieve a higher learning success than through pure planning and design projects. Logging and reflecting on the construction process was therefore part of the course. The school children were involved in the preliminary work for the construction site. The excavation and enlargement of the pond was already prepared when the implementation started.

The implementation began with a further survey of the construction site. The heights and slopes played a special role to ensure a powerless flow of water. A total of 12 foundations were poured, six for the filter trough and six for the timber frame that will support the rainwater storage tank and septic tank. As part of the concrete work, the swale stones were also poured and dried (Figure 12).


(a) (b)

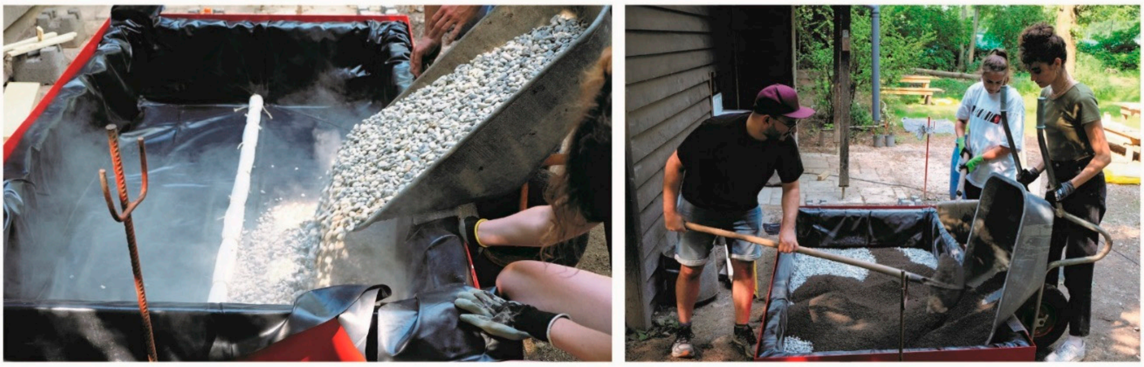
Figure 12. (**a**) The shore zone of the pond is planted with marsh plants. (**b**) The swale stones are poured and dried on site.

The students planted the perennial bed to the right of the entrance. The pond was completely redesigned. In the shore zone, a step was modeled all around, on which the marsh plants would later be placed. A layer of fleece was laid as protection and the pond liner was laid on top. The pond was half filled with water and then filled with substrate and stones for stabilization. The students arranged the plants according to the design concept and planted them in the edge zone of the pond (Figure 12). The large concrete stone was placed to embellish the pond inlet. The sump zone was further filled with substrate and stones, then the water level was raised to the final height. For the observation site, a wooden trunk with a diameter of 70 cm and other logs were positioned as seats.

The roof gutters were adjusted. Until now, they drained in the direction of the pond. Now they should drain towards the entrance to be available there as an additional water source for the filter.

The work continued with the work on the constructed wetland. For the outlet of the steel trough, the students had to drill a hole in one wall. At the outlet, a recess was made in the insulation and the foil was fixed with a special thread to seal it. The drainage pipe was covered with fleece, connected to the outlet and the slope necessary for the water flow was controlled. The filling began with a first layer of gravel (15 cm) and the lava sand on top (Figure 13), which was heavily compacted.

The three chambers of the septic tank were prepared. A sieve and grease separator provide pre-treatment of the greywater. The filter loading and the connection of the trough to the pond had not yet been finally solved. The students tested what worked and was practicable directly on the building site. From the outlet of the tub to the concrete block marking the inlet to the pond, a straight excavation was made for the swale stones. The heights had to be very precise because the gradient was small. The swale stones were placed on a leveled sand bed and initial feeding tests showed that the slope was sufficient.



(a) (b)

Figure 13. Construction work on the filter trough. (**a**) The drainage layer consists of 15 cm of gravel. (**b**) A layer of lava sand follows the gravel.

Towards the end of the construction work, the filtration bed was planted with the selected marsh plants. The swale stones were fixed and connected with concrete. The rainwater storage tank is conceived in such a way that it fills up completely during heavy rainfall. A valve then closes the storage tank and diverts the rainwater into an overflow that discharges into the constructed wetland. The filtration bed thus has several inlets: two narrow pipes distribute the greywater on the planting bed and a wide gutter in the middle is available for the overflowing rainwater.

Wires were stretched between the timber frame beams, which would serve as trellises. The clematis was planted directly as a climber. The final task was to connect the septic tank between the sink and the filtration bed. After everything worked properly, the plant was handed over to the school.

4. Results

4.1. Built Result and First Practical Experiences

The first of three research questions of this study was: can the design strategy for BGA be used to create a functional and aesthetic system that meets the users' requirements? As a key result, it can be concluded that the blue-green architecture that was designed and built as part of the course is a functioning system that meets the requirements of the client. The grey water produced in the kitchen of the classroom hut and by the outdoor washbasin is treated on site and fed into a natural system. The teacher of the school garden is also very satisfied with the design solution. The color differentiation of the system's components makes it easier for the pupils to understand how everything works and fits into the overall appearance of the garden (Figure 14). Consequently, the application of the design strategy to structure the planning and design process has proved to be a useful tool.

The blue-green system has been running trouble-free for about 10 months at the time of manuscript completion. The plants have grown well in the first year, but will only reach their full density and size in the coming years. The pond was swarmed by insects very quickly (Figure 15).

For winter operation, the septic tank was removed as planned and bypassed with a pipe. In this context, it must be ensured that no more solids are discharged into the system. Cleaning of the loading pipes was necessary once so far. The objectives for the built structure have thus been successfully achieved.

Figure 14. Built result of the BGA project 10 months after completion. The operation ran without any disruptions. In winter, the septic tank was bypassed. In the meantime, summer operation was resumed. The plants on the constructed wetland all survived the winter well and will grow even bigger in the next few years.

Figure 15. The pond has become a biodiverse habitat.

4.2. Students' Learning

The second research question of the study was the following: do the students experience a learning success through the research-based and practical teaching method? The course intended to teach the students integrated blue-green planning processes in interdisciplinary teams and to enable them to achieve a high level of learning success through a concrete application and 1:1 implementation. The students' construction site protocols and experience reports contained reflections on their own actions and the procedures in the planning and implementation process. The statements show that a great learning effect has been created by the chosen teaching method. Two exemplary statements from the reports (translated from German into English) are:

- “My hope that this seminar would give me the opportunity to apply my interests in planning and designing blue-green systems in an urban context and also to gain practical experience was completely fulfilled, and it was a great experience to realize, build and see a project that I had worked out myself.”
- “I found it very fascinating to realize such a project as a team and to see that we all have a practical skill to implement what we are planning and that we are not pure theoreticians.”

In summary, there were differences in how much students felt part of their planning group (blue/green/integration) or part of the larger team. This identification had an effect on communicative aspects. Such manners could also occur in real construction practice and influence the motivation for cooperation. Basically, it is important that all disciplines act independently and represent their (professional) interests. However, the sense of the overall project should not move too much in the background, because the key to good cooperation is compromise and not drawing boundaries.

The students repeatedly gave the feedback that they prefer practice-oriented courses in their studies because it is important to them to be well prepared for their future professional life. The close interlinking of research, teaching, and practice has a particularly positive effect on the education of architects and landscape architects and should be intensified in the future. The fields of activity of architects and landscape architects are currently separate from each other, and architecture usually dominates the design processes [46]. It is important to counteract this development and strive for more equal cooperation. Anchoring interdisciplinary projects in the curriculum is a first step in this direction.

4.3. Evaluation of the Integrated Design Strategy for Blue-Green Architecture and Lessons Learned

The third underlying research question related to the evaluation of the design strategy for BGA: what conclusions can be drawn from the design and planning process to improve the design strategy for BGA? The integrated blue-green planning and implementation process of the described project provided insights into the applicability and practicability of the design strategy for BGA. It was an important goal of this study to reflect these lessons learned back into the design strategy so that it can be revised and improved.

All in all, the design strategy for BGA was a valuable and helpful basis for structuring the planning and design process. In particular, the division of the students into groups and the representation of disciplines and responsibilities was a central support for the entire approach. The specific ‘blue’ and ‘green’ aspects were integrated into the project process from the very beginning and were thus decisive for the design and function of the BGA. The students’ understanding of interdisciplinary collaboration was enhanced. Since there is potential for improvement in terms of interdisciplinarity not only at universities but also in building practice, this insight can equally be transferred to planning teams of larger projects.

The topics of water and vegetation are comparatively new and unfamiliar to architects. Therefore, they are very challenged in blue-green projects with the understanding of the framework conditions and planning parameters. Pre-structuring the planning process in the form of a design strategy is therefore an important support.

During the application, some situations occurred where the process was different from the one foreseen in the design strategy. In addition, there were points of importance in the planning that were not represented in the design strategy. These aspects are described below and serve as indicators for improving the approach.

Figure 16 shows the design strategy for BGA with suggestions for intervention points highlighted in green. This outlines the lessons learned without including a complete revision of the design strategy. In the case of a new version of the design strategy, the existing terms should also be examined and adapted if necessary. In the sense of blue-green architecture, ‘water sources’ and ‘greening potential’ should be defined more broadly in order to reflect the entire spectrum of initial situations and project concerns.

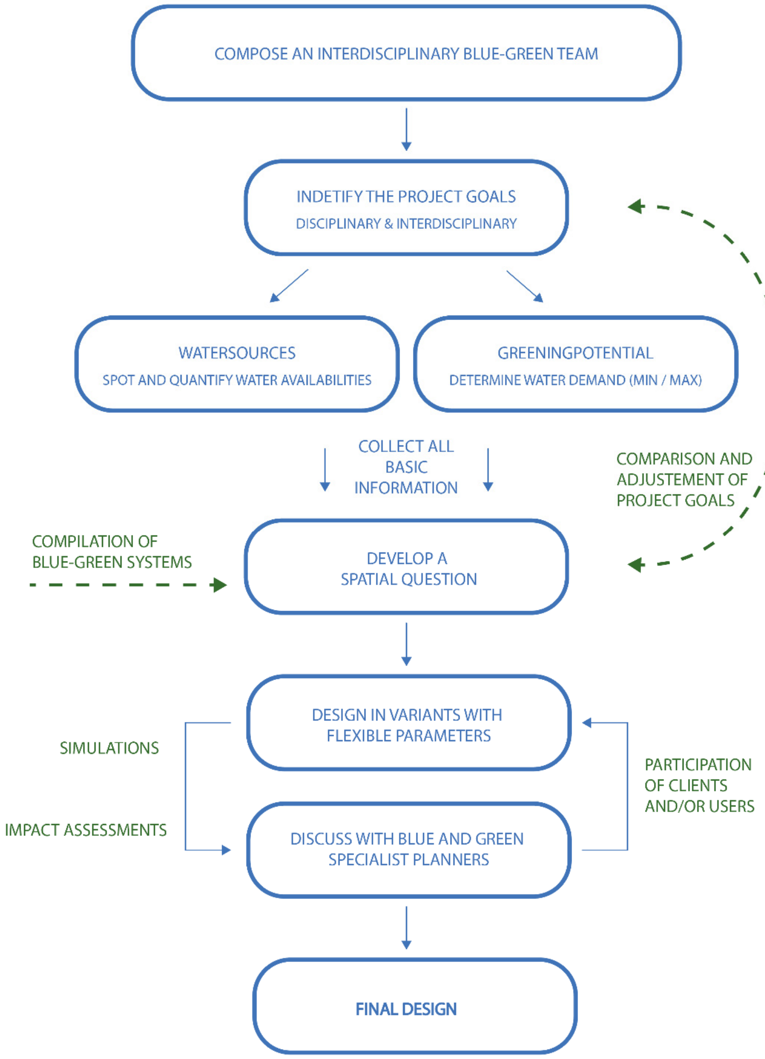


Figure 16. The design strategy for blue-green architecture was evaluated through its application in the presented project. In the course of planning and design, weaknesses emerged that should be considered in a revision. The lessons learned and considerations for possible points of intervention are shown in green.

One of the points that became apparent in the application of the design strategy is the procedure of setting project goals. Here, experience has shown that after the initial definition of project goals a further adjustment is needed once the framework conditions have been recorded. Here, it could be considered whether the definition of the spatial issue could rather consist of a design brief for the project. It could be reconciled with the objectives and these could be specified taking into account the blue-green framework (Figure 16).

When developing the spatial question, it is also helpful to be able to build on compilations of blue-green systems. In the study project, this knowledge was provided by a lecture on blue-green systems. In practice, there are very good overviews that can be of help to planners [13,44,47–49]. As already mentioned, a design brief could be made at this point, which would contain relevant parameters and specific goals for the BGA project.

In the project described above, the development of design variants did not take place as intended in the design strategy for BGA. This was mainly due to the fact that the planning time was very short and there was not enough time to do several loops. Instead, a continuous improvement of the design took place. This point will not be modified in the design strategy for BGA, but some aspects will be added that should be applied within this iteration (Figure 16). The collection of water quantities and the calculation of required storage for larger projects should be completed with the help of simulations [49,50] (pp. 56–61). In the project presented in this study, only monthly values were considered. A more comprehensive analysis of water quantities was not feasible within the scope of the course. A simulation with daily values over several years would provide information about dry periods, storage management, and occasional heavy rainfall events. Impact assessments can also take place here (cf. [51]). There are more and more digital tools on the market that support the comparison of the environmental effects of planning projects [52,53]. Another point suggested here goes back to a very positive experience from the project. The cooperation with the teacher and the pupils has proved to be very successful. The discussion with the client helped to solve challenging design issues in a constructive way. The involvement of the pupils in the implementation created a high level of acceptance and comprehension for the project. Therefore, it is suggested to make client/user participation an integral part of the iterative design process (Figure 16). A discussion of the design variants should not only take place internally in the planning team, but should also be directed outwards at certain points [54]. In this way, valuable inputs can be taken up and users' acceptance can be improved.

A key issue for the success of the project is the cooperation in the interdisciplinary team. There is a certain contradiction in the fact that the representatives of the blue and green aspects argue from their discipline-specific point of view and at the same time an integrated solution is supposed to emerge. There are points in the planning process where disciplines work separately, and other points where the planning team acts as a joint unit. Sensitive coordination is required here to ensure the appropriate weighting of perspectives. This requirement cannot be represented in the graphic. It is based on awareness and experience.

5. Discussion and Conclusions

The design, planning, and implementation of blue-green architecture presented here took place as part of a university course. This results in points for discussion with regard to the two research questions that focus on the built result and the evaluation of the design strategy for BGA. First of all, it becomes clear that this is not a planning project in the classical sense. The students represent their disciplines vicariously, similar to a role play. In practice, the cooperation of several project partners is different. For the approach based on the design strategy for BGA, the planning task and the processing by the students was nevertheless effective. The difference lies more or less in an experiment under laboratory conditions compared to a field study.

With regard to the remaining research question, which focused on the teaching, it can be stated that—in the future—it would be useful to involve students from environmental engineering and thus include water engineers in the planning team. This would possibly also have a positive effect on the learning success of the students, because they would have even more interdisciplinary exchange.

Concerning the built object, an absolute statement about functionality, resilience, user satisfaction, and aesthetics can only be made after several years. The fact that the system has been running trouble-free so far is a positive indicator. It remains to be seen whether the system will also prove itself in the future. Likewise, it would be advisable to take water samples in the pond and evaluate them in comparison to the other water bodies on the property and in the immediate vicinity.

The design strategy for BGA has proven to be target-oriented and effective in its application. Structuring and guiding blue-green planning processes is an effective way to support interdisciplinary project teams. Suggestions for improvements to the design strategy were presented in Section 4.3. There, it was also recommended to integrate digital tools into the planning process in order to obtain more precise values for dimensioning water storage tanks and water treatment plants. For the assessment of the impact of particular measures, digital tools are also a useful addition.

In the application of the design strategy, another point became apparent: the systematic combination of 'blue' and 'green' aspects does not fully cover the spectrum required for BGA. In the presented project, for example, solutions emerged that cannot be classified as blue-green. This includes the timber frame's trellis and the planting of the perennial bed. Both measures contribute to the overall concept, but are not coupled with the 'blue' side, the available water for irrigation. The system boundary of the BGA project must therefore be carefully weighed up and individually exceeded if it is conducive to the respective project.

A further application of the design strategy for BGA should now ideally take place in a larger-scale project. Such a continuation would not only support the implementation of blue-green projects, but also contribute to the further development of the design strategy against the background of different scales, contexts, and planning tasks. It can be assumed that in a practical real-life project, a field of tension will arise from additional requirements for sustainable architecture. Blue-green planning is only one aspect among many. It was the focus here because it has been underrepresented so far—especially in architectural projects. However, integrated planning also includes other sustainability aspects such as energy, mobility, and materiality. With regard to blue-green infrastructure, it is important to create larger networks that go beyond the individual property and span neighborhoods and cities. This increases the effectiveness of blue-green solutions because water needs and water availability can be coordinated on a larger scale. Networks are also more effective than individual projects in terms of biodiversity and socio-cultural impact.

Finally, even though it is a very small-scale project, this study has shown how BGA can be designed and implemented in practice. The future of livable cities depends on the adaptation of planning and building for climate change. Therefore, the knowledge gained here should be further developed and taken into account in future research, teaching, and practical projects.

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