Facade greening:
an example of knowledge transfer
from research to school
to promote
Sustainability Education



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Table of content

Abstract 3
1 Introduction 4
2 Results 8
2.1 First publication - A Literature Review on Facade Greening: How Research Findings May Be Used to Promote Sustainability and Climate Literacy in School 8
2.2 Second publication – Facade greening - from science to school 38
2.3 Third publication – Sustainability Education Through Green Facades: Effect of a Short-Term Intervention on Environmental Knowledge, Attitude, and Practices. 50
3 Discussion 77
3.1 Effects of the didactic intervention 77
3.2 Extension of the didactic intervention 80
3.3 Further strategies for achieving pro-environmental changes in the KAP triad 84
4 Conclusions 89
5 References 90
6 Appendixes 93
6.1 Appendix 1 - Materials of the project days 93
6.2 Appendix 2 - Questionnaires 99

Abstract

Green facades, i.e. any way of setting plants on the vertical facade of a building, are Nature-Based Solutions to improve urban sustainability. Research highlights several multi-functional benefits: lowering internal building temperatures thus reducing summer cooling costs, sequestering CO_2 through photosynthesis, absorbing air pollutants, preserving biodiversity, and improving human health and well-being.

At the same time, sustainability has been promoted over the last 30 years by UNESCO through education for sustainable development and the Sustainable Development Goals (SDGs). More specifically SDG n. 4 aims at equipping learners with knowledge and competencies necessary to understand environmental issues and actively promote solutions. One way to achieve the above is through a transfer of scientific knowledge from research to school. However, to be successful, this approach should refer to research findings that are suitable for school students as well as for integration in school curricula, i.e. they should fulfill certain criteria.

The present dissertation investigates how to transfer scientific findings on sustainability from research to school, thereby using green facades as an exemplary topic and referring to evaluation criteria for lesson planning derived from W. Klafki. A subject-specific literature review, which was conducted first, proved to be an effective strategy for developing a comprehensive, multi-phase teaching concept. Part of this concept was implemented through a didactic intervention. The effect of this intervention on the KAP (knowledge, attitude practice) triad was then evaluated.

The results show that even a short intervention (being mainly based on experiments) may lead to longer term (4 weeks) changes in pro-environmental knowledge. Changes in pro-environmental attitude were only evident in the short term, but not in longer term. In addition, pro-environmental knowledge and attitude seemed to be predictive of different types of actions (cognitive or “care-oriented”). Therefore, both aspects (knowledge and attitude) should be addressed in teaching. For future interventions, practical activities should go beyond pure knowledge gain (e.g. by conducting experiments) and include actions that benefit society and the environment (like service projects) to support a holistic development of learners.

1 Introduction

Facade greening means any way of setting plants on the vertical facade of a building (Wong et al., 2010). This practice has been proven to be more than just greening buildings' walls. Green facades are in fact **Nature-Based Solutions (NBS)** in cities, i.e. "... actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g., climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016). NBS are helpful to make urban areas more sustainable.

Green facades are NBS capable of effectively reducing the internal temperature in buildings (Pérez et al., 2014) (Pérez et al., 2018) and consequently providing comfort for residents and saving energy particularly in the cooling period (summer). They also have a beneficial effect on climate and environment, since they contribute to sequestering CO_2 from the atmosphere through photosynthesis (Marchi et al., 2015), improving air quality by absorbing air pollutants (Perini & Roccotiello, 2018), and preserving biodiversity (Chiquet, 2014; Madre et al., 2015; Mayrand et al., 2018). In addition, by compensating the lack of greenery in cities, they improve psychological human well-being (Elsadek et al., 2019).

Scientific findings (Pacini et al., 2022) (Aduse-Poku et al., 2024) highlight green facades effectiveness in providing multifunctional ecosystem services, and their positive impact on sustainability.

Sustainability has been promoted over the last 30 years by the United Nations (UN), particularly, by establishing in 2015 the 17 **Sustainable Development Goals (SDGs)** (UN, 2015). The United Nations Educational, Scientific and Cultural Organization (UNESCO) led and coordinated the Education 2030 Agenda through a guidance document, "**Education for Sustainable Development (ESD)** — Learning Objectives" (UNESCO, 2017). It serves as a resource bank for educators and teachers to promote sustainability among young people, who are key in reaching the SDGs as the main actors for change. ESD has become an integral part of the SDGs, as no. 4, Quality Education, explicitly highlights. Notably, ESD leads to achieving all SDGs "… by equipping them [learners] with the knowledge and competencies they need, not only

to understand what the SDGs are about, but to engage as informed citizens in bringing about the necessary transformation" (UNESCO, 2017, p. 8).

ESD should, therefore, have a special status at school. There are several options to do so, for example to use new knowledge and methodologies resulting **from research** and **transfer** them **to school**.

More specifically, knowledge transfer from scientific research to school is intended with the aim of:

1. Teaching students about novelties in research referring to topics already covered in established school curricula, such as the topic of environmental issues.
2. Addressing topics not yet included in school curricula, such as specific strategies to solve environmental issues.

For such transfer processes, new research findings must be processed in such a way to be suitable for students' age, their performance level, their culture and residential area, as well as the learning objectives pursued. In addition, topics should be inserted into a specific context, which must be previously determined, so that there is a good fit between topics and context. The assessment of these aspects allows the definition of didactic strategies and methodologies, timelines, and reference sources.

The best way to introduce a new topic in school would be to add it to the school curriculum. However, the school curriculum is rarely adaptable to addressing completely new topics in the short term, because the process to update such curriculum is complex and requires approval by the relevant educational institutions.

An easier way to introduce new topics in school is by linking them to well-established topics (Aduse-Poku et al., 2024, p. 700), to go deeply into an already existing content (for example, the loss of biodiversity may be addressed while explaining ecosystems and their features, sequestration of CO_2 while dealing with photosynthesis, or the cooling effect of green facades while referring to transpiration through stomata).

A direct knowledge transfer from research to school may also be put into practice by inviting students to lectures or practical courses dedicated to them at a university, or another public or independent research center, without modifying the school classes,

syllabus, and curriculum, i.e. through additional educational activities in extracurricular contexts (Pacini et al., 2025, p. 2) (Rushton & Batchelder, 2020).

Overall, the following **criteria** could make a topic worthwhile for school students and easier to integrate into teaching. These criteria, with the first three of them referring to W. Klafki (Klafki, 1995; Meinert & Rakhkochkine, 2018), were proposed in the first publication of the present research (Pacini et al., 2022):

1. Exemplarity [exemplarische Bedeutung]
2. Students' current life meaning [Gegenwartsbedeutung]
3. Students' future life meaning [Zukunftsbedeutung]
4. Link to school curricula
5. Feasibility
6. Inclusivity (however, it is not discussed further in this dissertation)

Considering these criteria, green facades may be selected as a suitable topic to transfer knowledge from research to school regarding sustainability, because green facades are exemplary for a NBS (criterium 1), they may be found in pupils' living environment, even if students may not be aware of them yet (criterium 2), and they can make a significant contribution to achieving certain SDGs (Pacini et al., 2022) (Aduse-Poku et al., 2024) which lay the foundation for the future of our society (criterium 3):

- Goal no. 3: good health and well-being
- Goal no. 11: sustainable cities and communities
- Goal no. 13: climate action
- Goal no. 15: life on land

In addition, green facades offer several links to the curriculum (e.g., photosynthesis, transpiration, biodiversity) when referring to their pro-environmental impacts (criterium 4). These pro-environmental effects of green facades can be easily demonstrated by small experiments and observation tasks (criterium 5). Accordingly, the topic allows practical work in groups and thus enables students of different ability levels to participate as they can assist each other (criterium 6).

Since, as just demonstrated, green facades seem to be a suitable topic for sustainability education, this gives rise to the main questions of the current study: (i)

How should the topic be addressed in class? (ii) What impact does this topic have on students in terms of their knowledge, attitudes, and practices? To answer these questions, the following steps were taken, each of which is reflected in a publication.

- A literature review of scientific findings on green facades was conducted, and a comprehensive teaching concept was derived from this (**1st publication**).
- A central element of this teaching concept, which is the "natural-scientific research approach", is further specified so that it can be implemented in the classroom (**2nd publication**).
- The effect of the "natural-scientific research approach" on students' knowledge, attitudes, and practices related to green facades is analyzed based on an intervention study (**3rd publication**).

The three aforementioned publications are included in the following chapter on results. Key findings are also highlighted in the text.

The "**discussion**" chapter relates the findings of the three publications to one another. It discusses (i) why the intervention had only minor effects, (ii) whether extending the intervention (from the purely natural-scientific approach of the investigative phase to the implementation of the entire teaching concept) may eventually lead to different results with regard to the KAP triad, (iii) which other teaching approaches might be conceivably more effective in achieving pro-environmental changes in the KAP triad.

The "Conclusion" chapter finally summarizes whether the chosen strategy of transferring knowledge from scientific research to schools is an effective way of promoting greater sustainability among students.

2 Results

2.1 First publication - A Literature Review on Facade Greening: How Research Findings May Be Used to Promote Sustainability and Climate Literacy in School

For the first publication, a literature review on facade greening had been performed to analyze the status of scientific knowledge on this topic. In addition, the educational relevance of the scientific findings was analyzed and implications for teaching were deduced. In summary, green facades can be seen as a suitable example for sustainability education because this topic raises students' awareness of environmental problems and at the same time allows them to experience it as a solution to these problems. Based on this literature review, a **teaching concept** on green facades was proposed (FIG. 1). It turned out that the structure of the scientific review proves also to be appropriate for the teaching concept (Pacini et al., 2022, p. 17). Moreover, the teaching concept is designed in such a general way that it can also be applied to other topics. It consists of three phases:

- a **descriptive phase**, consisting of an inventory of the object of interest
- an **investigative phase**, which may have a natural-scientific or social-scientific focus, or ideally both. If both focuses had been considered, then students would have been able to analyze the extent to which the results from these different research approaches (the natural- and social-scientific one) support or even contradict each other (because what appears reasonable from a scientific point of view is not necessarily supported by the general public).
- a **communicative phase**, to bring the results of the investigative phase to the public's attention (i.e. public outreach)

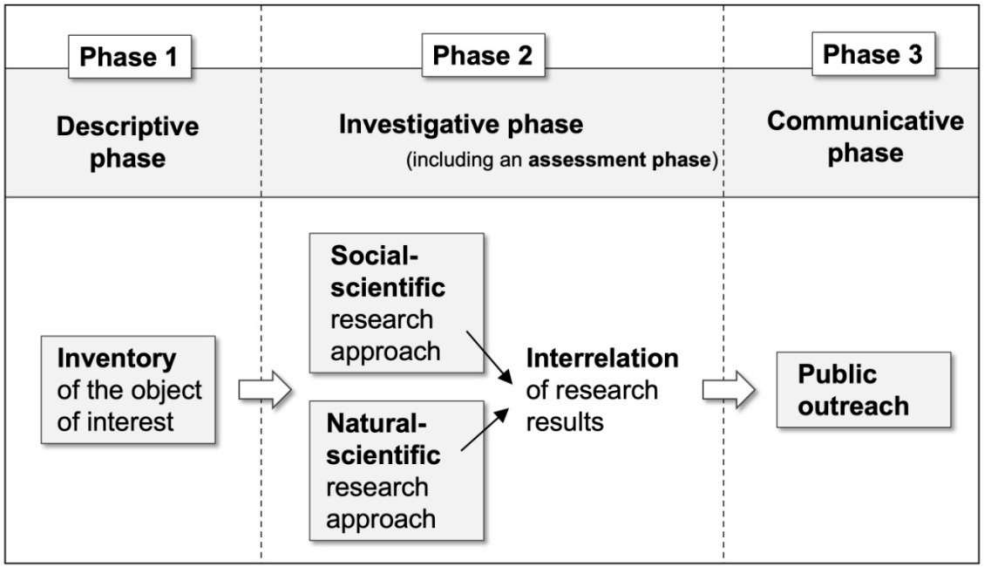


FIG 1: Possible phases of a teaching concept on green facades.

In the following, the **teaching concept** is **applied to** the topic of **green facades** to describe it in more detail.

- The **descriptive phase** should be based on real green facades in the city where the teaching takes place (here: Cologne). The primary goal is to consciously perceive green facades in one's environment. The secondary goal is to identify differences between them. For this purpose, students may independently discover green facades in the neighborhood and take pictures of them. Alternatively, teachers may provide images of green facades, whereby the motivating aspect is less significant than if the students were to do it themselves. Based on these images (or by using small replica facade models), the following activities can then be done:
  - Determining the type of green facades based on tables and reference schemes (Pacini et al., 2022, p. 3). There are four types of green facades that can be distinguished: (i) soil-based plants which grow directly on the wall or (ii) on a support, or (iii) plants which are set in panels fixed to a wall, or (iv) plants which constitute a curtain around a building.
  - Classifying the different plant species by looking at leaves and plant shapes (in North Rhine-Westphalia, frequently employed plants are: *Hedera helix* = Ivy, *Parthenocissus quinquefolia* = Virginia Creeper, *Parthenocissus tricuspidata* = Boston Ivy).

- Marking the green facades discovered on a map of the city. This green facades city map could also include photos previously shot autonomously by students as well as information about the type of facade and the respective plant species.

- The **investigative phase**, including an assessment phase, is based on inquiry-based learning. Ideally, two approaches are taken into account whose findings may subsequently be related to one another:
  - a natural-scientific research approach
  - a social-scientific research approach

  The natural-scientific approach, being based on hands-on activities, requires students to perform experiments on green facades to autonomously understand how they work and to grasp the advantages they bring to the climate, nature, and humans. The social-scientific approach allows students to plan a survey or interviews about the pros and cons of green facades with residents in the area where they live (social-scientific approach). In this way, they find out whether the public is aware of the advantages of green facades, which they had previously discovered using the natural-scientific approach.

- In the **communicative phase** the results of the investigative phase may be shown to the broader public. This can be either other students in the school, or parents or residents in the local area. Contributions in a school journal or (oral) presentations at an open day in the school would be possible means. In this way, students are doing public outreach and see themselves as ambassadors for green facades to enhance sustainability in cities.

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Review

A Literature Review on Facade Greening: How Research Findings May Be Used to Promote Sustainability and Climate Literacy in School

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Abstract: The promotion of Climate Literacy is a central concern of our time. To achieve this ability, one can draw on different content areas. One possible area is Nature-Based Solutions (NBS), such as Vertical Greening Systems (VGS), and their effectiveness in mitigating climate change. However, VGS is not yet an established topic in environmental education, even if the pro-environmental effectiveness of VGS has been proven from a scientific point of view and this topic is close to everyday life. To facilitate the transfer of knowledge from research to school, this paper presents an example of a possible procedure. This procedure starts with a narrative review of the scientific literature on VGS. Then, the main results of this review are related to the Sustainable Development Goals, Climate Literacy, and general educational goals to capture its educational relevance. Finally, a flow chart for a teaching sequence is developed, with the phase sequence derived from the performed narrative review. Thus, a parallelism between the structure of a scientific review and an action-oriented environmental education becomes visible. To what extent this parallelization may be generalized, and whether teaching based on it is effective, will have to be tested.

Keywords: green facades; vertical greenery system; climate literacy; climate change; education for sustainability; knowledge transfer; nature-based learning; review

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1. Introduction

Today's young generation increasingly claims the right to choose their future and expresses concerns about environmental deterioration. Among the environmental problems that will have to be addressed, one of the most urgent is climate change. Large cities have a substantial ecological footprint for CO_2 emissions and energy use, and rapid increase in urbanization and energy consumption has profound environmental consequences [1]. Science teachers should accompany young people on this difficult path to a more environmentally conscious and sustainable life, which requires transferring scientific knowledge from research to school. Promoting Science Literacy and Climate Literacy is, in fact, crucial to this extent, but this is not enough. Practical experience of nature is also necessary to develop pro-environment attitudes and behaviors [2]. Facade greening is a topic that allows students to experience nature and, at the same time, learn about climate change and basic climate protection measures. However, facade greening is not yet considered a topic in school curricula. To make this topic better known and show the breadth of possible focal points, we prepared a narrative review of the findings on facade greening.

The goal of this narrative review is partially different from the goals of conventional reviews. On the one hand, the purpose here (as in conventional reviews) is to summarize the findings and emphasize focal points of research. On the other hand, the focus of this review is less on identifying research gaps and more on inferring the educational relevance of the scientific findings. Therefore, at the end of each content section of the review, there

is a small paragraph which discusses implications for teaching. In a next step, the main research findings on effects of VGS (based on the review) are mapped against significant educational objectives, namely the UN Sustainable Development Goals (SDG) and the principles of Climate Literacy. In addition, the extent to which the topic of VGS meets general pedagogical requirements is assessed. Finally, a proposal for an action-oriented teaching unit is developed, inspired by the review in terms of content and structure. Thus, we provide an example of a scientific review to become a template for the instructional design of the corresponding topic in school. An instructional flow chart is then developed (Section 3.3), which in its first two phases reflects those perspectives by which the review was structured: a design, social, and natural scientific perspective. Due to the general structure of the flow chart, it can be used for other science topics to be taught in classroom, especially those that are application-based and socially controversial. In summary, this article provides an example of a strategy for transferring knowledge from research to school.

As a lead-in to the narrative review, we will start with some definitions of central terms, which will guide us to the main topic, the greening of facades.

A possible solution to climate change and other environmental problems could be provided by nature itself. The International Union for Conservation of Nature (IUCN) defines Nature-Based Solutions (NBS) as: " . . . actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g., climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits" [3] (p. XII). The European Commission defines NBS in somewhat more detail still as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience; such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions." It is emphasized that "NBS must benefit biodiversity and support the delivery of a range of ecosystem services." [4] (p. 5). NBS may be a tool to achieve climate change mitigation and adaptation and sustainable management of urban areas, where more than half of the global population lives. [5].

Urban Green Infrastructures (UGI) can be defined as the interlinking of two elements: green spaces (and their associated ecosystem services) and urban planning [5]. Green spaces such as urban parks, green roofs, green facades, and green walls are all examples of UGI in the general framework of the NBS. Their manifold benefits consist of the mitigation of and adaptation to climate change effects, as well as the improvement of the physical and psychological well-being of the entire community [6]. These green spaces also constitute oases for other living beings that are advantageous in preserving biodiversity [7]. This literature review will focus on a particular type of NBS: Vertical Greenery Systems (VGS), such as green facades and living walls.

2. Findings of Scientific Research on Façade Greening

Most of the studies on VGS have been conducted by engineers and architects. They are primarily focused on the engineering aspects of construction techniques, energy saving, cooling of building interiors, etc. However, while addressing their interests in their own technical fields, the researchers have also defined general concepts and models that allow a more comprehensive understanding of the VGS topic. In particular, findings of general interest are related to the classification/characteristics of the various types of VGS, and the plant species most suitable for use in VGS. Other relevant findings are on the public acceptance of VGS and the effects of VGS on buildings, climate and environment, and health and well-being.

2.1. Different Types of Vertical Greenery Systems (VGS)

According to Wong et al. [8], VGS is any way of setting plants on the vertical facade of a building. A clear, easy-to-follow VGS classification was proposed by Pérez, Coma,

Martorell, Cabeza [9]. This approach distinguishes two main categories of VGS (Table 1): green facades (GF) and living walls (LW).

Table 1. Classification of VGS.

VGS Type	Subtype
Green facades	In traditional green facades, climbing plants grow directly on the wall/facade of buildings. In general, these plants are planted directly in the ground around the building. In double skin green facades, there is a separation between the wall and the foliage cover. The plants can grow, for example, with the support of meshes, cables, wires, etc. In perimeter flowerpots, hanging shrubs are planted in a structure on top of the building and constitute a green curtain around the building perimeter.
Living walls	In living walls, plants are grown in panels or geotextile felts, sometimes pre-cultivated, which are fixed to a vertical support or on the wall structure.

A similar and more recent classification is based on the functional elements of VGS, consisting of: (i) supporting elements; (ii) growing media; (iii) vegetation; (iv) drainage; and (v) irrigation [10]. In this classification, green facades are characterized by a low systemic technology. Instead, living walls require more materials and more technologically complex structures and may be continuous or modular. Green facades can be further divided into two subgroups: direct green facades and indirect green facades. In the first case, the plants grow directly on the wall, whereas in the second case, there is a structural support for plant growth [10].

Implications for teaching. Two main VGS classification systems have been identified. Due to its lower complexity, we consider the first classification system more appropriate for teaching purposes, because it can be easily used to classify VGS in the immediate vicinity of the students, and possibly design or set up a VGS in their school.

2.2. Suitable Plant Species

The choice of plants to be used in a VGS depends firstly on the VGS type.

Traditional green facades require climbing plants, which may be deciduous or evergreen species. Two species are mainly used: *Hedera helix* (an indeciduous species), and *Parthenocissus tricuspidata* (a deciduous species) [9].

Green facades with supporting structures mounted on the wall allow a greater variety of plant species in the VGS. This is because the climbing species that use filiform tendrils, spines, and other strategies for vertical development can take advantage of the support structures to grow.

An even greater variety of species may be used with living walls, also in combination. Shrubs, grasses, perennials, and herbaceous plants (well adapted to local conditions) may be used, but shrubs and herbaceous plants, which are evergreen, are most commonly found [9].

Since the plant species chosen should be suitable to the environment of the geographical area in which they grow [11], the choice is also conditioned by the climate of the place where the green facade is set up. The climate determines plant species' survivability and their growth. To compare and standardize the scientific literature findings, we follow the Köppen-Geiger classification (Figure 1) [9,12].

This classification divides the various climates into five main climate groups, with each group being categorized on the basis of seasonal precipitation and temperature patterns. Examples of a selection of plant species based on the VGS type and climate are reported in Table 2.

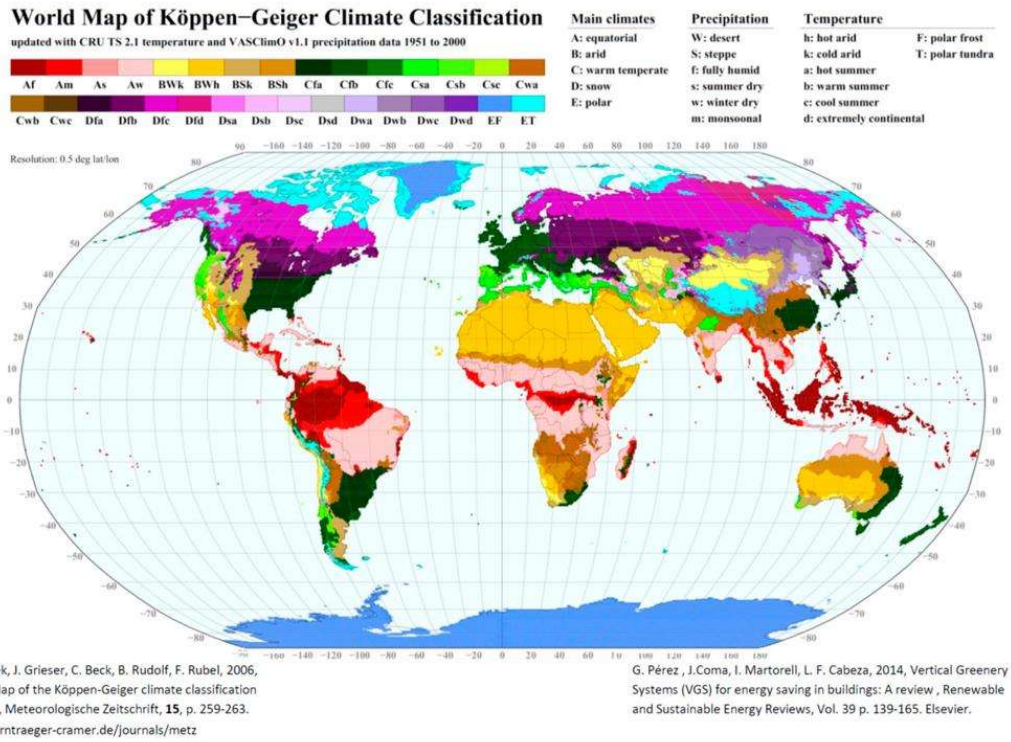


Figure 1. Köppen-Geiger climate classification based on five main climate groups [9,12]. (Permission to reprint granted by the authors and publisher).

Table 2. Examples of plant selection depending on VGS type and climate according to the terminology of Köppen-Geiger.

Type of VGS		Climate (Köppen Geiger Classification)	Plant Species
Traditional green facade	Cfa	Warm temperate; fully humid; hot summer	*Parthenocissus tricuspidata* (Boston Ivy) [13]
	Cfb	Warm temperate; fully humid; warm summer	*Hedera helix*(Ivy) [14] *Parthenocissus tricuspidata* (Boston Ivy) [15] *Stachys byzantine* (Lambs' Ears) [16]
	Dfa	Snow, fully humid, hot summer	*Parthenocissus tricuspidata* (Boston Ivy) [13]
Double skin green facade	Cfa	Warm temperate; fully humid; hotsummer	*Phaseolus vulgaris* (Common Bean) [13]
	Cfb	Warm temperate; fully humid; warm summer	*Hedera helix* (Ivy) [13] *Parthenocissus quinquefolia* (Virginia Creeper) [13] *Phaseolus vulgaris* (Common Bean) [13]
	Csa	Warm temperate, summer dry, hot summer	*Clematis* sp. [13] *Hedera helix* (Ivy) [13] *Lonicera japonica* (Japanese Honeysuckle) [13] *Parthenocissus tricuspidata* (Boston Ivy) [17] *Pandorea jasminoides* (Bower of Beauty) [18] *Rhyncospermum jasminoides* (Star Jasmine) [18] *Wisteria sinensis* (Chinese Wisteria) [13]
	Cwb	Warm temperate, desert, warm summer	*Clitoria ternatea* (Asian Pigeonwings) [19] *Pentalinun luteum* (Hammock Viper's-Tail) [19] *Sedum* sp. [19]
	Dfc	Snow, fully humid, cold summer	*Parthenocissus inserta* (Thicket Creeper) [20]

Table 2. *Cont.*

Type of VGS	Climate (Köppen Geiger Classification)		Plant Species
Living wall	Cfa	Warm temperate; fully humid; hot summer	*Carex brunnea* (Greater Brown Sedge) [21] *Fatsia japonica* (Japanese Aralia) [21] *Geranium sanguineum* (Bloody Crane's-Bill) [21] *Rosmarinus officinalis* (Rosemary) [21] *Sedum spurium* (Caucasian Stonecrop) [21] *Salvia nemorosa* (Woodland Sage) [21] *Zoysia matrella* (Manila Grass) [21]
	Cfa/ Cfb	Warm temperate; fully humid; hot/warm summer	Several shrubs, herbaceous, climber species. [13]
	Csb	Warm temperate, summer dry, warm summer	Several shrubs, herbaceous, climber species [13]
	Cwa	Warm temperate, winter dry, hot summer	*Euphorbia* sp. [9] *Zoysia japonica* (Korean Lawn Grass) [9]
	Csa	Warm temperate, summer dry, hot summer	*Sedum* sp. [13]

In addition to the above general criteria of VGS type and climate, other criteria for the selection of plants are related to energy efficiency, particularly their performance in terms of cooling and energy saving in buildings [11]. The energy efficiency depends on four characteristics of the plant: structural parameters of the plants such as height and Leaf Area Index (LAI), radiative properties (albedo and emissivity), plant traits (e.g., leaf hairiness, color, thickness), and biological processes (stomatal conductance and resistance, leaf water loss) [22]. Some of these technical terms are explained in Table 3.

Table 3. Definition of selected plant parameters affecting the energy efficiency of VGS.

Plant Parameter	Definition
Leaf Area Index (LAI)	The one-sided green leaf area per unit ground surface area (LAI = leaf area/ground area, m^2/m^2) in broadleaf canopies [17].
Albedo	The reflectivity of the leaves: i.e., the fraction of incident solar radiation reflected by the leaves (while *leaf emissivity* is the thermal radiation emitted from leaf surface, via outgoing long-wave radiation) [22].
Stomatal conductance	The rate of water vaporization on leaf surface, i.e., water vapor exiting through the stomata of a leaf and changing with environmental conditions to conserve moisture in plants (while *stomatal resistance* is the opposite) [22].

Mosses are also used sometimes in green walls and may be a low-cost and low-maintenance option because of their low requirements of growing substrates, water, and nutrients, and due to their high desiccation tolerance [23].

Implications for teaching. A large variety of plant species may be used in VGS in relation to the VGS type, climate and plant specific traits. Depending on where students live and the climatic conditions in that area, the VGS plants to be studied in class are selected. These plants should be part of the local environment and easy to find in the proximity of schools. Thus, more relevance to students' life can be ensured.

2.3. Public Acceptance of VGS

A key point in designing and setting green facades in an urban environment is how citizens perceive them.

A study conducted in 2020 [24] investigated the pleasantness of spaces with or without green facades, through an online survey aimed at two target groups (ordinary citizens and architecture and urban planning specialists) in two European countries (Slovenia and the Netherlands). The study supports the initial hypothesis: people in general perceive walls covered with greenery as more pleasant than bare walls, although with differences between the citizens of the two countries interviewed and also between the two target groups

(general public and professional community). In addition, the reasons for appreciation are not always the same between different countries: the authors mention as an example that, while in Greece an opinion poll showed citizens particularly attentive to the aesthetic aspect, a Malaysian study revealed that citizens see green facades as a form of "street art", while in hot and humid cities such as Singapore, vertical green is perceived as a type of urban greening.

In another study conducted in Genoa (Italy) in 2015 [25], a survey was carried out to understand the perception of citizens on the setting of green facades on the walls of buildings before their installation. By doing the survey first, the socio-cultural environment of the area can be considered in a better way. The study showed that the citizens of the area were more favorable than the employees working in the building on which the green facade would be set, the latter being worried about the possibility of maintenance work or renovation of the wall due to damage to the facade by the climbing plants. However, all the respondents considered the contribution to biodiversity and air quality a particularly valuable effect. Previous studies had highlighted ambivalent feelings: if in Sydney (Australia) green envelopes are now known and accepted, other studies made across Europe showed wariness of possible negative effects, such as damage to the facade, need for maintenance, or presence of insects. The improvement in air quality and the possibility of a habitat for birds was perceived as a positive effect.

In another study conducted in Lisbon in 2018 [26], a survey tool was created to estimate the socio-economic feasibility of setting up green walls in public buildings, analyzing the economic costs and benefits (cost/benefit analysis). The building in question was a primary school, so the attention was focused on the users of the building: children in the development phase for whom the negative and positive effects are crucial. As a major benefit, it was considered that the application of VGS could play a significant positive role in the physical, psychological, and social well-being of children, in their cognitive development, and consequently in their academic performance. Since it may be assumed that green facades positively affect children's well-being and improve student learning, schools could be the ideal location to set VGS.

Implications for teaching. The presence of VGS is generally accepted by the public, however it may also raise concerns and controversies. A survey might be prepared in class and then carried out by students to understand the public perception of VGS pros and cons. The survey results may be analyzed in the class with regard to possible barriers to the installation of VGS, whether these barriers are valid and how one could try to reduce these barriers for the benefit of climate protection.

2.4. Effects of VGS

2.4.1. Effects on Buildings (Urban Ecology)

Research in the last decade has focused on VGS as a good solution for saving energy inside buildings, in the cooling as well as in the heating period, obtaining positive evidence. Energy efficiency is linked to environmental sustainability as demonstrated by econometric models [27].

A comprehensive literature review was carried out in 2014 [9] in which the authors organized the literature findings on the effectiveness of VGS for energy saving in buildings. The different operating mechanisms of VGS to save energy are:

- Shade effect, i.e., the solar radiation interception provided by plants.
- Cooling effect, due to evapotranspiration from the plants and substrates.
- Insulation effect, due to the insulation capacity of the different layers (the vegetation layer, the substrate layer, the air between the various layers, etc.).
- Wind barrier effect, i.e., the capacity to modify the direct wind effect over the building facade.

Quantitative findings on energy saving attained by the different VGS types are as follows [9,28]. For traditional green facades, the reduction on the exterior surface temperature of the building facade wall ranges from 1.2–1.7 °C to 13 °C in warm temperate climate (C), and between 7.9 °C and 16 °C in snow climate (D) during the summer period. The ex-

terior surface wall temperature reduction for double skin green facades covers a marginally broader range than for traditional green facades: 1 °C to 15–18 °C in a warm temperate climate (C). The most effective, however, seem to be living walls, that reduce the exterior surface temperature of the building wall from 12 °C to 20.8 °C in the summer period of the warm temperate climate (C). In all cases, the effect depends on the species used, the facade orientation, the foliage thickness, the substrate typology and thickness, and the air gap thickness between the plant layer and the building facade wall. Simulation studies on VGS showed an even higher efficiency: reductions in energy consumption between 5% and 50% were observed, the most frequent being between 20% and 30% in warm temperate (C) and arid (B) climates.

These findings led the authors of the review [9] to conclude that the external wall surface temperature reduction of a building is the most relevant parameter when determining the effectiveness of different VGS types, because it is the most direct effect of the presence of a sunscreen. In fact, "neither the heat fluxes through the wall nor the interior surface wall temperature are comparable due to the differences between constructive systems of the facade building wall" [28] (p. 102). Furthermore, the climate also influences the energy saving performance of the whole system (building and VGS). The climate has an effect not only on the thermal performance of the building but also on specific aspects of the plants used in the VGS, such as their growth (foliage density, plant height) and their physiological responses (transpiration, position of leaves) [28]. The authors also mentioned the main gaps in VGS research at the time of their study: although the potential of VGS to reduce energy consumption in buildings in the cooling period was demonstrated, a lack of data was highlighted for the heating period. Moreover, other aspects could be studied in more depth, such as which species are the most suitable for different climate types, the influence of facade orientation, foliage thickness, presence of air layers, and finally, substrate layer composition and thickness, in the case of green walls [9].

Other studies have tried to fill the above-mentioned gaps. Research conducted during the heating period has highlighted that:

- A green coating of *Hedera helix* covering the north wall of a building in Manchester (UK) increased the mean external wall temperature in winter by 0.5 °C, with energy losses reduced by around 8% [14]. In another experiment covering brick cuboids with *Hedera helix* in Reading (UK) for two winters, green facades were able to enhance wall surface temperatures up to 3 °C and increase energy efficiency by 40–50% [29]. It was also found that the colder the temperature the more effective the insulation [14], and that the largest energy savings were associated with more extreme weather conditions, such as cold temperatures, strong wind or rain [29].
- "As Sternberg et al. pointed out, since the insulation provided by climbers can reduce the temperature fluctuations of walls, they can reduce the chances of outer walls freezing in winter, preventing frost deterioration of the building materials" [14] (p. 32).
- In an experiment carried out in Puigverd de Lleida (Spain), under Mediterranean continental climatic conditions (Csa), living walls made with evergreen species demonstrated higher heating and cooling performance than green facades covered with deciduous vegetation (*Parthenocissus tricuspidata*). In the heating period, the energy saving was approximately 4.2%, due to the thermal stability supplied by the polyethylene modules [13].

Finally, several studies have focused on the beneficial effect of VGS concerning evapotranspiration in the cooling period and concerning the moisture balance. Through evaporation, incoming energy converts water into water vapor, rather than increasing the sensible heat. If the water is within the plant and the plant releases water vapor, then the term is modified to "evapotranspiration" [30]. The key findings are the following:

- The cooling potential of different plant species used in VGS was investigated, showing that certain species are more effective in cooling through evapotranspiration than through the shade effect. Evapotranspiration cooling is due to the exiting of water vapor from the stomata, i.e., to stomatal conductance, whereas the shade effect is due

to leaf size, leaf morphology, and the leaves' arrangement along the stem. For example, Fuchsia is more effective in evapotranspiration cooling, while Jasminum and Lonicera provide a greater shade effect [16].

- A lack of moisture balance may be a risk for buildings in the weather conditions of the northern hemisphere. One of the traditional and frequent ornamental species used in Scandinavia, *Parthenocissus inserta*, was selected to investigate the impact of the climbers on the moisture performance of facades, using a double skin green facade. VGS provides effective protection from wind-driven rain and improves moisture safety [20].

Implications for teaching. VGS has been demonstrated to have a significant effect on energy saving in buildings through several operating mechanisms. This part of the literature review is important for two reasons: the first reason is that research on VGS started here, intending to demonstrate the energy saving potential of VGS in buildings and other beneficial effects. Thus, this is basic knowledge to build on for teaching/learning about sustainable development in cities. The second reason is that this kind of knowledge may serve as a basis for developing practical activities for science lessons (for example, the measurement of relevant parameters such as temperature and humidity). This can only occur by knowing which parameters to measure and what to compare.

2.4.2. Effects on Climate and Environment

Climate change poses one of the greatest threats to society. In terms of heat waves, droughts and flooding, their effects on people and the environment are particularly evident in cities where about half of the earth's population lives [31]. Urban temperature and local warming depend on large-scale climatic changes and localized phenomena such as the Urban Heat Island (UHI) effect, as a function of urban building density without vegetation area. This effect is caused by three main factors: "(1) increasing amount of dark surfaces such as asphalt and roofing material with low albedo and high admittance, (2) decreasing vegetation surfaces and open permeable surfaces such as gravel or soil that contribute to shading and evapotranspiration and (3) release of heat generated through human activity (such as cars, air conditioning, etc.)" [5] (p. 17).

Potential side effects should also be highlighted. Phenomena such as global warming and UHI increase energy consumption in more extreme weather events, i.e., more heating is needed for extremely cold temperatures and more air conditioning/cooling for extremely hot temperatures, thus increasing air pollution and greenhouse gas emissions [32,33].

The environment in cities is also threatened by air pollution. The main air pollutants are particulate matter (PM) and nitrogen oxides (NO_x, NO_2, and NO). A secondary pollutant, resulting from chemical reactions of NO_x with volatile organic chemicals (i.e., VOCs), is ozone (O_3) at a low level in the atmosphere. PM with a diameter of 10 µm and below poses a great danger to human health if inhaled. In fact, these very small particles (PM_{10}, $PM_{2.5}$, $PM_{0.1}$) may penetrate the lungs, then enter the circulatory system, and reach different organs of the human body. These ultra-fine particles may also enter via the nose the olfactory nerves, and thus be transported directly to the brain. NO_x, and in particular NO_2, can have serious effects on health. They may increase mortality risk and asthma, decrease lung function in children and adults, determine low birth weight and affect cognitive development [32]. Recent research indicates that fine dust also gets into the fetus of pregnant women.

In this part of the review, the focus will be on the effects of NBS (greenness, parks, trees, green facades, and green roofs) and, in particular, the effects of VGS on the city's climate and environment. We will try to extend the evidence about the beneficial effects of NBS to VGS, because the amount of greenery in an area is increased in both cases. Therefore, similar outcomes can be expected.

Vegetated areas are generally cooler than sealed surfaces and, therefore, they are useful in an urban context to cope with the UHI effect and climate warming. The most important mechanisms through which vegetation contributes to heat reduction are the higher albedo

(i.e., lower absorption of radiant heat from the sun during the day and lower re-irradiation at night) and the cooling effect due to evapotranspiration [28]. Furthermore, trees and VGS reduce heat by providing direct sun shading [34].

Among the various possibilities of using NBS in cities, VGS is particularly promising, especially where there is not a lot of space available for a park, an urban forest or a green area. The use of VGS may allow the formation of "green street canyons", by covering with plants the vertical surface of buildings, which is much larger and available than the horizontal [28,35].

Since VGS contributes to temperature regulation and energy savings in buildings, it potentially contributes to mitigating the Urban Heat Island (UHI) effect [16,28] and also global warming [33]. As an indirect effect, these positive outcomes lead to lower greenhouse gas emissions [32,35].

Concerning the experimental evidence of the effectiveness of VGS on the urban microenvironment, findings in the scientific literature are not always concordant. On the one hand, many authors indicate an important potential of lowering urban temperatures when the building envelope is covered with vegetation [36], depending on the VGS features [8]. On the other hand, a very significant temperature reduction due to VGS influence on the surrounding built environment is not always demonstrated, pointing out the necessity of more studies [28]. Anyway, some specific research findings on the effects of NBS and VGS are presented below.

1. Sequestration of CO_2 from the atmosphere Photosynthesis in all types of plants leads to an increase of O_2 level and a decrease of CO_2 level, improving air quality. In a wider view, green infrastructures such as NBS may be used to adapt cities to climate change, since urban vegetation removes CO_2 from the atmosphere and stores it in its structure and in the soil, so that its release is delayed [32]. For instance, a recent study conducted in Rome highlighted that CO_2 sequestration by the vegetation developing in parks of historical residences was equivalent to 3.6% of the total CO_2 emissions for the city in 2010 [37]. Several studies indicated that CO_2 sequestration is also possible with VGS [35,38]. More specifically, in a study conducted in 2014 in the Mediterranean climate, a dynamic model was developed to simulate the total sequestration of CO_2 by a VGS, from its setup until its composting in the soil (the accumulated carbon being finally stored in the soil). It was estimated that an area of 98 m^2 of VGS captures an average flux of CO_2 between 13.41 and 97.03 kg CO_2eq per year. More specifically, an area of 98 m^2 of living wall constituted by *Sedum spurium*, *Salvia nemorosa*, *Rosmarinus officinalis*, *Geranium sanguineum*, *Carex brunnea*, and *Fatsia japonica* could capture an average CO_2 flux of 60.87 kg CO_2eq per year. The results were validated by comparing the data with the literature [21]. In another study [19] conducted in 2017, a double skin facade was considered to evaluate how much carbon (C) is captured per m^2 of this VGS (set in Acapulco, Mexico) with two typical plants of this region (*Clitoria ternatea* and *Pentalinon luteo*). Both species covered an area of 1 m^2 per individual plant. The carbon content in the plant biomass was evaluated by triturating a plant and analyzing the powders with an organic elemental analyzer. Then it was estimated that for every gram of assimilated carbon, 3.66 g of CO_2 were removed from the atmosphere [19]. The results are in line with the study of 2014 mentioned above.
2. Improvement of air quality Greenness in a city introduces extra surfaces and allows larger deposition velocities per unit area (compared with buildings or sidewalks or parking lots) for airborne particles, pollutants, and dusts. However, the presence of plants and trees may also constitute a barrier for airborne particles' dispersion. The barrier effect influences the air flows, so an assessment of the position of this barrier should be made before setting plants. Whereas leaf surfaces collect particulate matter, some volatile chemical compounds (i.e., VOCs) can be directly absorbed through the cuticle, and some gases such as NO_2 can be captured via the stomata. This all improves air quality [32,39–41]. On the contrary, air pollution can negatively affect the growth of plants and the species of plants that can grow in a given area [35,41]. Studies

have confirmed that VGS has the above-described effects on airborne particles uptake (dusts and airborne pollutants such as NO_x and O_3). Influencing parameters for pollutants' reduction are: leaf morphology, the leaf area index (LAI), foliage density and shape, plant's health, VGS structure, VGS type, plant species, site, building canyon's structure, season, and climate [33,35,42].

3. Effects of evapotranspiration The evapotranspiration phenomenon in plants increases latent heat (energy transferred in a process without changing the body's temperature) rather than sensible heat (energy transferred in a process with a change of the body's temperature). While the measured temperature indicates sensible heat, latent heat cannot be perceived as warmth, because it transforms liquid water into water vapor. The air humidity is thus a measure for the latent heat energy. Thus, an increased air humidity (for instance, energy consumption for evaporation) supports the downregulation of air temperature [30] and counteracts the dry air effect of the UHI. Several studies confirmed this effect for VGS [33,39,43].
4. Regulation of temperature In addition to the evapotranspiration effect, plants contribute to temperature control through the absorption of radiant heat and the shading effect. In the specific case of VGS, the shading effect works together with the wind barrier effect and the insulation effect [9], reducing the temperature inside/nearby the building (as described in 2.4.1). If a green facade has been set on a yard's fence, the temperature regulation would also be outside.
5. Regulation of water flow In general, trees and greenness provide better water management by absorbing water through the roots. The presence of permeable surfaces and rainfall interception by plants reduces water runoff and allows better water flow regulation. In addition, VGS can positively contribute to water management at the building level and urban scale. This effect has been indicated by several studies that, in addition to the mentioned rainwater runoff control mechanism, also highlighted a positive contribution to water management of the evapotranspiration effect [30,38,39,44].
6. Generation of urban breeze Parks in a city may generate urban breezes, due to cooler air, that goes from green to built spaces, counteracting the UHI effect. Furthermore, at the urban boundary layer (the layer of the atmosphere immediately above the ground), a cooling effect is also caused by greenness increasing surface roughness and improving convection efficiency [39]. "In vegetated areas, the coupling between the land and the atmosphere becomes more efficient because an increase in surface roughness lowers aerodynamic resistance, generates more turbulence and higher sensible and latent heat fluxes, and leads to a wetter, cooler atmospheric boundary layer" [41] (p. 4). However, this effect has not yet been observed for VGS.
7. Muffling noise Vegetation and green areas in cities muffle noise, especially for sites adjacent to roads. Studies on this aspect for VGS are limited. Still, some initial findings indicate that VGS may constitute an effective passive acoustic insulation system, showing similar or better acoustic absorption characteristics than common building materials [40,45].
8. Safeguarding biodiversity Biodiversity gives value to an ecosystem, both in the city and beyond. This concept should be taken into account in the re-greening of a city. A study carried out in 2018 analyzed the opportunities to protect and increase biodiversity in a city. For example, green roofs, green walls, and facades may support animal life in the city [7]. A doctoral thesis [46] focused entirely on the contribution to biodiversity by green facades and living walls, analyzing which species benefited from this kind of green infrastructure. Birds, snails, spiders, insects, in general, find in these urban infrastructures oases or corridors to move from one green area to another, within the city and outside. Species' movement and the number of species also depend on the particular characteristics of the VGS considered: area of the vegetated vertical surface, plant richness and density, type of foliage (evergreen vs. deciduous), the surroundings (adjacent land, vehicle, and pedestrian traffic), and the seasonality [46]. Other studies have shown that among arthropods, good

dispersers such as winged insects and species carried by the wind, such as spiders, are over-represented, depending on the resource provided (nesting habitat, food, and protecting areas) [47,48]. Living walls show the highest occurrence of beetles and spiders. At the same time, green facades (both traditional and double skin) are ideal habitats for generalist and common invertebrates. They are also highly visited by specialist flower visitors (honeybees, bumblebees, bristly flies, and butterflies) for nectar and pollen [48,49]. At last, the abundance of detritivores, herbivores, and predators depends on the climbing species and the wall age [46,48]. One research study estimated the public's perceived value of green walls for urban biodiversity, in the form of their willingness to pay for it. Results indicated a willingness to pay [50]. Although with little money, willingness to pay demonstrates the feelings of citizens towards biodiversity, which VGS may improve.

Implications for teaching. VGS has been demonstrated to have a positive effect on the environment of urban areas by contributing to the improvement of the air quality, regulation of temperature and humidity, and safeguarding biodiversity. This part of the literature review can be closely linked to the concept of teaching/learning based on the possibility of making some of the described effects tangible through student experiments in school. This allows direct experiences with nature and provides insights into environment protection measures.

2.4.3. Effects on Physical Health and Mental Health

The biophilia hypothesis suggests that humanity has an innate tendency to seek connections with nature, trees, forests, plants, flowers, and animals. Edward O. Wilson defines biophilia as "the urge to affiliate with other forms of life" [51].

With cities becoming increasingly crowded over time, humanity suffers from a lack of nature, threatening mental and physical health. In this regard, several effects may be observed, such as depression and anxiety, linked to heart diseases, high blood pressure, stroke [52]. Air pollution is linked to respiratory diseases and lung cancer, as well as those already mentioned in Section 2.4.2, with regard to the various types of air pollutants.

According to the World Health Organization (WHO), anxiety and depression may also lead to harmful behaviors such as smoking or drinking alcohol. Enhancing greenness in cities may reduce those effects and improve citizens' health. Activities with increasing levels of engagement with nature are: watching nature, walking, running, biking in a park, caring for gardens or vegetable gardens [52]. Even the simple view of a green landscape may improve psychological and physiological well-being [53,54]. Greenness has direct and indirect beneficial effects [55–59].

Direct effects include psychological relaxation, stress reduction and recovery, more opportunities for physical activity, reduced exposure to noise (which is a stress factor), reduced exposure to air pollution, reduced exposure to heat, and boosting the immune system by the chemical and biological agents of plants.

Indirect effects include reduced blood pressure, reduced mortality rates from circulatory diseases, reduced headaches, positive effect on cognitive ability or functions, positive effect on mental processes [57], positive effect on attention restoration, faster healing, and better social ties [60]. Furthermore, the improvement of sleep (a side effect of psychological relaxation and stress reduction) has an important effect on well-being. The underlying mechanisms of the above effects are [60]:

- The view of greenness (even the simple experience of silent contemplation of nature) is linked to a better physiological and psychological state since images of nature reduce sympathetic nerve activity and increase parasympathetic activity, causing psychological relaxation.
- In turn, psychological relaxation lowers inflammatory cytokines, which are risk factors for diabetes, cardio-vascular diseases, and depression. It also counteracts the negative effects of stress on energy metabolism, insulin secretion, and inflammatory pathways.

- Many plants release phytoncides, antimicrobial volatile organic compounds, boosting immune functioning and reducing blood pressure.

A study examines the associations between the duration, frequency, and intensity of exposure to nature and health in an urban population. It concludes that there is a minimum dose of 30 min where some effect of nature on health might be observed [61].

The possibility to access nature is also important because a significant increase in stress was observed for people living more than 500 m away from green areas compared to those living in proximity of green areas [62].

Once again, the evidence of the positive health effects of NBS may be extended to VGS. In a recent study on VGS, the beneficial effect of viewing a green facade landscape instead of a bare building wall was demonstrated in enhancing physiological and psychological relaxation [63]. But why do people feel more comfortable with plants? It was found that around 2.000 shades of green color can be distinguished by the human eye, while 100 shades of the color red can be distinguished [52]. A possible explanation could be that recognizing a plant's shade of green was important to know whether to eat it or use it for shelter or medicine throughout human evolution.

Implications for teaching. The literature review reveals that nature and various forms of greening directly affect the health and well-being of people and, therefore, of students. This aspect is important to know, but difficult to be made directly tangible for students. Thus, this kind of information is more suitable to be acquired in knowledge-based, theoretically oriented lessons.

2.4.4. Effects on Teaching/Learning

Increasing evidence shows the close link between nature, learning, and personal development (having a view on a natural landscape, studying in a park or a garden, doing outdoor recreation, gardening, moving around in a natural environment) [64]. Several studies aim to show how green areas provide a "remedial" effect against stress to improve young people's cognitive performance [65–67]. Even just the classroom view of green landscapes produces better results on tests of attention, due to students' recovery from stressful experiences [68,69], therefore improving learning, behavior, and academic performance [68–71].

A study conducted in 2005 in Spain, in primary schools, found an improvement in cognitive development associated with surrounding greenness, particularly with greenness at schools, also mediated by air pollution reductions. Contact with nature plays a crucial and irreplaceable role in brain development. It positively influences cognitive development inciting engagement, risk taking, discovery, creativity, mastery and control, strengthening the sense of self, inspiring basic emotional states including the sense of wonder, and enhancing psychological restoration [72].

A recent study aims to prove that nature and the direct experience with nature improve learning. Nature increases attention, improves concentration, increases intrinsic motivation and self-discipline, relieves stress, and provides a better context for learning [2]. Furthermore, nature gives children more freedom to engage with one another. This leads to improving students' cooperative relationships with peers and adults, and, in turn, improves their behavior and their development as a person. The authors also highlighted how experience with nature improves students' behavior towards nature, also promoting students' development as an environmental steward [2]. A positive childhood nature experience appears to play a key role in fostering pro-environmental behavior in adulthood [73].

Several other studies highlight the social utility of learning in a natural context [74], in preschool (concerning the development of cognitive abilities, social skills, and motor development) [75,76], for young people from low-income neighborhoods [70,77,78], and for students with special needs or disabilities, where a decrease of hyperactivity and inattention was observed when conducting activities in various types of green settings ("green outdoor", "built outdoor" and "indoor" settings) [79,80].

However, most cities do not necessarily allow for the implementation of strategies for education based on nature. A study [81] uses the term "nature-deficit disorder" to describe the loss of nature in the experiences of children who live in cities without parks or wild edges. Over the years many studies have pointed out the necessity of planning cities with greenery integrated at multiple levels (from landscaping around homes, schools, and childcare centers, to linked systems of urban trails, greenways, parks, and "rough ground" for children's creative play). Unfortunately, this is difficult to realize in increasingly crowded cities, especially in the poorest suburbs or economically deprived areas. The use of VGS and green roofs could at least partially compensate for this lack.

The term "Nature Based Learning" (NBL) has been introduced in recent years. NBL occurs through exposure to nature or by implementing nature based activities, both in natural contexts (excursions to green spaces) and in built environments, such as a school in which elements of nature have been introduced (plants, animals, fungi, algae, water containing microorganisms) [82].

The definition of NBL fits VGS in its introduction of natural elements at school. It might be argued that the beneficial effect of nature may be in part extended to the case of VGS, set up on the school's wall, in the school garden, in the surrounding neighborhood, or in a botanical garden outside the school. Still, there are a few studies on this topic. Some examples are the following.

Based on the idea of the environment as a teacher, one author assumes that a school garden (including green facades) could improve students' ecological awareness. The author proposes then to include greenery elements in the design of school buildings [83].

Furthermore, Montessori's idea of the school environment as a "third teacher" may be extended to identify sustainable schools as a vehicle for interest and awareness of environmental issues and sustainability [84]. VGS may have a manifold effect in a sustainable school: raising awareness about the importance of ecology, acting as 3D teaching textbooks on sustainability, being a perfect tool to teach about the environment, being used by students in biology or art classes, inspiring real world thinking [59].

A recent study finally highlights that implementing green walls inside schools provides environmental health benefits and enables hands-on investigations with students in the classroom, making lessons more interesting and inspiring critical thinking. A connection can be established between the indoor environment (where students are) and the outdoor environment (where nature is). Green walls can inspire critical thinking through a combination of project-based learning strategies and environmental education [85].

Implication for teaching. There is a close link between nature and learning/personal development. This link has been translated into the concept of NBL, which occurs through exposure to nature or by implementing nature-based activities. Practical activities with VGS may be proposed in school to extend the general concept of NBL to VGS. This is particularly beneficial in those contexts where a lack of nature could be partly compensated by using VGS as a way to introduce nature in schools.

3. VGS Research Contents Suitable for Science Teaching

As highlighted in the introduction, this literature review aims to use a nature-based solution such as a VGS (a green facade or a living wall) as an example of knowledge transfer from research to school, selecting research contents with a real life relevance for the students. This section will show how the selected research contents may be used to introduce crucial issues such as sustainability and climate change.

3.1. Support for Sustainable Development Goals and Climate Literacy

UNESCO coordinates and promotes Education for Sustainable Development (ESD) in all countries of the world, to give young people the opportunity to make informed decisions and act for environmental integrity, economic sustainability, and an equal society for present and future generations [86,87].

During the United Nations Conference on Sustainable Development (Rio+20) held in Rio de Janeiro in June 2012, the member states of the United Nations agreed on a three-year path finally reaching the definition of 17 Sustainable Development Goals (SDG), whose purpose is to ensure a sustainable, peaceful, prosperous and equitable life on Earth for all, now and in the future.

Education for Sustainable Development (ESD) follows the 2030 Agenda for Sustainable Development (UN, 2015). This means that "ESD aims at developing competencies that empower individuals to reflect on their own actions, taking into account their current and future social, cultural, economic and environmental impacts, from a local and a global perspective. Individuals should also be empowered to act in complex situations in a sustainable manner." [86] (p. 7).

VGS can be a topic of ESD. In fact, among the 17 goals, VGS suits the following three:

- Goal no. 11: Sustainable city and communities: Make cities and human settlements inclusive, safe, resilient and sustainable. With this objective, students can learn the basic principles of sustainable city planning and sustainable buildings.
- Goal no. 13: Climate action: Take urgent action to combat climate change and its impacts. With this objective, students can learn about adaptation and mitigation strategies for climate change.
- Goal no. 15: Life on land: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. With this objective, students will understand the importance of biodiversity and ecosystem services provided to humanity.

Among the various goals, no. 13 (climate action) is of particular interest due to the urgency of the problem and the emotions and reactions that this topic inspires among adolescents.

In 2009, the U.S. Global Change Research Program had proposed Climate Literacy as a guide for individuals and communities, giving the following definition: Climate Literacy is an understanding of your influence on climate and climate's influence on you and society [88]. Climate Literacy is founded on a guiding principle, "Humans can take actions to reduce climate change and its impacts", in addition to seven essential principles of Climate Science. These principles may work as discussion starting points for scientific inquiry and promote Climate Science Literacy.

Some of the principles of Climate Literacy may be linked to the effect of VGS on climate. For instance, Principle no. 2 states: "Climate is regulated by complex interactions among components of the Earth system." The key point of this principle is that the abundance of carbon dioxide in the atmosphere is reduced by accumulating plant biomass, which acts as a counterweight to burning fossil fuels. Setting up a traditional or double skin green facade may act as an example to show how the plants of a VGS affect the (micro-) climate. This example is also relevant to Principle no. 3: "Life on Earth depends on, is shaped by, and affects climate.". The interdependence between climate and plant species used for a VGS, and other species living in a VGS, can also be shown. Finally, Principle no. 6 states: "Human activities are impacting the climate system." The key point of this principle is that, as indicated with large consensus in the scientific literature, the rise in global average temperatures since the latter part of the 20th century is due to human activities. Deforestation also played an important role in this process by removing CO_2 sinks. However, VGS may act as partly compensatory CO_2 sinks.

Several effects of VGS (Section 2.4) may be related to the Sustainable Development Goals of the UN, as well as to several principles of Climate Literacy. Table 4 summarizes these relations between VGS, the Sustainable Development Goals of UN and the principles of Climate Literacy.

Table 4. How VGS fits the Sustainable Development Goals no. 11, 13, 15 and some of the principles of Climate Literacy (guiding principle, principles no. 2, 3, 6).

	Sustainable Development Goal [86]			**Climate Literacy Principle** [88]			
	Goal no. 11: Sustainable city and communities: **Make cities** and human settlements inclusive, safe, resilient and **sustainable**. **Goal no. 13**: Climate action: Take urgent action to **combat climate change** and its impacts. **Goal no. 15**: Life on land: Protect, **restore** and promote **sustainable use of terrestrial ecosystems**, sustainably manage forests, combat desertification, and halt and reverse land degradation and **halt biodiversity loss**.			**Guiding principle:** "**Humans can** take actions to **reduce climate change** and its impacts." **Principle no. 2:** "Climate is regulated by complex **interactions among components** of the Earth system." **Principle no. 3:** "**Life** on Earth **depends on**, is shaped by, **and affects climate.**" **Principle no.6:** "**Human activities** are **impacting** the **climate** system."			
VGS key points	**Goal no. 11.**	**Goal no. 13.**	**Goal no. 15.**	**Guiding principle**	**Principle no. 2**	**Principle no. 3**	**Principle no.6**
VGS **regulates** the **temperature** inside a building (VGS is a tool to adapt to climate change), see Section 2.4.1.	X	X		X			X
VGS **allows energy saving**, less energy consumption, and less greenhouse gases emitted into the atmosphere (VGS is a tool to mitigate climate change), see Section 2.4.1.	X	X		X	X	X	X
VGS **removes CO_2** from the atmosphere (VGS is a tool to mitigate climate change), see Section 2.4.2.	X	X		X	X	X	X
VGS **improves** the **air quality** (VGS reduces dusts and gas pollutants), see Section 2.4.2.	X		X				
VGS **counteracts** the **dry effect** of UHI and climate warming with evapotranspiration, see Section 2.4.2.	X	X	X	X		X	X
VGS **safeguards biodiversity** in the city, see Section 2.4.2.	X		X				
VGS **muffles noise**, see Sections 2.4.2 and 2.4.3	X						
VGS **regulates** the **water flow**, see Section 2.4.2.	X						
VGS **safeguards** human **well-being** in cities, see Sections 2.4.2 and 2.4.3	X						

Table 4 also shows how VGS key points may be linked to environmental sustainability and the ecological footprint, an indicator to estimate the supply and demand of nature, how much nature we consume and how much nature we have. Currently, the increasing human exploitation of natural resources significantly impacts the environment and the earth's capacity to renew these resources [89].

In Section 2.4.4, the importance of VGS for teaching/learning was assumed, extending the beneficial effects of greenery in school to VGS, based on the definition of Nature-Based Learning (NBL). According to the studies reported in Section 2.4.4, experiencing nature plays a key role in promoting pro-environment attitudes and behaviors. This suggests that theoretical knowledge of sustainability or climate change issues is insufficient to change students' behavior. Instead, practical experience with nature is linked to becoming aware of environmental issues and acting as an environmental steward [2]. Additionally, evidence from the literature on how to introduce the topic of climate change to young people suggests that educational practices that involve actions and feelings, besides knowledge, are particularly effective for becoming aware of the problem and coping with it [90].

As an example, if students are asked to memorize the definition of "sustainability", stating that "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" [91] (p. 16), they probably will. Yet, they will not be able to internalize and implement this concept.

Similarly, for the ESD, the teaching of goal no. 13 (climate action: take urgent action to combat climate change and its impacts) will not be effective by solely relying on the guide for Climate Literacy [88], but will also need practical experiences to be better understood and learned. Another study [92] showed that educational interventions which use an interdisciplinary approach, based on direct experience and promoting discussions, are very effective among adolescents by reducing the psychological distance to climate change. Furthermore, it was demonstrated [93] that the combination of theoretical and practical activities in a primary school within a project where scientists shared research results on the effects of climate change (in this case on sea life) produced a clear gain in knowledge, teamwork skills, and communication. Positive educational outcomes also resulted from participation of schools in research activities [94] on climate change and from cooperation between research and education [95]. These findings seem to validate the approach chosen in this paper to transfer knowledge on VGS from research to school, based on practical experience and interaction with others, as a possible strategy for teaching climate literacy.

3.2. Criteria to Select Research Contents Suitable for School

Before the practical activities, it is necessary to establish the criteria that make the topic "VGS" valid in the curriculum of a class. To this purpose, the following criteria, with the first three referring to Wolfgang Klafki [96,97], a very well known German pedagogue, will be applied.

1 Exemplarity [96,97]:

- VGS, such as a green facade or a living wall, is an example of NBS to make cities more sustainable. Therefore, VGS may be used in teaching/learning in the general framework of the UN goals for sustainable development (goals no.11, 13, 15).
- The literature provides evidence regarding the importance of experiencing nature for young people. Such experiences may be conducted with VGS.
- Young people need to have a problem solving-oriented approach to questions and issues. VGS can be considered as one possible response to address the climate change problem, and is therefore well suited for inquiry-oriented lessons and problem-solving approaches.

2 Students' current life meaning [96,97]:

- Students are confronted with information about air pollution and air quality in everyday life. Similarly, students often hear about the necessity to sustainably manage a city and to take mitigating/adapting actions against climate change, and about the behaviors citizens need to have and the tools to use for such purposes. VGS is a valid tool to improve air quality and to make a city more sustainable. VGS is also eye-catching because it changes the appearance of houses, gives them a special look, and thus is interesting for students.
- Students need to connect themselves with actual life around them, comparing ideas and sharing experiences and behaviors with peers, family members, and people in the neighborhood or city. VGS may stimulate this interaction, trigger discussions, and put into practice sustainable behavior and pro-climate actions.

3 Students' future life meaning [96,97]: To become responsible citizens and adults who can take a position on socially important issues, such as climate change and environmental protection, students should know the consequences of climate change, pollution and other threats to the environment, and then develop critical thinking to assess strategies to solve these problems. To come up with a solution to a problem, responsible citizens should consider both the benefit to the community (in this case, limiting further global warming) and the needs and feasibility for the individual (additional costs). The aim is to find a compromise that is acceptable to all parties. VGS may be a tool to foster these important objectives for their future (change of perspectives, weighing of interests, finding compromises).

4 Inclusivity: As highlighted in Section 2.4.4, the literature suggests that nature-based lessons are the ideal context to create an inclusive learning environment offering more cooperative relations [2] and different learning approaches according to students' abilities, with the learning approaches ranging from descriptive, observational, and measurement activities, to uncovering and interpreting theory–practice connections. VGS may be a good solution to set up a green space in a school or a nearby location when natural greenery is not available, thus creating a suitable context for Nature Based Learning and the inclusion of all students.

5 Link to school curricula: There are several possible links between VGS and the topics of school curricula in the natural sciences. Examples include photosynthesis and CO_2 sequestration, knowledge of plant species and plant parts, the atmosphere and greenhouse effect, energy and the environment, evapotranspiration, the water cycle, the solar irradiation and how this energy is transformed within a natural system, sensible heat and latent heat, the temperature and the thermometer, measurements and charts, the human body and health (nervous system, stress recovery in the presence of greenness, respiration, homeothermy connected with UHI, the immune system), ecology and interactions between living beings and the environment, and the exchange of matter and energy between plants and environment.

6 Feasibility [98]: Lessons/activities on VGS have to be possible with affordable instruments in nearby or easy to reach locations and in a reasonable time.

3.3. Possible Practical Activities with VGS

In the following pages, we will provide examples of actions and practices using VGS as a tool to act, articulated in various phases: a descriptive, investigative, and, finally, communicative phase (as shown in Figure 2).This sequence of phases corresponds to the structuring of subtopics in the narrative review (when referring to phases 1 and 2).Thus, the structure of a scientific review can be used as a guide for structuring activity-based lessons, in this case, on the topic of VGS.

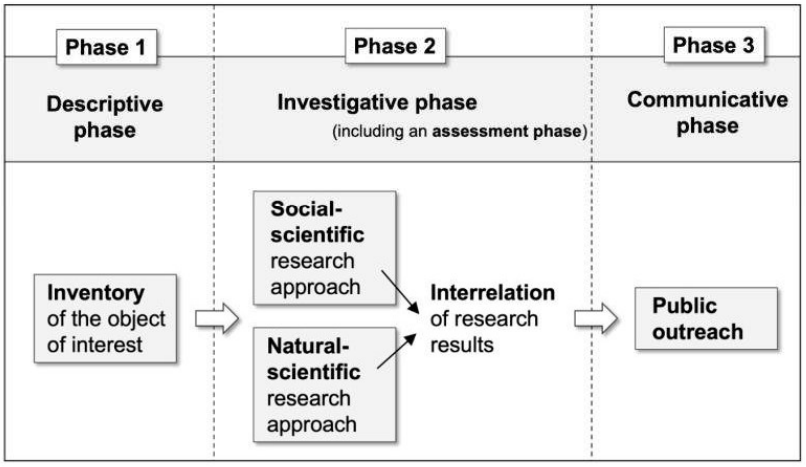


Figure 2. Possible phases of a teaching unit on VGS.

The descriptive phase includes creating an inventory of already existing examples on the topic of interest (VGS) and structuring them according to established criteria. The investigative (inquiry-based) phase may be split into two sets of activities, one with a social-scientific focus and one with a natural-scientific focus, with the aim to look for inter-relations between the respective results of each one. The communicative phase aims instead to public outreach, to share what has been learned and raise awareness in the public

of important issues, such as climate change, and the effectiveness of certain strategies (such as VGS) to counteract them.

3.3.1. Design

Initially, students could collect photos of existing VGS in their city (photo safari) to compare them with reference pictures of VGS types and plants to recognize what they have found (Figure 3).

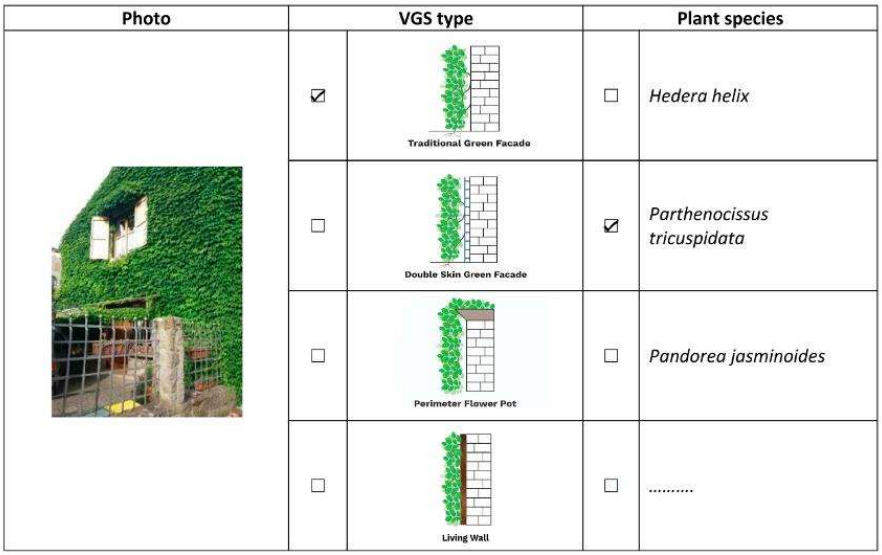


Figure 3. Recognizing a VGS type through comparison with references.

Shooting photos around the city is a way to observe and "take home" pieces of the city and analyze them. Before studying green facades, it makes sense for students to observe what is already around them, with the eye of the scientist, observing in a targeted way. Green facades do not exist only in books, but also on the walls of their cities.

Students should identify different VGS types, how they differ, and compare them with theoretical knowledge on VGS. For instance, the teacher may bring various photos of VGS to class, including close-up/detailed photos. In the photos, the structure of the VGS and the plant species used should be clearly visible. With the help of additional material (for instance, a simplified identification key), the students should be able to determine the type of facade, the plant species, and the climate requirements of these plants.

In doing so, students will get an idea of the most common green facade types in their area and the plant species in use. These activities should also enable them to estimate which kind of facade could be suitable for their own school (in order to design a VGS and eventually set it up).

3.3.2. Social Aspects

Students should get an impression of what people think about VGS and whether they are willing to support the installation of a VGS. To do so, students may conduct interviews to collect people's beliefs and acceptance of VGS (Section 2.3). Such a survey should present the advantages and problems of VGS, to show a controversy for which a solution must be found.

Students can then extract ideas and arguments from these interviews regarding the climate and environmental relevance of VGS. These interviews can thus serve as a basis for deriving hypotheses that will be taken up in the scientific orientation of the lesson. An

example of a possible structure and content of a survey, inspired by the literature [25] and adapted to the situation of a student who interacts with family members or friends, is shown in Figure 4.

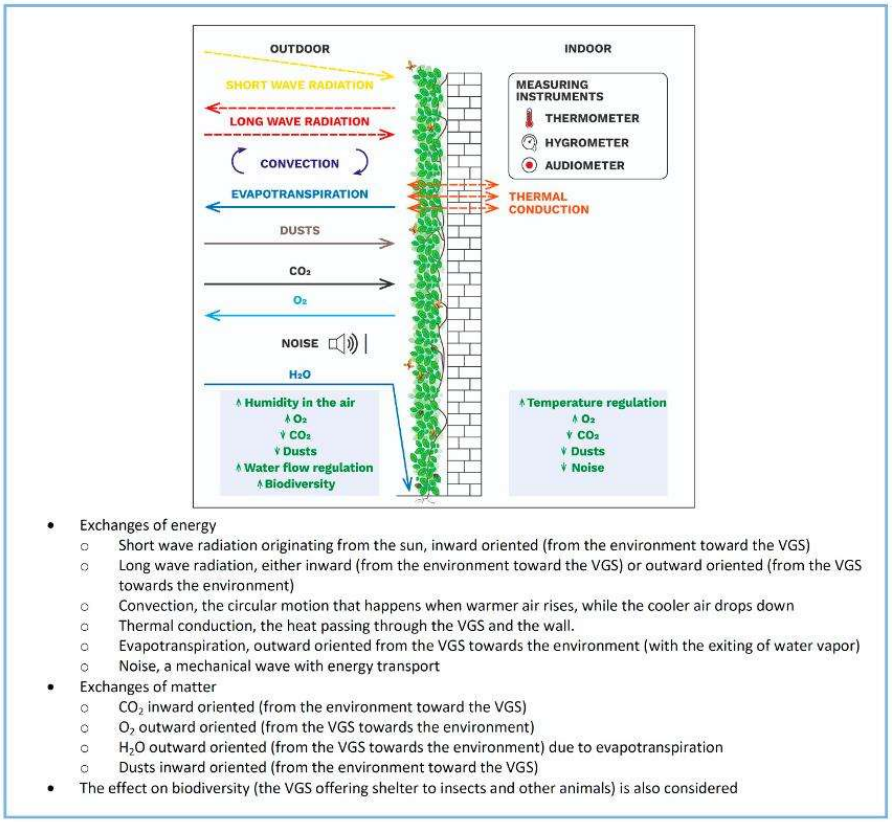
- I'm a/an ...
  - ☐ Student
  - ☐ Adult at the age of parents
  - ☐ Adult at the age of grandparent
- Do you live in a neighbourhood with greenery nearby?
  - ☐ Yes ☐ No
- Have you ever heard something about green facades?
  - ☐ Yes ☐ No
- Do you think a green facade may positive affect a city?
  - ☐ Yes ☐ No
- If yes, why? (multiple selections possible)
  - ☐ More nature in the city
  - ☐ Esthetical reason
  - ☐ Wellbeing improvement
  - ☐ Biodiversity improvement
  - ☐ Air quality improvement
  - ☐ Temperature regulation, especially in summer
  - ☐ Humidity regulation
  - ☐ Temperature regulation also in winter
  - ☐ Reduction of noise
  - ☐ Contribution for Environmental education
  - ☐ Reduction of the greenhouse effect (CO_2 sequestration by plants)
  - ☐ Regulation of water flow
  - ☐ Other reasons (please note): _____
- Do you think a green facade may harm a city?
  - ☐ Yes ☐ No
- If yes, why?
  - ☐ Cost of green facade's maintenance
  - ☐ Management problems
  - ☐ Difficulty to renovate the building
  - ☐ Damages to the wall
  - ☐ Presence of animals and insects
  - ☐ Dirt due to animal presence
  - ☐ More humidity in winter
  - ☐ Other reasons (please note): _____
- Have you ever heard about mitigation and adaptation strategies to cope with climate change?
  - ☐ Yes ☐ No
- If yes, do you think a green facade may help better adapt to climate change in a city?
  - ☐ Yes ☐ No
- If yes, do you think a green facade may help mitigate climate change in a city?
  - ☐ Yes ☐ No
- If a green facade is to be set up on the school wall or it is already set up on the wall of the school...
  - Do you think that this green facade may help students feel better at school?
    - ☐ Yes ☐ No
  - Do you think the green facade may help students be more focused on learning?
    - ☐ Yes ☐ No

Figure 4. Example of a survey about people's beliefs and acceptance of VGS, inspired by the literature [25] and adapted for teaching/learning purposes.

3.3.3. Scientific Aspects

To introduce the topic "VGS" at the level of the teaching staff in school, a model could be used as a starting point, such as the one in Figure 5, which summarizes all the important effects a VGS may have, in particular the exchanges of energy and matter between a VGS

and the outside environment, using oriented arrows. This model serves as an orientation for the teacher on which aspects can be addressed in class and investigated experimentally.



- Exchanges of energy
  - Short wave radiation originating from the sun, inward oriented (from the environment toward the VGS)
  - Long wave radiation, either inward (from the environment toward the VGS) or outward oriented (from the VGS towards the environment)
  - Convection, the circular motion that happens when warmer air rises, while the cooler air drops down
  - Thermal conduction, the heat passing through the VGS and the wall.
  - Evapotranspiration, outward oriented from the VGS towards the environment (with the exiting of water vapor)
  - Noise, a mechanical wave with energy transport
- Exchanges of matter
  - CO_2 inward oriented (from the environment toward the VGS)
  - O_2 outward oriented (from the VGS towards the environment)
  - H_2O outward oriented (from the VGS towards the environment) due to evapotranspiration
  - Dusts inward oriented (from the environment toward the VGS)
- The effect on biodiversity (the VGS offering shelter to insects and other animals) is also considered

Figure 5. VGS Model.

The graph should initially contain only the VGS. The students can subsequently add the various environmental factors that are changed by the influence of the VGS as possible assumptions/hypotheses. Some of the assumptions may be derived from the results of the survey carried out when studying the social aspects. These assumptions can then be investigated experimentally by the students. In this way, students can test their hypotheses, which allows inquiry-based learning.

One way to investigate the scientific aspects is to measure relevant parameters depicted in the model. By doing so, students try to quantify and get insights into the natural processes and phenomena happening in a VGS (see Sections 2.4.1 and 2.4.2). For example, regarding the temperature, the building external wall surface temperature reduction is the most obvious parameter because the VGS acts like a sunscreen (as mentioned in Section 2.4.1).

The measurement of relevant parameters should be made with affordable and easy-to-use instruments, suitable for schools. Table 5 gives an overview of some relevant parameters and their possible measuring instruments.

Table 5. Examples of relevant parameters and possible measuring instruments.

Parameters	Measuring Instruments
Surface temperature of green walls compared with bare walls	Temperature logging i-buttons Thermohygrometer with sensor
Surface temperature of walls "indoor" compared with bare walls	Temperature logging i-buttons Thermohygrometer with sensor
Moisture on green walls compared with bare walls	Humidity logging i-buttons Thermohygrometer with sensor
CO_2 sequestered	CO_2 sensor
Dusts, airborne particles captured	Laser egg
NO_2 uptaken	NO_2 sensor
Biodiversity	Direct observation

In addition, students should learn how to interpret the collected data, for instance, by looking at comparative measurements on greened and bare facades and by comparing their data with published ones (examples in Figure 6 for the temperature and Figure 7 for the humidity).

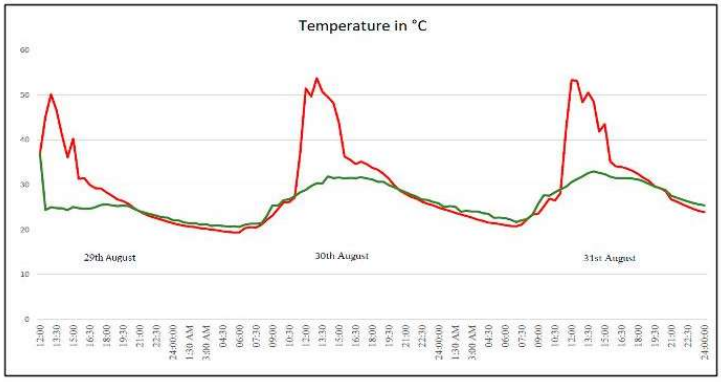


Figure 6. Temperature variation over three days on a building wall with (green line) or without (red line) an ivy green facade [99]. (Permission to reprint granted by the authors and publisher.).

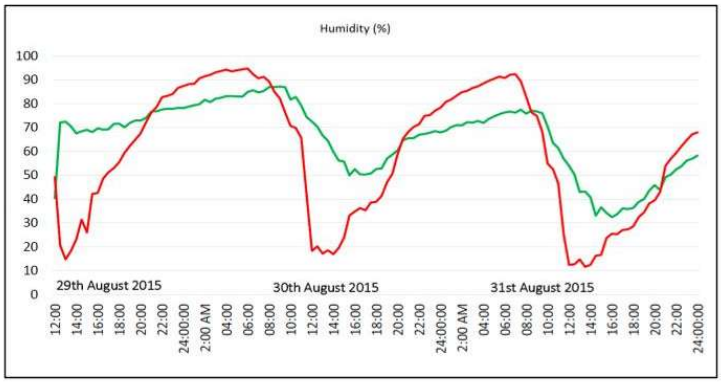


Figure 7. Humidity variation over three days on a building wall with (green line) or without (red line) an ivy green facade [99]. (Permission to reprint granted by the authors and publisher.).

After understanding the significance of the collected data, the teacher should guide students to put this new knowledge into the more general framework of environmental issues, such as climate change, and draw meaningful conclusions that will be communicated in the next phase.

3.3.4. Knowledge Transfer to the Public

Communicating and discussing what has been learned and experienced about climate change is important for students, who thus become "agents of change" for spreading awareness and knowledge of environmental issues in society, for influencing public opinion, for promoting climate-friendly policies, and for motivating people to adopt more sustainable behaviors [100,101]. Researchers have highlighted the multiplier effect of education, which means that entire families and communities have a benefit when individuals share what they have learned. This is particularly true in the case of climate change education: what has been learned about climate change mitigation and adaptation can be passed on to other citizens, so that they are more able to participate in civil society and influence decision making [102].

Therefore, the discussion with peers and adults will be an important phase to multiply and reverberate knowledge, beliefs, and actions into society. Since in this review the focus has been on using VGS as an example of a tool to learn about and act against climate change, the knowledge transfer should be focused on VGS as a starting point for a broader discussion on climate change.

Examples of public outreach may be: discussions among peers (in class, with other classes of the same school, or outside with friends), discussion with adults (family, neighbors, etc.), open days at schools, participation in public events.

Another way to communicate what has been learned externally could be the setting up of a VGS as a living example of a Nature Based Solution (adapted to the climate and environment where students live) to counteract climate change.

4. Conclusions

This literature review analyzed the status of scientific knowledge on VGS and suggested a way of implementation in schools as an example of knowledge transfer from research to school to raise awareness of environmental problems (particularly sustainability and climate change) in young people, as well as for the general purpose of teaching/learning natural sciences. The structure of this narrative review is based on the different content areas of publications, which range from design principles of VGS to research on social acceptability, to research on the effectiveness of VGS. The chosen structure for the review proves also to be an appropriate structure for the design of a teaching sequence on VGS, that can also be applied to other NBS such as green roofs, or in general to green areas in a city.

Moreover, it widens the perspective from the specific object of interest (VGS) to more general issues of social relevance such as environmental protection and climate change. In this regard, the principles of Climate Literacy constitute a guide for educators and teachers to help students in bridging the gap between the specific VGS contents they have learned and more general scientific issues. At the same time, practical experience should facilitate more effective learning and long-lasting learning outcomes.

The design of a prototypical teaching unit (derived from the structure of the review) includes three different phases: a descriptive, an investigative, and a communicative phase. The first phase is an inventory of the object of investigation (VGS) in one's own living environment and a classification of the different forms found. The second phase refers to an inquiry-based approach. Thereby, a distinction is made between two sub-phases: a social-scientific and a natural-scientific research approach. The order in which these two sub phases is performed can vary. In our view, it makes sense to first ask about public opinion and, based on this, then to conduct natural-scientific investigations to determine the extent to which the expressed assumptions are appropriate. Alternatively, however, the

natural-scientific investigations could be carried out first, and then the extent to which these findings are known to the public could be surveyed. In this latter case, the attitude/belief questionnaire (Figure 4) could even be designed by the students themselves. In the third phase, which is the communicative one, the results of the second, investigative phase, are processed so that they can be presented to a larger audience (e.g., at an open day in the school). In this way, students are doing public outreach and see themselves as ambassadors for climate literacy and sustainable development. All proposed instructional activities are consistent with action-oriented, student-centered learning and promote different areas of competence, such as subject knowledge acquisition, inquiry competence, and communication competence. However, the proposed classroom activities will need to be further developed and subsequently tested to analyze whether or not students' scientific knowledge has increased, whether their awareness and behaviors towards sustainability and climate change have improved, and any effect on inclusion observed. These will be future steps to take in this research project.

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2.2 Second publication – Facade greening - from science to school

The second publication (in its second part) specifies the “natural-scientific research approach” of the teaching concept (FIG. 1), so that it can be implemented at school.

The paper consists of two parts:

The first part addresses scientific research data on the topic of green facades, which were collected by Prof. H.G. Edelman’s research group at the University of Cologne. On the one hand, the data pertains to cooling/insulation effects of green facades, with measurements in the field (i.e., on actual building facades rather than on models in the laboratory). On the other hand, the data refers to the absorption of pollutant gases by green facades, which was measured in the laboratories of the University. The beneficial effects of green facades for cities and citizens, biodiversity, and climate change are highlighted.

The second part addresses a didactic intervention that mainly focuses on the “natural-scientific research approach” of the teaching concept described in the first publication. This natural-scientific approach is crucial, as it allows students to acquire new knowledge about the pro-environmental effects of green facades. The intervention is mostly based on hands-on activities, requiring students to perform experiments on green facades (measurement of CO_2 reduction through photosynthesis, cooling through shading, and increase of humidity through transpiration). In addition, models of different types of (green) facades as well as diagrams based on research data are also used as working materials – with the research data referring to plant physiological studies conducted at the University of Cologne (such as the reduction of particulate matter concentration in the air by green facades). Working with these materials allows students to learn through doing, i.e. through direct experience, which makes learning more effectively, as argued by John Dewey (Dewey, 1938).

It should be noted that the intervention described here is a bit more comprehensive than the one that was used in the didactic intervention study (see third publication) where the number of stations in a station-based learning program was limited to four.

Author contributions: AP contributed to the development of the didactic intervention, tried out students' experiments, and assisted in preparing the student project days. Furthermore, she was responsible for investigating the effectiveness of the intervention (involvement in study design, further development of survey instruments, implementation of the study, and evaluation). She co-authored the second part of the paper (original draft preparation: What students should know).

Survey

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Façade greening – from science to school

Fassadenbegrünung – Forschung gestaltet Unterricht

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Abstract: The growing need for cities to adapt to anthropogenic climate change has ushered into a new paradigm where architecture synergistically meets nature. Façade greening may help to take over multifunctional ecosystem services that impact on city residents' well-being as well as on building energy budget. In recent studies on façade greenings, we demonstrated a cooling effect in summer, an insulation effect in winter and a Nitrogen dioxide absorption potential. Introducing this knowledge into school by offering project days led to longer-term changes in students' knowledge, but not in their environmental attitudes. The latter will probably require constant reminders such as a series of project days focusing on environmental issues, bioengineering solutions and personal adaptation strategies.

Keywords: façade greening; climate change; energy saving; air quality; teaching; school experiments

Zusammenfassung: Die Anpassung an den anthropogenen Klimawandel wird für Städte immer notwendiger. Dies hat zu einem neuen Paradigma geführt, bei dem Architektur und Natur synergetisch zusammenwirken. Ein Beispiel dafür sind Fassadenbegrünungen. Sie können multifunktionale Ökosystemleistungen übernehmen, die sich auf das Wohlbefinden der Stadtbewohner und den Energiehaushalt der Gebäude auswirken. In aktuellen Studien zu Fassadenbegrünungen konnten wir einen Kühleffekt im Sommer, einen Dämmeffekt im Winter und ein relevantes Stickstoffdioxid-Absorptionspotenzial nachweisen. Der Transfer dieser Erkenntnisse in die Schule erfolgte durch das Angebot eines Projekttags im universitären Schülerlabor. Dieser führte bei den Jugendlichen zu längerfristigen Veränderungen bzgl. ihres Wissens, aber nicht ihrer Umwelteinstellungen. Um Letzteres zu erreichen, wäre ein umfangreicheres Angebot wünschenswert, wie z. B. eine Reihe von Projekttagen, die sich mit verschiedenen Umweltfragen, Lösungen aus den Bioingenieurswissenschaften und persönlichen Anpassungsstrategien befassen.

Schlagwörter: Fassadenbegrünung; Klimawandel; Energieeinsparung; Luftqualität; Unterricht; Schulexperimente

1 What science tells us

1.1 Introduction

Cities contribute to climate change and are themselves severely affected by its consequences. Prolonged high temperatures with increasingly tropical nights turn densely built and heavily sealed urban neighborhoods into heat islands with negative effects on the health of city dwellers, biodiversity and urban greenery. Climate protection and adaptation to climate change are therefore necessary strategies that cities need to adopt.

Harnessing plants' refined and multifunctional ability to guarantee ecosystem services such as urban heat reduction and air phytoremediation is one example of how "nature's engineering" might help cities to adapt to the various detrimental effects of anthropogenic climate change. Incorporating plants into densely built environments presents a sustainable solution, helping to decrease urban heat [1] and gas pollutants such as Nitrogen Dioxide (NO_2) and Ozone (O_3) [2], to reduce noise and to preserve and strengthen biodiversity.

The potential for reducing the heat budget of buildings through façade greenings has been a subject of discussion for quite some time. The reason for the lack of consensus on specific values is primarily due to the dynamic nature of the topic under investigation. Different experiments conducted under varying climatic conditions have

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resulted in various degrees of cooling achieved by different façade greening systems [3]–[6]. In addition, there is limited information available regarding the air phytoremediation potential of climbing plants, as the relevance of façade greening for urban climate adaptation has only recently been recognized.

The aim of the various projects of our research group is to carry out measurements on thermal impacts of façade greening systems under real conditions. Also, data were collected from gas-flow measurements under experimentally standardized laboratory conditions, to compare the influence of green ("green architecture") and non-green ("grey architecture") façades on parameters such as temperature, Nitrogen Dioxide (NO_2) and Ozone (O_3) – both considered as harmful anthropogenic gases in cities [7].

The results of the data collection will be incorporated into an overall assessment of the thermal benefit potential of façade greening systems (to improve the urban climate) and air quality as an ultimate urban adaptation strategy to climate change.

1.2 Cooling and insulation potential of green façades

To quantify the cooling and insulation effects of ground-based ivy façade and wall-bound façade greening, wall-surface temperature profiles were collected using data loggers on south exposed façades in two different locations.

1.2.1 Ground-based ivy façade

1.2.1.1 Methods

Data loggers (iButtons) were programmed for an hourly reading and placed on the wall surfaces of two buildings adjacent to each other in the city of Bonn (Figure 1). The house under investigation has had a *Hedera helix* (ivy) façade greening for the past 25–30 years. While the adjacent house was a white-painted façade without greening. Both had concrete surfaces. Results obtained from predominantly hot and cold days were compared to each other as shown below.

1.2.1.2 Results

Wall surface temperatures (shown in Figure 2) varied up to about 25 °C on a typical summer day with peak periods between 12 and 2 pm where the temperature difference was at the highest.

During cold periods the green façade acted as an additional insulating layer, providing a warmer temperature on the surface of the wall as compared to the adjacent wall as shown in Figure 3.

1.2.2 Wall-bound façade greening

1.2.2.1 Methods

Similar to the previously described method, data loggers were fixed to the surfaces of both a greened and a white wall without greening (Figure 4).

1.2.2.2 Results

The data collected for the temperature parameter shows that the wall-mounted façade greening has a consistent cooling effect on warmer days, compared to the non-greened façade sections (see Figure 5).

The temperature profiles for colder periods also showed that the wall-bound façade greening has a continuous insulating effect compared to non-greened façade sections.

1.2.3 Discussion

Improvements in the building's energy budget can be observed in both extreme weather conditions (hot and cold days).



Figure 1: An image of the ground-based façade greening under investigation; with arrows showing locations of data loggers.

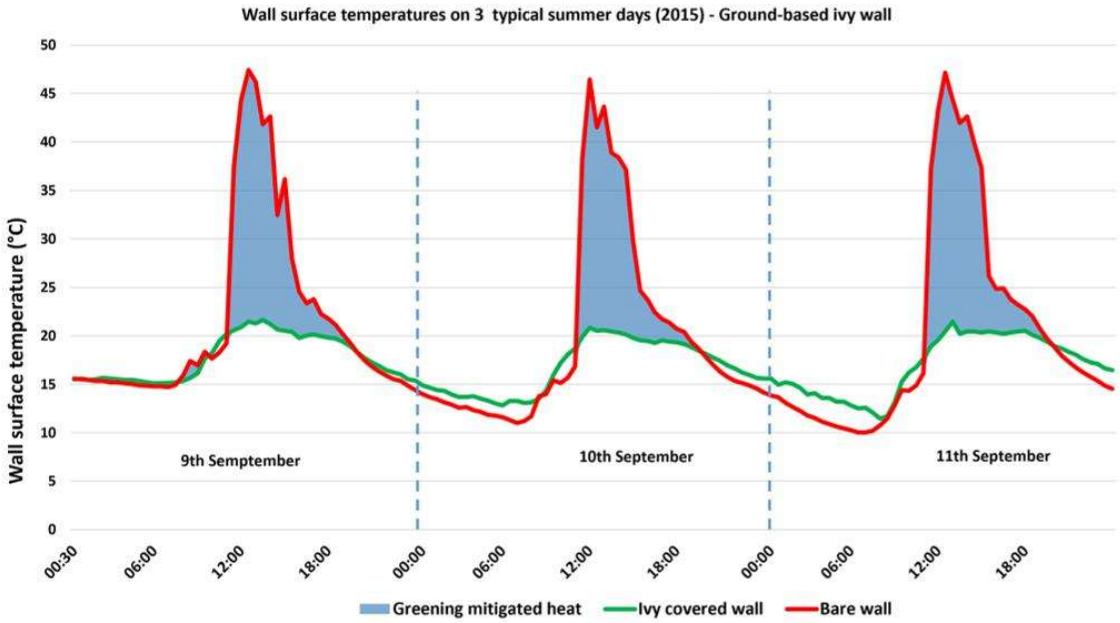


Figure 2: Temperature profiles of a greened and a white painted wall; showing surface temperature differences on summer days, and a relatively stable surface temperature of the greened wall while the white wall undergoes temperature rise and fall.

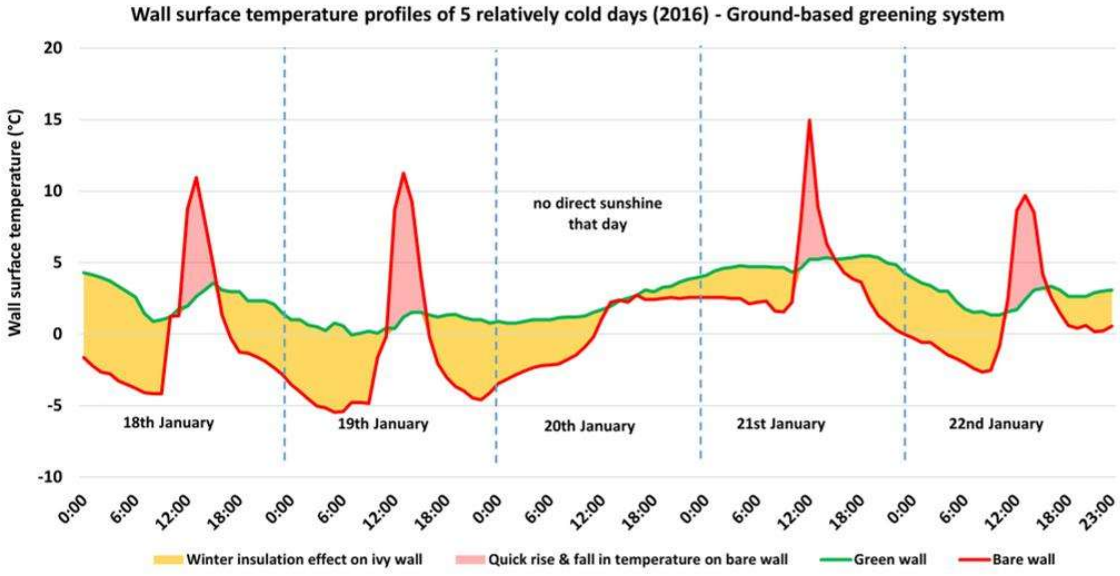


Figure 3: Surface temperature profiles of an ivy wall and white painted wall; showing insulation effect of the greened wall and its relatively stable temperature while the white wall undergoes temperature rise and fall.

During warm periods, the climbing plants offer a protective layer which prevents direct sunlight from reaching the surface of the wall it is covering, hence reducing the amount of energy incident onto the surface of the wall. This is due to the proximity of the plants to the wall with the leaves absorbing light energy and casting their



Figure 4: Image of the wall-bound façade under investigation.

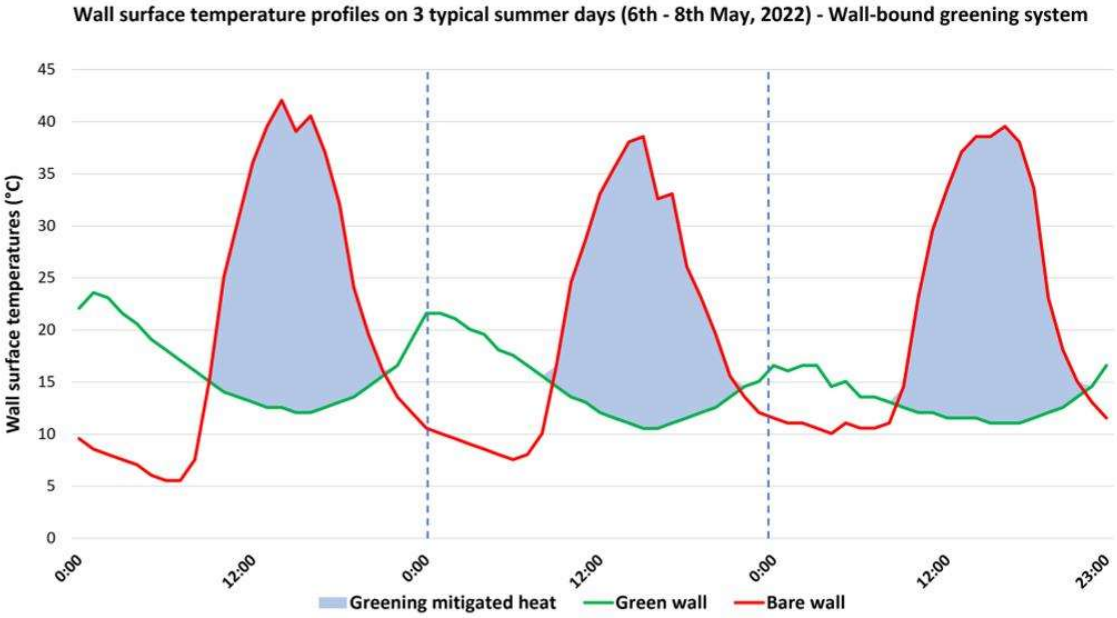


Figure 5: Temperature profiles on a south oriented façade: showing the difference in temperature on the surfaces of both greened and bare-white wall simultaneously (6th–8th May 2022).

shadows onto the surface which contributes to temperature reduction.

In addition, the process of evapotranspiration or transpirational cooling which involves the use of energy from the leaves and its environment as temperature regulating mechanism contributes to the overall cooling effect observed on the surface of the green wall as compared to that of the white wall.

On the other hand, cold temperatures tend to produce a rather more interesting effect as an evergreen vegetation layer (like an ivy façade) assumes the role of an extra insulation layer. During cold temperatures the flow of heat

energy from buildings is usually from within the apartment to the outside environment. This is because temperatures inside are mostly between 18 and 20 °C making energy loss from inside to the outside environment the main driver of energy consumption. With the extra vegetation acting as an insulation layer, the rate of heat loss from the greened house is significantly reduced.

There are great similarities between the cooling effect of both ground-based and wall-bound systems; however, there is also a noticeable difference: the wall-bound system presents a peculiar rise in wall-surface temperatures at night. This is cooled through out the day and rises again at night. This could be explained by the possible blocking of the radiative heat energy emitted by the building at night, as it serves as an insulation layer preventing or reducing the dissipation of heat energy from the building at night.

Finally, there is an important aspect of façade greening often overlooked which is the protection of the building from extreme thermal stress which has a direct link to the longevity of the building.

1.3 Absorption of pollutant gases (NO_2 & O_3)

There is ample evidence showing different absorption potentials of greenhouse and pollutant gases in some woody plant species [8]. However, information on the air phytoremediation potentials of commonly used climbers in façade greening is limited. Given the heterogeneous distribution of air pollutants in the built environment, plants happen to be the best options for their control in our sparsely greened cities.

To methodically examine this effect, we subjected common climbing plants in a flow-through device to specified amounts of air constituents and examined how these compounds were affected by the plants by examining the compositions of the effluent air with two gas analyzers namely, a mid-infrared laser absorption spectrometer (TDL) and a cavity-ring-down spectrometer (CRDS).

The fundamental idea behind the experimental strategy was to apply brief, pulse-like feeds of gases and analyze the concentration changes that occurred right after the pulses. The quick impacts of the plants on the filtration of the applied gas components were analyzed by plotting the time-dependent lowering of the pulse-induced peaks in both illuminated and dark-phases. In this section the absorption potential of NO_2 will be presented because of its status as a pollutant gas of great concern in cities. N_2O, which is a stable tropospheric gas was used as a control, with its source being ambient air.

1.3.1 Experimental design

A graphical representation of the instrumental setup is shown below (Figure 6) with the ivy subspecies "Plattensee"

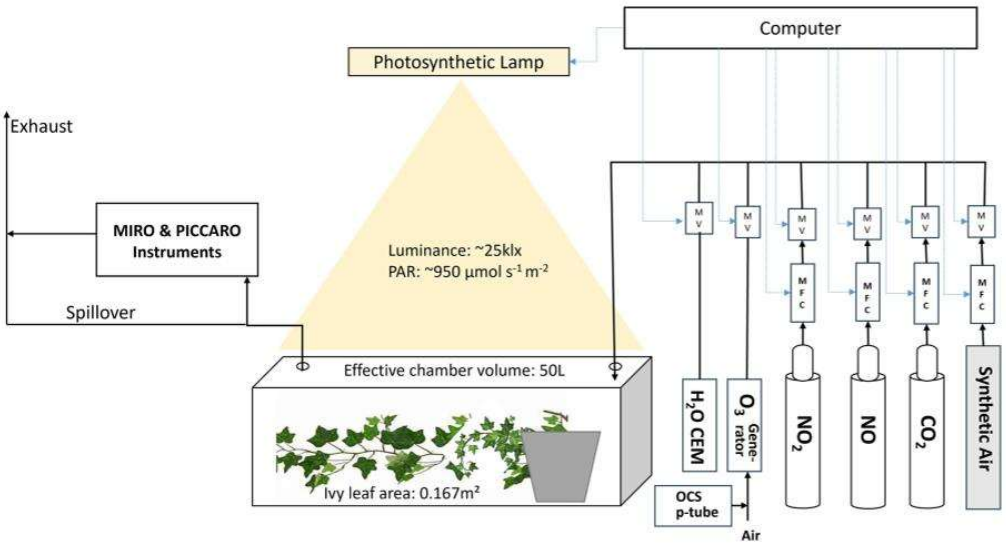


Figure 6: Experimental setup (with an ivy plant) for the greenhouse and pollutant gas absorption experiment. The reaction chamber incorporates a ventilator and a temperature sensor. The constant volume flow rate of synthetic air through the reaction chamber is 10 L/min. The term "MFC" denotes mass flow controllers and "MV" magnetic three-way-valves. The leaf area of 0.167 m^2 given in this figure relates to a specimen of the ivy variety *Hedera helix* "Plattensee" used in this experiment.

as an example. The plants were placed in a small reaction chamber and subjected to a day-night cycle using an LED lamp. The illuminated phase (day) of the experiments ranged from 9 am to 6 pm, after which the lights were switched off for the dark phase (night). The operating temperature in the chamber has been monitored using a temperature sensor called "ibutton" (Hygrochron data logger) averaging 24 °C+/−2 °C.

1.3.2 Results

It was observed that the absorption of NO_2 presented diurnal variations, with most of the absorption occurring in the illuminated phase of the experiment. The results for *H. helix* "Plattensee" are summarized and presented in Figures 7 and 8. Similar results were also obtained for other plant species used for façade greenery.

The time scale in Figure 7, collated over a 24-h period under both illuminated and dark phases of the experiment translates into an absorption rate of about 95 µg/h NO_2 for a leaf area of 0.16 m^2 at a concentration of 40 µg/m^3 NO_2 during the illuminated phase of the experiment as shown in Figure 8 below.

A more detailed explanation of how the absorption rates were calculated can be accessed through Aduse-Poku et al. [9].

1.3.3 Discussion

The permissible limits of Nitrogen Dioxide (NO_2) in the European Union have been revised to align more with the Air Quality Guidelines of the World Health Organization by 2030 because of the EU- Green Deal [10]. For NO_2 this results in a reduction of 50 % from an annual average of 40 µg/m^3 to 20 µg/m^3. What this means is that cities will have to find innovative ways to reduce these pollutants to conform with the revised limits by 2030.

This will be a constraint on the cities already exceeding the current limits. According to the results obtained, *H. helix* at a concentration of 20 ppb NO_2 (about 40 µg/m^3) has the potential to reduce 5493 µg NO_2/m^2 leaf area/day. Projecting these results onto a typical street canyon with the conditions of the laboratory experiments presents about a 17 % reduction in NO_2 pollution levels if the street is covered by an ivy plant.

2 What students should know

2.1 Introduction

It is important that the knowledge gained about the environmental effectiveness of green façades is passed on to

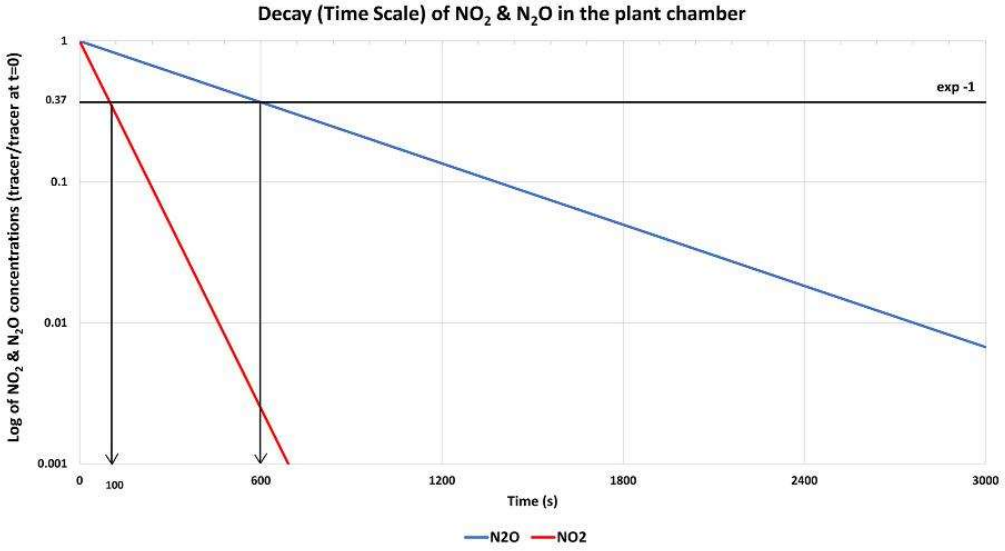


Figure 7: Timescale of decay – the time taken for N_2O (control) and NO_2 to be absorbed or eliminated from the plant chamber using the ivy variety *Hedera helix* "Plattensee". Every hourly collated point (see Figure 8) is a summary of the above-described decay trends of both NO_2 and N_2O.

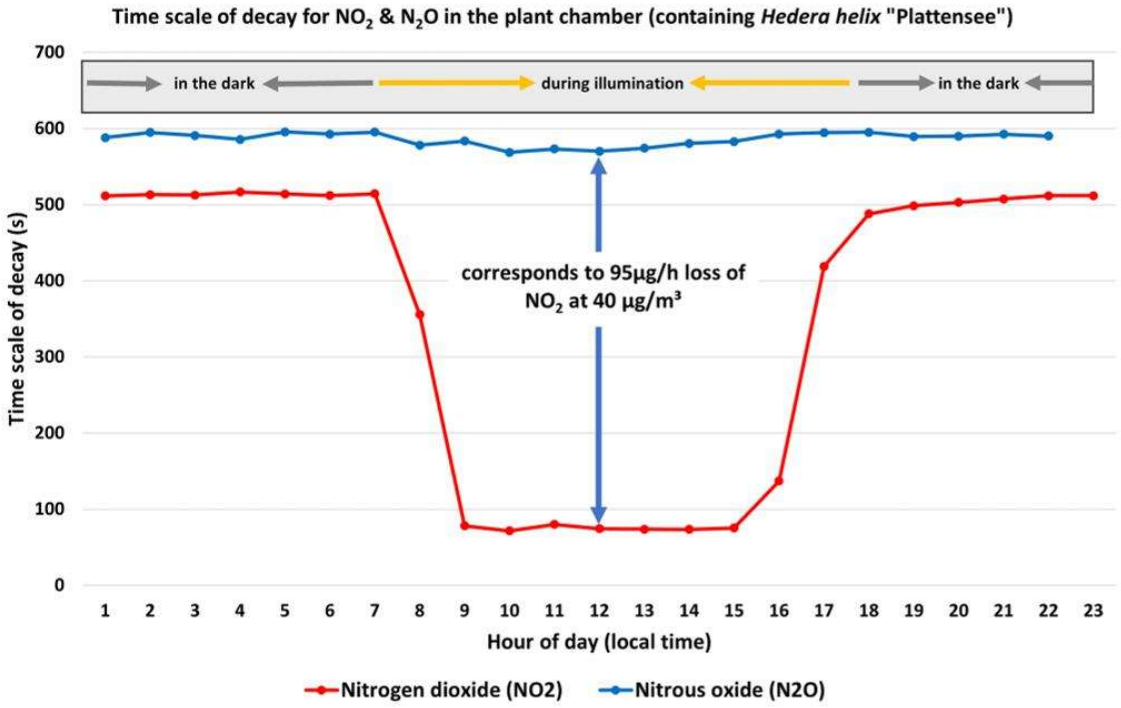


Figure 8: NO_2 uptake by *Hedera helix* "Plattensee" with a leaf surface area of 0.16 m^2.

the next generation [11]. By this, the acceptance of climate-friendly measures (in this case green façades) should be strengthened and the implementation of these measures, particularly in urban centers, should be accelerated. Schools offer themselves as a place of mediation, so that young people can transfer the newly acquired knowledge to their families and support climate-friendly initiatives.

However, the question remains as to how these current topics can be integrated into school lessons, even if the curricula do not (yet) specify them. Three strategies are briefly outlined here. (i) Linkages could be established between the new topic to be taught (in this case green façades) and existing curriculum content. The basic scientific knowledge (on photosynthesis, shading, evaporative cooling and knowledge of species) is then applied in a new context, namely that of façade greening. (ii) New topics, such as façade greening, can be integrated into pre-service-teacher training so that student teachers can bring their experience directly into their lessons when they enter the profession and act as multipliers. (iii) In order to reach in-service-teachers with their classes, teacher training programs can be developed on the one hand and school project days can be offered on the other. Such project days can be organized as extracurricular learning opportunities provided by scientific institutions, e.g. in their school laboratories.

2.2 Intervention

At the University of Cologne, we developed a project day on the topic of façade greening for students in grades seven to nine and tested it with a total of more than 130 pupils. It allows pupils to acquire new knowledge using (a) models, (b) simple experiments (taken from the literature but being newly compiled) and (c) current data from scientific research. The project day is divided into three phases, which are briefly described below. This description refers to a more comprehensive version of the project day than the one tested for effectiveness (see below).

The project day starts with a short introductory phase in which different environmental problems in urban centers are identified by asking students for their prior knowledge in a plenary discussion. The following overarching question is whether façade greening can contribute to mitigating at least some of the problems identified by the pupils.

The work phase is a station-based learning program. The aim of this phase is to familiarize students with the

different types (station 1) and effects of green façades (station 2–6). The stations address topics of biology and physics lessons, like photosynthesis (station 2), absorption and thermodynamics (station 3 and 4) or biodiversity (station 6). Three stations (2–4) refer to experiments in which individual plants (such as ivy) are used as models for an entire façade. Other stations focus on scientific activities like species identification (station 6) or interpreting scientific data (station 5).

- The aim of Station 1 is to introduce students to different types of façade greening using models (or alternatively real façades or photos). The focus here is not only on the technical construction, but also on familiarizing students with different plant species that are suitable for different types of façades. In this way, students' knowledge of species is also increased.
- At station 2, students investigate the extent to which plants reduce the level of the greenhouse gas CO_2 in the air. For this purpose, the change in the CO_2 content is measured in closed containers (e.g. aquariums), with and without plants, using a sensor over a defined period of time. If required, the effect of CO_2 as a greenhouse gas can also be demonstrated in a separate experiment by irradiating closed containers containing air with different CO_2 concentrations with a light source and measuring the temperature increase.
- Station 3 demonstrates the shading effect of a green façade, which leads to a lower temperature rise inside a building. This is also a model experiment in which a temperature sensor is located in a wooden box that is exposed to a radiation source either directly (naked) or covered with ivy.
- Station 4 demonstrates that plants transpire and that this process leads to a cooling of the environment. In total, there should be two separate model experiments. In the first experiment, a sensor is used to demonstrate an increase in humidity in a closed container when a plant is present. In a second experiment, students should experience the cooling effect caused by the evaporation of water molecules from a moistened cloth.
- Station 5 deals with the topic of particulate matter concentration in the air and the extent to which this can be reduced by green façades. As student experiments on this topic are difficult to carry out, experimental data from research is presented, which should then be interpreted by the students. Ideally, the young people would be shown a short video of the experiment at the beginning so that they have a better idea of how the results were obtained.
- At Station 6, the influence of façade greening on biodiversity is to be recorded. For this purpose, living organisms can be searched for on a bare as well as a green façade and assigned to different animal groups in order to record the diversity of species and number of individuals. Alternatively, students can work digitally with photos of different magnification levels.

In the final phase of the lesson, the collected data is summarized and it is examined to what extent the problems which students have associated with conurbations, can be reduced by green façades. Based on the modelling experiments and the recorded data, qualitative statements can be made. If the measured effects could additionally be extrapolated to an entire building façade or a whole street canyon, then the effects would be even more impressive. This could further enhance the project day and may be a task for the future.

2.3 Analysis

Ongoing research on the effectiveness of our project day has so far led to the following findings: It resulted in an increase in students' knowledge, which was still present four weeks later. This knowledge includes both general environmental knowledge relating to green façades and specialized experimental knowledge acquired by the students as a result of carrying out the experiments. However, the project day did not bring about a change in general environmental attitudes. Only the attitude towards green façades changed to a more positive one immediately after the project day, but had decreased again four weeks later. Longer-term and/or repeated interventions are necessary if major changes in environmental attitudes are to be achieved [12], [13]. This could involve a series of several project days on various environmental topics, through which the relevance of environmental measures is repeatedly reminded to the pupils. It would therefore make sense for school laboratories to expand their programs by developing several project days relating to biological engineering and its potential for environmental protection.

2.4 Conclusions

In conclusion, it can be said that the topic of façade greening is very well suited to transferring scientific findings into school education because of its concreteness, good comprehensibility and comparatively easy implementation. Wherever possible, such a relationship between science and school should be established to demonstrate the benefits of biological engineering in moving our society towards greater sustainability. School laboratories can play a major

role here when it comes to imparting solution-based knowledge relating to environmental problems.

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Research ethics: The present survey did not require the approval of an ethics committee, because the research did not pose any threats or risks to the respondents, and it was not associated with high physical or emotional stress.

Author contributions: The authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Competing interests: The authors state no conflict of interest.

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Data availability: The data presented in this paper are available on request from: Bio-data: HE, Educational data: KS.

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2.3 Third publication – Sustainability Education Through Green Facades: Effect of a Short-Term Intervention on Environmental Knowledge, Attitude, and Practices.

The third publication presents the results of an intervention study. The intervention referred to the “natural-scientific research approach” of the teaching concept similar to how it was described in the second publication (a more detailed description can be found in the appendix 6.1).

This didactic intervention was implemented by inviting school students (mainly secondary level I) to a student laboratory of the University for a short session of 4 hours. The short time span was chosen due to practical limitations in space and time (because it may be difficult for classes to be excused from normal lessons to visit an extracurricular learning location).

The goal of the didactic intervention was not only to transfer knowledge from research to school, but also to affect students’ pro-environmental attitude and to induce certain behaviors associated with the project day (e.g., independently learning more about green facades or caring for a plant). In terms of its structure, the intervention consisted of a short introductory lecture phase (referring to common climate/environmental issues in cities, like Urban Heat Island effect, loss of biodiversity, and air pollution), followed by an extensive experimental phase.

The didactic intervention was evaluated in terms of its effects on the KAP triad (FIG. 2), which is students’ knowledge (K), attitude (A) and the relation of these components (K and A) to students’ (intervention related) practices (P) (Pacini et al., 2025). A pre-post-follow-up design was used for evaluation, with the questionnaires being mainly self-developed due to the necessity of a specific thematic focus related to green facades.

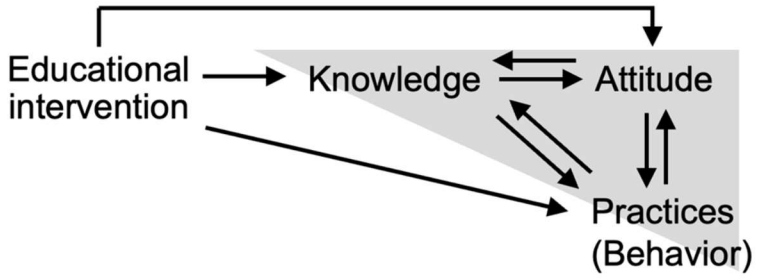


FIG. 2 The KAP triad and possible interactions (modified graphic based on Iverson and Portnoy) (Pacini et al., 2025)

The data were analyzed using ANOVA (Pacini et al., 2025) for the effects of the didactic intervention on knowledge and attitudes. In addition, regression analyses were performed to analyze the effect of knowledge and attitude on behavior. The main findings are described below.

Effects on knowledge

(i) Knowledge increased significantly from the pre-test to the post-test (immediately after the intervention). (ii) Even four weeks later, in the follow-up test, knowledge was still significantly higher than in the pre-test, although it had decreased again. (For results (i) and (ii), see Fig. 3 (a, b) in paper 3 (Pacini et al., 2025, p. 11.)

A distinction can be made between content knowledge (relating to structure and function of green facades and their connection to environmental problems) and technical knowledge (relating to the experiments in the laboratory). (iii) In the preliminary test, students' technical knowledge was less developed than their content knowledge. (iv) The increase in knowledge between the pre-test and post-test was greater for technical knowledge than for content knowledge. (v) The decline from post-test to follow-up test was greater for technical knowledge than for content knowledge. (For results (iii) to (v), see Fig. 3 (a, b) in paper 3 (Pacini et al., 2025, p. 11).

Effects on attitude

A distinction can be made between general environmental attitude and specific environmental attitude (i.e., attitude toward green facades). The paper refers only to the results on the specific environmental attitude. This section, however, also contains

results on general attitudes. (vi) No significant changes in general attitudes were found between the survey dates (see below FIG. 3). (vii) The specific attitude increased significantly from the pre-test to the post-test. However, it also decreased significantly again in the four weeks following the post-test. Thus, there was no significant change between the pre-test and the follow-up test (see Fig. 4 in paper 3 (Pacini et al., 2025, p. 12)). (viii) Looking at the specific attitude items individually, 3 out of a total of 8 showed a significant change between the pre-test and post-test (item 1, 2 and 4). However, these items also subsequently fell back to a value that did not differ significantly from the initial one (see below Fig. 4, and Tab.1 in paper 3 (Pacini et al., 2025, p. 13)).

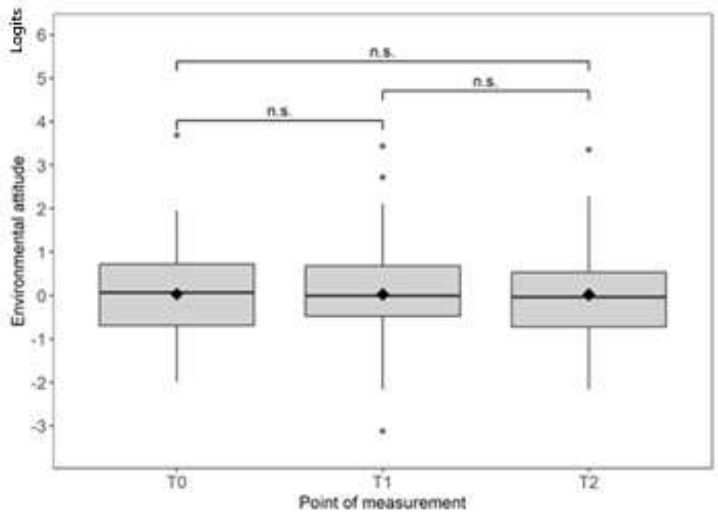


FIG. 3 – General pro-environmental attitude over time. N = 62. Box plots including mean (♦). Outliers (gray dots). Instrument used for the survey: adapted version (Baierl et al., 2022) of the behavior-based environmental attitude scale for adolescents (Kaiser et al., 2007) and the 2 factor model of environmental values (2MEV model) scale (Bogner & Wiseman, 2006). The data were presented at the ERIDOB conference in Lyon, 2024. At that time, the analysis included only those students who had completed the questionnaires in full – hence the lower number of students (not 71, but just 62). The figure and underlying calculations were provided by Marie Brüggemann.

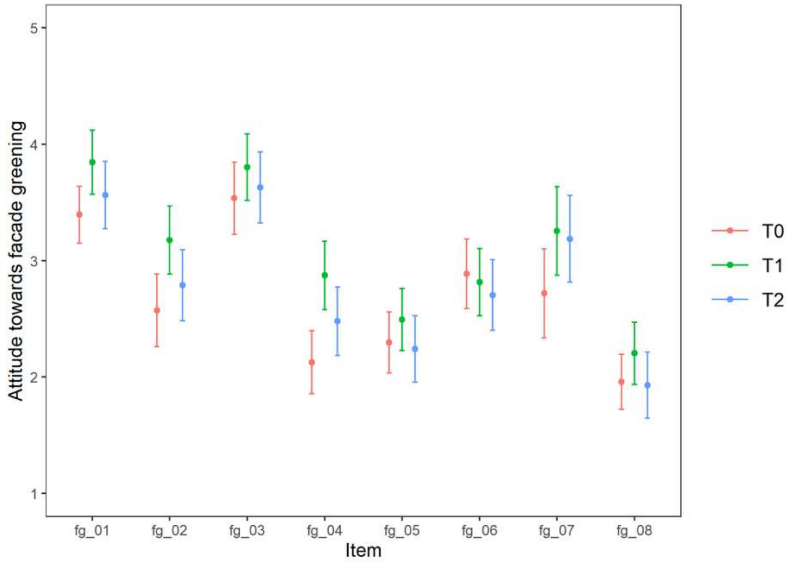


FIG. 4. Differences in the level of agreement with specific attitude items (relating to facade greening = fg) across three measurement points. (Visualization of the data of Table 1, p. 13, paper 3 (Pacini et al., 2025)). Response format: 5-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. Meaning of the items (item text): fg_01* = The greening of house walls is so important that it should be supported by the government. // fg_02* = If I had a house, I would green the house walls (facade). // fg_03 = Cities would be more beautiful with more green walls/facades. // fg_04* = For new buildings, facade greening should be mandatory. // fg_05 = I would donate money for the construction of green facades on public buildings. // fg_06 = I would take part in maintaining a green facade at my school (e.g., cutting back vegetation on the facade). // fg_07^{r} = It would bother me if I had more spiders around me because of a green facade. (r = reverse item) // fg_08 = I would distribute informational flyers in my free time to promote green facades. * Significant increase in agreement from the pretest (T0) to the posttest (T1), which, however, does not last until the follow-up test (T2). The figure and underlying calculation were provided by Marie Brüggemann.

Effects on practices

The students were asked about a total of 9 activities. Of these, 2 related to the project day (reflecting on it or talking about it), 3 items related to an offered plant to take home and to care about it (plus an additional item about the condition of the plant, whether it is still alive), and 4 items to a flyer to take away, to read it and to implement activities proposed therein. (ix) FIG. 5 shows how many students performed a specific activity, with activities such as taking the flyer or a plant home and reflecting on or talking about the project day being the most common ones. (x) FIG. 6a shows how many flyer-related activities were performed by how many students, while FIG 6b illustrates that the performance in the knowledge test (combined content & technical knowledge

immediately measured after the intervention/T1) being predictive for the sum of flyer-related activities done during the next 4 weeks after the project day. No corresponding result could be found for plant-related activities. (xi) FIG. 7a shows how many plant-related activities were performed by how many students and FIG 7b illustrates that the attitude/opinion on facade greening (immediately measured after the intervention/T1) being predictive for the sum of plant-related activities done during the next 4 weeks. No corresponding result could be found for flyer-related activities.

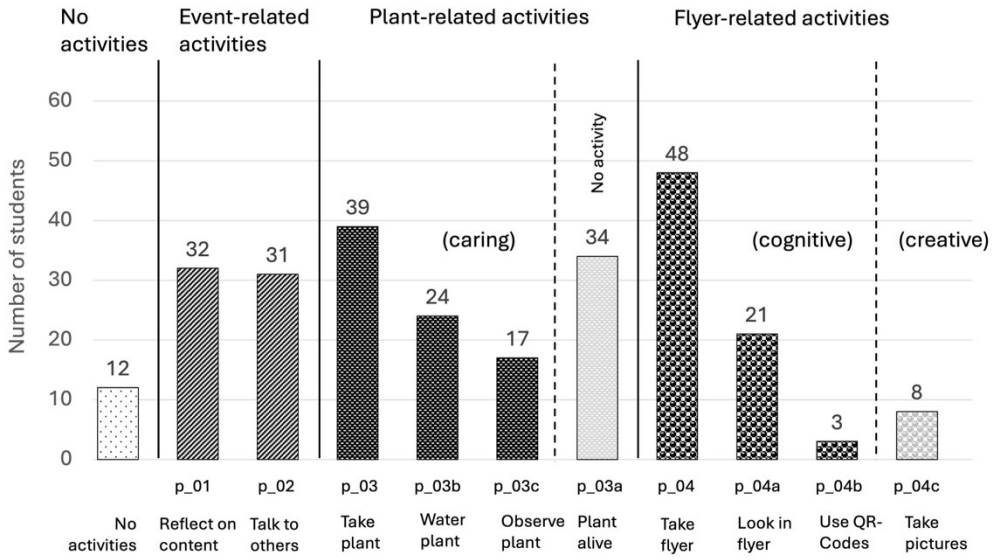
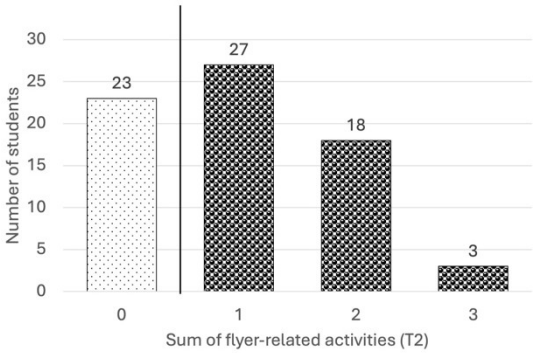
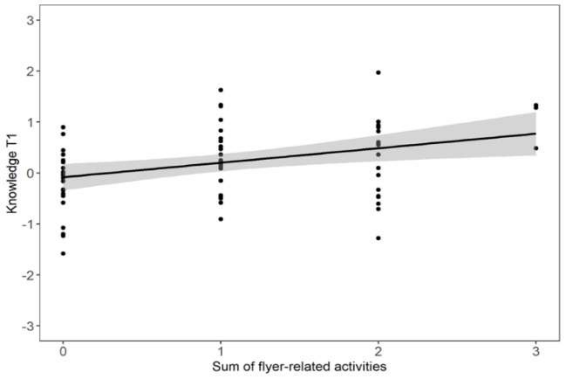


FIG. 5: Frequency of follow-up activities. n = 71 students. Wording of the items: p_01: Over the past four weeks, I have been reflecting on what I had learned. // p_02: After the project day, I talked to others about the content (e.g., the experiments). // p_03: I took a plant home with me from the project day. // p_03b: I myself have been watering my plant regularly. // p_03c: I have been observing the growth of my plant. // p_03a: The plant is still alive. // p_04: I took a flyer from the project day. // p_04a: I looked at the flyer again after the project day. // p_04b: I looked at the examples of other green facades using the videos and websites (QR codes) provided. // p:04c: I took photos of green facades in my neighborhood. The response scale for most items was dichotomized (no = 0; yes = 1). Only the first two items (p_01, p_02) had a 5-point Likert scale ranging from never to very often. This was also dichotomized by grouping the two lowest categories (never and seldom) as absent (0) and the three higher categories (sometimes, often, and very often) as present (1).



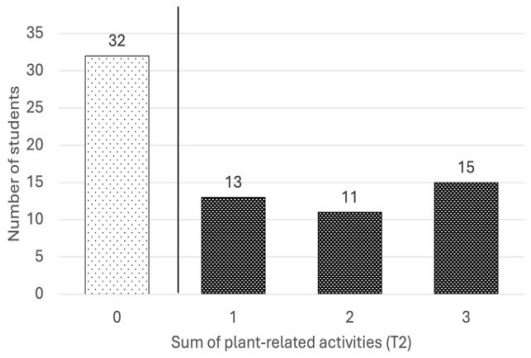
6a

FIG. 6a: Number of students (n= 71) in relation to the sum of flyer-related activities they performed. (i.e., taking a flyer, looking inside the flyer, using the QR codes in the flyer to obtain additional information about green facades).



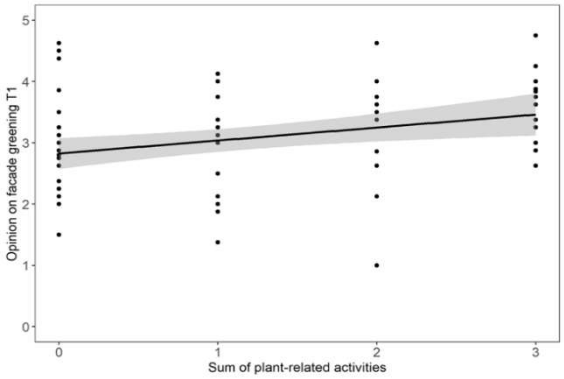
6b

FIG. 6b: The regression analysis yielded a significant result (*at the 5% level), with performance in the knowledge test (combined content & technical knowledge immediately measured after the intervention/T1) being predictive for the sum of flyer-related activities (measured in the follow-up test/T2). No such correlation could be found for plant-related activities. The unit of the knowledge scale are logit values.



7a

FIG. 7a: Number of students (n= 71) in relation to the sum of plant-related activities they performed. (i.e., taking a plant, watering the plant, observing the plant).



7b

FIG. 7b: The regression analysis yielded a significant result (**at the 1% level), with opinion on facade greening (measured immediately after the intervention/T1) being predictive for the sum of plant-related activities (measured in the follow-up test/T2). No such correlation could be found for flyer-related activities. The unit of the opinion/attitude scale are Likert scale points ranging from 1=*strongly disagree* to 5= *strongly agree*).

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Sustainability Education Through Green Facades: Effects of a Short-Term Intervention on Environmental Knowledge, Attitude, and Practices

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Abstract: Teaching can contribute substantially to achieving the Sustainable Development Goals (SDGs) by addressing traditional curriculum-relevant topics in new contexts related to sustainability. A suitable context is green facades, which support several SDGs at once. The aim of sustainability education should be to foster all components of the KAP triad, i.e., not only promoting environmental knowledge (K) and attitude (A) but also enabling appropriate practices (P). This study analyzes the effect of a short-term didactic intervention on green facades (4 h) on the KAP triad. Pre-, post-, and follow-up tests were conducted with $n = 71$ students aged $M = 14.19$ ($SD = 1.54$). Knowledge and attitude development were analyzed using ANOVA. Regression analyses were calculated to assess the relations of knowledge and attitude with practices. The results show that even a short-term intervention can lead to longer-term effects regarding knowledge growth but will only bring about short-term changes in attitude. Attitude items with the strongest change were not related to students' direct or immediate activities. In addition, environmental knowledge and attitude appear to support different kinds of activities. Therefore, it seems important that didactic interventions focus on knowledge and attitude to enable students to engage in pro-environmental behaviors.

Keywords: facade greening; sustainability; SDGs; education for sustainable development; extracurricular learning; knowledge; attitude; practices; behavior; KAP

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1. Introduction

Sustainability has been promoted over the last 30 years by the United Nations (UN). Particularly, in 2015, the 17 Sustainable Development Goals (SDGs) were defined [1]. The United Nations Educational, Scientific and Cultural Organization (UNESCO) led and coordinated the Education 2030 Agenda through a guidance document, "Education for Sustainable Development (ESD)—Learning Objectives" [2]. It serves as a resource bank for educators and teachers (topics and activities) to promote sustainability among young people, who are key in reaching the SDGs as the main actors for change. ESD has become an integral part of the SDGs, as no. 4, Quality Education, explicitly highlights. Target 4.7 of this SDG states: "By 2030, ensure that all learners acquire knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development [. . .]" ([2], p. 8). Notably, ESD leads to achieving all SDGs: "ESD enables all individuals to contribute to achieving the SDGs

by equipping them with the knowledge and competencies they need, not only to understand what the SDGs are about, but to engage as informed citizens in bringing about the necessary transformation" ([2], p. 8).

ESD should, therefore, have a special status in school lessons. It is thus necessary to consider which traditional curriculum-relevant topics can be summarized under an environmental context and taught with a new focus. Such a new focus could be provided by referring to green facades, because this context allows teachers to address various SDGs, particularly 3, 11, 13, and 15 (see Section 2.1.1). However, such a new context, which often originates in research, seldom finds its way directly into school lessons, but rather via the "detour" of extracurricular learning venues and activities. The latter usually offer courses of limited duration, e.g., half a day or one day. This raises the question of the impact of these short-term offers, whereby longer-term effects are desired. Ideally, these effects should relate to all components of the KAP triad, i.e., students' knowledge (K), attitude (A), and practices/behavior (P) in the context of interest. Our study therefore focuses on the longer-term effects on the KAP triad caused by an extracurricular project day on green facades for students aged around 14 at a German university. In other words, the aim of the study is to evaluate the effects of a short-term intervention about green facades on knowledge and attitude and to investigate their relation to relevant practices.

2. Theoretical Background

2.1. Green Facades, an Exemplary Topic for Teaching About Sustainability

There are content-related and educational reasons why the topic of green facades is suitable for teaching about sustainability in schools.

2.1.1. Content-Related Reasons for Teaching About Green Facades

Content-related reasons why green facades should be addressed in the classroom relate to various SDGs touched upon by this topic; they are as follows:

- Goal no. 3: good health and well-being;
- Goal no. 11: sustainable cities and communities;
- Goal no. 13: climate action;
- Goal no. 15: life on land.

The relation between the aforementioned SDGs and green facades can be explained as follows. Green facades are any way of setting plants on the vertical facade of a building [3]. They are regarded as a type of nature-based solutions, since they have the potential to counteract several environmental problems in cities, such as climate warming emphasized by the Urban Heat Island (UHI) effect [4,5], a lack of green areas [6], unhealthy living conditions [6–8], and the loss of biodiversity [9–11]. More precisely, they regulate the temperature inside the buildings [5,12] through shading, the "albedo effect", and evapotranspiration ("cooling effect"). Temperature regulation results in less energy consumption and, in turn, less CO_2 emission. Consequently, green facades provide summer thermal protection that is beneficial for human health (SDG no. 3) and mitigate climate warming (SDG no. 13). In addition, green facades sequester CO_2 [13] through the photosynthesis process, another contribution to mitigating climate warming (SDG no. 13). Furthermore, green facades capture dust and air pollutants, thus improving the air quality [7] and providing healthier conditions for people (SDG no. 3). They contribute to improving the psychological well-being of people since they fill the lack of greenness in dark-gray cities (SDG no. 3) [6]. In addition, green facades muffle noise [8] and determine better humidity conditions for dry, warm cities [5] (SDG no. 3). They also contribute to counteracting the loss of biodiversity, hosting little animals (SDG no. 15) [9–11]. Overall, green facades make cities more sustainable (SDG no. 11).

2.1.2. Educational Reasons for Teaching About Green Facades

From an educational perspective, the topic of green facades is also suitable for science lessons. This can be seen, for example, if one takes Klafki's reasons for selecting teaching themes as a basis [14]:

- Exemplarity: Green facades are an example to demonstrate the multiple positive environmental effects of greening measures in general (parks, hedges, etc.). In addition, green facades support thinking in another spatial dimension, namely not only in the horizontal but also in the vertical, which may also be relevant for plant cultivation;
- Students' current life meaning: Green facades may be present in students' neighborhoods and could provide a direct object of study. However, even with a green facade, students may pass but not realize it. Nevertheless, they should notice and appreciate it because of its strong pro-environmental power;
- Students' future life meaning: Students should know about the pro-environmental benefits of green facades to support such (and other) greening measures, both on an individual and societal/political level.

In addition, there are also other criteria related to school practices that support the selection of green facades as a teaching topic:

- Link to school curricula: Teaching about green facades can address various curriculum-relevant topics, such as photosynthesis, light absorption and reflection, heat transfer as latent heat during evaporation, and the transpiration process in plants;
- Feasibility: The topic of green facades can be easily integrated into lessons, as various effects of the facade plants can be shown in short-term, cost-effective laboratory experiments at school.

Due to their content-related and educational relevance, green facades are used in the present study to design an intervention, which can be seen as a central phase of an ideally even more comprehensive teaching unit [15].

2.2. The Theoretical Construct of the KAP Triad

The KAP triad [16,17] is a construct referring to the relationship between individuals' knowledge, attitude, and practices related to a specific topic. The abbreviation KAB, which can also be found in the literature, with the B referring to behaviors, is considered equivalent to practices in several publications [18–20]. Although there may be small interpretative differences between the two terms [21], these are not relevant to the present study. In general, the KAP triad can be applied in different ways: On the one hand, KAP data can be used to describe the baseline situation in a study population and, subsequently, to plan adequate didactic interventions. On the other hand, it can be used to evaluate the impact of a didactic intervention.

A didactic intervention may affect the KAP triad in different ways (Figure 1). In the 1970s, Iverson and Portnoy [22] summarized many of these relations. Knowledge and attitude can be seen as important factors in explaining and influencing the third one, behavior, even if they alone are not sufficient as a basis for explanation and optimization [22,23]. Various personal and situational factors contribute to this relationship, e.g., competing needs and motives, different levels of self-efficacy, or the presence of others who provide support [16,17]. However, the present study will not address these additional factors because they are outside the realized intervention.

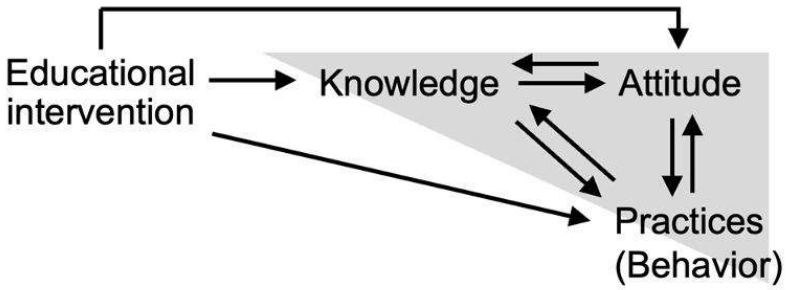


Figure 1. The KAP triad and possible interactions (modified graphic based on Iverson and Portnoy [22]).

2.3. Empirical Results Referring to the KAP Triad

KAP data have been collected in various fields of research, such as analyzing sustainable agriculture [24], immunization practices [25], waste management [26], health education [27], and environmental education [28]. Here, we focus on the latter content area, which is important for the well-being of humanity on earth. The impact of environmental education, particularly education for sustainable development, on young people was demonstrated in a recent meta-analysis [29], which showed an improvement of environmental knowledge, environmental attitude, and pro-environmental behaviors. The effect sizes were high for knowledge and small to medium for attitude and behaviors. Interventions that differed in the type of student activities (ranging from traditional classroom activities to field trips and camps) or in their length (one vs. several days) appeared to be similarly effective [29]. This could indicate that even short-term programs, such as those often offered by extracurricular learning venues, can be effective.

However, other studies found an effect of the duration of the intervention.

In a study by Bogner [30], a one-day outdoor program was compared with a five-day outdoor program in a national park. The one-day environmental education had a positive effect on knowledge and attitude, but the longer program had positive and consistent effects on attitudes and behavior over a long-term period of six months.

On the other hand, there are also short-term didactic interventions that found effects on KAP. For example, a study on students' attendance in a "green classroom" for just half a day had positive effects on knowledge and raised awareness about small animals and plants compared to a control group [31]. The authors argue that these positive changes could support the importance of educational programs outside school. Thus, intensive and authentic nature discovery, e.g., in a botanical garden as form of a "green classroom", could be essential factors for fostering knowledge and pro-environmental attitudes [30,32]. However, such out-of-school experiences gained in nature [33] may differ from those gained in a laboratory conducting experiments (as with our didactic intervention on green facades). Therefore, the question of the pro-environmental long-term effects of a short-term didactic intervention is still relevant, as the effects may differ depending on the type of intervention in terms of its closeness to nature.

In general, this raises the question of which teaching strategies on sustainability or, more specifically, on climate protection can be categorized as effective in bringing about changes in K, A, and/or P. Monroe et al. [34] conducted a systematic review on this and were able to identify six strategies: Thus, it is important (i) to offer content which is personally meaningful (e.g., if issues are not only considered globally but are also related to local conditions and thus become tangible) and (ii) to use student-centered teaching strategies, such as inquiry-based learning, in which the learners are actively involved. Further strategies being more specific to a particular topic refer to (iii) interacting

with scientists and experiencing the scientific process, (iv) addressing misconceptions, (v) enabling deliberative discussions, and (vi) involving learners in school and community projects. All these strategies can help to improve the learning outcomes of single or multiple components of the KAP triad. It therefore makes sense to consider at least some of these strategies for an intervention.

Further research shows that the three components of the KAP triad also affect each other. In the context of teaching and learning about environmental topics, the literature shows that environmental knowledge significantly influences ecological behaviors [35–38]. However, this relation has also been mediated by more proximal factors, such as attitudes [39,40], which are meaningful predictors of pro-environmental behaviors. In addition, when examining pro-environmental behaviors, it must be considered that different kinds of behaviors are implemented with varying degrees of ease because of higher or lower psychological barriers or other costs [29,41].

More recently, the learning process itself has been considered a form of pro-environmental behavior, in which attitudes play a double role: they control how likely learning will occur and also how intensively students will engage in the learning process [42–44].

Overall, the literature suggests a connection between the three components, namely knowledge, attitude, and practices. However, there does not seem to be one unequivocal causal direction.

2.4. Possible Subcomponents of the KAP Triad

When analyzing the effect of interventions on the KAP triad, the question arises as to whether there are subcategories in knowledge, attitude, and practices.

With environmental knowledge, a distinction is made between three different types of knowledge: system, action-related, and effectiveness knowledge [35,37,45,46]. System knowledge refers to understanding how environmental systems function, while action-related knowledge focuses on the necessary steps to ensure resource conservation and environmental protection. Finally, effectiveness knowledge is about how to achieve the best resource conservation, namely knowledge about the effectiveness of various behaviors, i.e., their impact.

When imparting knowledge at extracurricular learning centers (such as students laboratories at universities), the focus is usually on the subject matter and less on individual action knowledge, i.e., how to improve one's pro-environmental behavior. Thus, primarily system and effectiveness knowledge (e.g., the impact of greening measures on the environment and their contribution to sustainability) is imparted, which we will summarize here as *content knowledge*. If extracurricular learning centers allow experiments to be carried out and scientific data to be collected, another type of knowledge is also imparted, which we would like to call *technical knowledge*. Regarding green facades, content knowledge addresses the structure and function of green facades and their relationship with environmental problems and the SDGs. In contrast, technical knowledge focuses on experiments, measurement instruments, and environmental parameters directly experienced by students during laboratory work.

Concerning attitude, indicators can be rather general, referring to many different environmental-relevant areas of life [47] or specific to a certain topic, such as green facades [48]. Although it is questionable whether these indicators (general vs. specific) represent different underlying dispositions [42], a more specific indicator can be seen as beneficial if an intervention is limited to a certain content domain. This is because changes may occur more easily in this specific domain than in related ones, and the specific indicator focuses exactly on this domain and is therefore more sensitive than a general indicator. In the survey data presented

here, we thus refer to the specialized attitude towards green facades and not to a general (pro-)environmental attitude.

Regarding practices, two different lines of action may be considered: Behaviors that rather address one's mind and cognition versus behaviors that focus more on one's emotions and responsibility. These action lines may then be related to knowledge and attitude.

Figure 2 provides an overview of the possible subcomponents of the KAP triad described above. The relationships among them examined in the present study are marked with arrows.

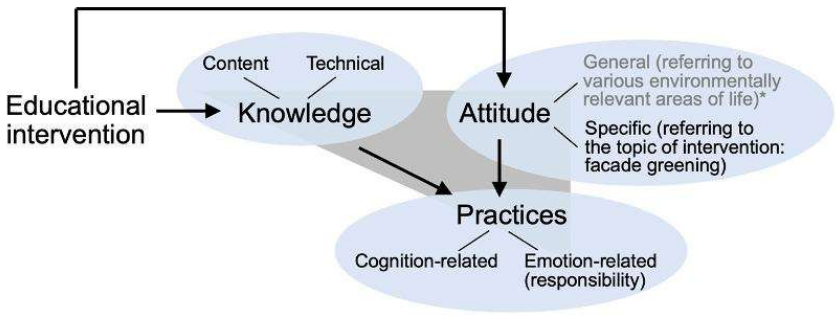


Figure 2. Possible subcomponents of the KAP triad. * Although the general environmental attitude was also surveyed, the data are not included in this publication because the focus in this publication is a different one.

3. Research Questions

Our research aims to investigate how a didactic intervention on facade greening in the form of a half-day visit to an out-of-school place of learning (i.e., a German university) affects components of the KAP triad. In this paper, we seek to answer the following research questions:

1. K: How does the intervention affect students' knowledge, considering content and technical knowledge?
   Based on previous studies [29], we assume that knowledge (content and technical) strongly increases after the intervention, and that this effect is still partially present after four weeks [30].
2. A: How does the intervention affect students' attitudes towards green facades?
   Based on previous studies [29], we assume that the level of this specific attitude increases slightly after the intervention, and that parts of this change are still detectable after four weeks [30].
3. P: How do knowledge and attitude correspond to students' practices?
   Based on the KAP framework, we expect positive relations between knowledge and practices, as well as attitude and practices. We will explore these relations, considering cognitive and emotional lines of action.

4. Materials and Methods

Additional material such as detailed information on the didactic intervention and the knowledge questionnaire can be found in the online Supplementary Material.

4.1. Study Design

A didactic intervention on facade greening was performed and analyzed using a longitudinal treatment-only design (pre-test, post-test, and follow-up) regarding its effect on the components of the KAP triad. The questionnaires were developed and tested in

the context of a prior project day and were modified and supplemented with further items for the current study. This was done to adjust the ad hoc knowledge measure to better fit the students' knowledge level and to add knowledge questions referring to the practical contents (not only to the theoretical ones) of the project day. Moreover, further items on attitude towards green facades were added to cover a broader range of difficulties and thus, achieve better differentiation between persons. The project days and data collection were conducted in autumn 2023 with students from six different classes and project groups (grade 5–11) from four different secondary schools (grammar and integrated comprehensive schools).

Participation was voluntary and anonymous. Parents or legal guardians were consulted prior to data collection. Points of measurement were matched using a personal code generated by the students.

4.2. Participants and Procedure

The final sample across all points of measurement consisted of $N = 117$ students ($n_{pre} = 105$, $n_{post} = 105$, $n_{follow\text{-}up} = 76$). Students who participated in the follow-up survey but not the intervention (i.e., T2 but not T1, $n = 11$) were excluded to reduce noise in the follow-up data, especially for the knowledge questions. Furthermore, we excluded 20 individual datasets (from $n = 10$ different persons) because of data quality concerns (i.e., suspected answering patterns or implausible person code duplicates). All remaining students (117) were used to determine the student's knowledge scores (see Section 4.4).

As we were interested in our constructs' development over time, we used the subsample of $n = 71$ complete cases (i.e., students who participated in all points of measurement) for our main analyses. The mean age in the complete cases subsample was 14.19 years ($SD = 1.54$), with a gender distribution of 39.3% females, 53% males, 4.3% diverse, and 3.4% not stated. The characteristics of the full and all subsamples can be found in the online Supplementary Material.

The surveys to evaluate the effect of the project day were conducted one week before the didactic intervention (pre-test, T0), directly after the didactic intervention (post-test, T1), and approximately four weeks after the didactic intervention (follow-up test, T2). The T0 and T2 surveys were filled out at the respective schools of the participating students, while the T1 survey was carried out at the university immediately after the didactic intervention. Students received paper–pencil questionnaires at all points of measurement, where they first answered items on their attitude towards green facades. In the second part, they answered questions about content and technical knowledge related to green facades. Lastly, they were asked for age, gender, and grade. At the beginning of the post-test questionnaire, students additionally indicated the stations on which they had worked during the project day.

Due to the limited time available at the end of the project day and to reduce the workload, we used a split version of the knowledge questionnaire at T1; i.e., not all students had to answer all items, but some items were administered to all students.

After the project day, students were given the option to take a small plant and a flyer home with them. The follow-up questionnaire therefore included further questions on the students' behaviors related to the plant and the flyer after the project day.

In addition, all questionnaires included further items (e.g., referring to students' general environmental attitude, their social environment, and additional behaviors) that were not used in the current research.

4.3. Didactic Intervention

This study implemented a short-term didactic intervention (4 h), which took place in an extracurricular setting (i.e., a student lab at a university). The intervention aimed at increasing students' knowledge about the environmental benefits of green facades, strengthening students' appreciation of green facades and greening, in general, and to motivate them to take on related follow-up activities (proposed in a flyer). In terms of its structure, the intervention was divided into three phases: an introductory phase, a hands-on experimental phase, and a wrap-up phase.

The introductory phase (frontal lecture style) was meant to introduce and link the topic to more general environmental issues and the SDGs. It highlighted the most common issues in cities, such as global warming and the Urban Heat Island effect, the loss of biodiversity, and pollution in the air, along with possible solutions based on nature, such as green facades. The introduction ended with open questions referring to whether, and in what way, green facade plants may counteract the mentioned problems and, thereby, contribute to the SDGs.

In the practical/experimental phase (hands-on, activity-based) students should answer the questions raised before. The focus of this phase was on several specific operating mechanisms of green facades: (i) CO_2 sequestration related to photosynthesis (SDG no. 13 and 11), (ii) temperature regulation due to shade and albedo effects (SDGs no. 3, 13, and 11), (iii) the increase in humidity due to the transpiration of plants (SDG no. 13 and 11), and finally (iv) the contribution to dust capturing (SDG no. 3) and biodiversity (SDG no. 15 and 11). Activity-based learning was chosen as a teaching method, with three stations (i–iii) requiring experimental work in laboratory conditions, while the fourth station was informative, involving the interpretation of measurement charts (data from research) and familiarization with common inhabitants of green facades using illustrations. Students were split into small groups during this practical phase and alternated between the various stations. For more details on the practical/experimental phase, see the online Supplementary Material.

The wrap-up phase (interactive, Q&A) was intended to collate, compare, and assess the workstations' results and to come to conclusions about the initial questions. Subsequently, follow-up activities at home were proposed to keep students engaged in the topic of green facades: A flyer was offered to recap the day and to suggest new activities for the students to carry out on their own, to stimulate them to recall the experience gained during the project day and talk about them with others. Reading the flyer and using the suggested links to websites with more information about green facades (including videos) was considered to belong to a cognitive line of action. In addition, a little ivy plant could be taken home to look after (e.g., watering it) and observe its growth. These activities have a caring aspect and were therefore counted as part of an emotional line of action.

Overall, the proposed didactic intervention addressed at least three of the six strategies identified by Monroe et al. [34] (see Section 2.3). In fact, students performed hands-on activities (ii), were exposed to scientific processes (iii), and were offered content meaningful for their personal life (i).

4.4. Survey Instruments

To answer our research questions on the effects of the didactic intervention, we assessed students' knowledge, attitude, and practices.

4.4.1. Knowledge

The knowledge part of the questionnaire consisted of two sections: The first section included items assessing content knowledge (i.e., knowledge concerning the structure

and function of green facades and their relationship with environmental problems). The second section encompassed technical knowledge items (i.e., knowledge concerning experiments, measurement instruments, and environmental parameters directly experienced by students during laboratory work). For content knowledge, we had one assignment task, 15 single-choice, and 13 multiple-choice questions. For technical knowledge, we also had one assignment task, one single-choice question, and 13 multiple-choice questions (for details on knowledge questions, see the online Supplementary Material). Single- and multiple-choice questions with only one correct answer were evaluated as correct (1) or incorrect (0). The assignment tasks and the other multiple-choice questions were evaluated using three categories: whether the answer was incorrect (0), partially correct (i.e., if not all correct answers for a multiple-choice question were selected) (1), and correct (2). At T1 and T2, only the questions concerning stations that students engaged with were considered, based on the students' indication of station engagement at the beginning of the T1 questionnaire (see Section 4.2). Questions related to stations where students indicated non-engagement were treated as missing. Moreover, systematically unanswered knowledge questions were treated as missing, i.e., when it was clear that the respective students stopped answering the questionnaire. In these cases, all unanswered questions before the last answered question were treated as incorrect, and all remaining questions were treated as missing. A model with all unanswered questions evaluated as incorrect was also calibrated. However, this did not improve the model fit.

We calibrated a two-dimensional partial credit Rasch model with content and technical knowledge for each point of measurement. Note that for Rasch models, parameter estimates can be determined even with incomplete data due to the maximum likelihood approach in the estimation procedure. In addition to handling missing values, Rasch models offer several advantages, such as a thorough evaluation of psychometric properties and no need for parallel test forms, which is especially useful in longitudinal designs (for more details, see [48]).

Calibrating both forms of knowledge in the same model reduces standard errors and increases reliability. Moreover, it accounts for relations between the dimensions and offers more precise correlation estimates [49]. To compare the knowledge estimates across the different points of measurement, we used the follow-up calibration (T2) as our reference as this represented the decisive point of measurement, i.e., whether the didactic intervention was successful in the long term. Therefore, we first aligned the two dimensions for this point of measurement (with person estimates fixed to zero and content knowledge as the reference dimension, see [50]) and then linked the item estimates of the other two calibrations (T0 and T1) to the reference calibration (T2) [51]. For the calibrations, the datasets of all 117 students were used to improve the fit. Overall, all models had a reasonable fit, with person separation reliabilities ranging from *rel* = 0.44 (technical knowledge at pre-test) to *rel* = 0.77 (technical knowledge at follow-up test). Subsequently, knowledge estimates for the 71 complete cases were extracted.

4.4.2. Attitude

Attitude towards green facades was measured using eight self-developed items on a 5-point Likert scale (see Table 1). Items included more general opinions (e.g., "Cities would be more beautiful with more green walls/facades".) or referred to personal commitment (e.g., "I would take part in maintaining a green facade at my school".) or to official measures ("The greening of house walls is so important that it should be supported by the government"). We calculated mean values to determine a person's attitude towards green facades. We refrained from calibrating a Rasch model as small sample sizes (<150), together with only few items are associated with low accuracy of parameter estimates due to rela-

tively few data points [52]. Reliabilities were high at all measurement points (McDonald's $\omega_{T0} = 0.88$, $\omega_{T1} = 0.86$, $\omega_{T2} = 0.88$).

4.4.3. Practices

Activities related to the flyer and the plant were measured using self-reports. Regarding the flyer, students were asked whether they took it (yes/no) and, if so, whether they looked at it again (yes/no) and whether they used the QR codes for videos and further information on green facades provided on the flyer (yes/no). These activities were interpreted to contribute to a cognitive activity strand. We excluded one further item from the evaluation because it was a creativity-oriented activity, namely going on a photo safari concerning green facades. Similarly, students were asked whether they took a plant after the project day (yes/no) and, if so, whether they watered the plant (yes/no) and whether they watched it grow (yes/no). These activities were seen as part of an emotion-oriented activity strand.

To analyze the practices, we created an index by summing up the number of respective activities for each student, i.e., whether students did not perform any activity, one activity (taking a flyer/plant), two activities (taking the flyer/plant and one additional flyer-/plant-related activity), or all three activities (taking the flyer/plant and two additional flyer-/plant-related activities). Hence, a higher value indicated a higher number of activities performed. Concerning the flyer, $n = 23$ students did not take a flyer, $n = 27$ students took a flyer but did not do any further activities, $n = 18$ also looked into the flyer again, and $n = 3$ students also used the QR codes mentioned in the flyer. Concerning the plant, $n = 32$ students did not take a plant, $n = 13$ students took a plant but did not do any further activities, $n = 11$ students did one additional activity (watering or observing the plant), and $n = 15$ students did two.

5. Results

5.1. Results to RQ1: How Does the Intervention Affect Students' Knowledge?

Knowledge results are reported in logit values, the metric of Rasch scales. We conducted repeated measures ANOVA with post hoc t-tests (one-sided and Bonferroni-corrected) to test for changes in knowledge over time. If Mauchly's test for sphericity was significant, we applied the Greenhouse–Geisser correction of degrees of freedom for the within-subject factor.

Due to incomplete questionnaires, the number of students for whom an estimate of technical knowledge could be derived was $n = 62$. To compare content and technical knowledge, we only considered this subsample for the following analyses.

The content knowledge of students significantly changed through the didactic intervention, $F(1.69, 102.96) = 6.76$, $p = 0.002$, $\omega^2 = 0.14$, 95% CI [0.03, 0.27] (see Figure 3a). The students had higher content knowledge after the intervention (T1: $M = 0.19$, $SD = 0.72$) than before (T0: $M = -0.12$, $SD = 0.59$), $p = 0.004$, $d = 0.40$, 95% CI [0.14, 0.66] (T0 vs. T1). The increase remained stable also after four weeks (T2: $M = 0.03$, $SD = 0.64$), although with a somewhat smaller effect size, $p = 0.033$, $d = 0.30$, 95% CI [0.04, 0.59] (T0 vs. T2). Removing one outlier with an extremely low knowledge score at the pre-test (see Figure 3a) led to a slight decrease in the overall effect size ($\omega^2 = 0.12$, 95% CI [0.02, 0.24]), and the knowledge increase from the pre-test to the follow-up (T0 vs. T2) was just not significant anymore, $p = 0.051$, but the effect size remained similar, $d = 0.28$, 95% CI [0.03, 0.55]. Using the whole subsample of complete cases ($n = 71$), effect sizes remained similar, with two outliers ($p < 0.001$, $\omega^2 = 0.16$, 95% CI [0.01, 0.18]) and without ($p = 0.003$, $\omega^2 = 0.13$, 95% CI [0.04, 0.24]), and the increase in knowledge from the pre-test to after four weeks was also significant and similar in size, both

with (p = 0.018, d = 0.31, 95% CI [0.06, 0.58]) and without outliers (p = 0.046, d = 0.27, 95% CI [0.03, 0.54]).

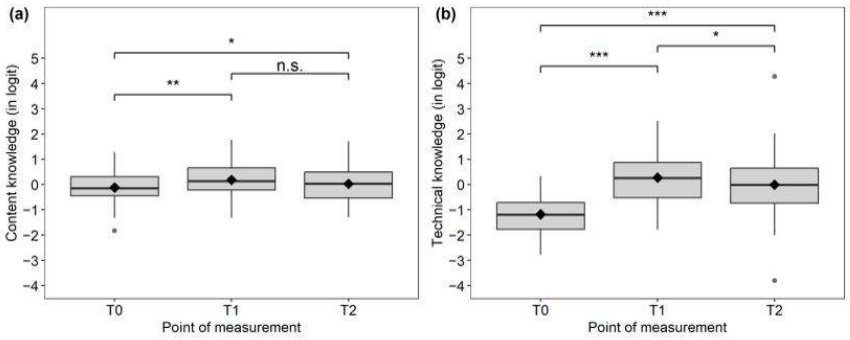


Figure 3. Content knowledge over time (**a**), technical knowledge over time (**b**). n = 62. Box plots including mean (♦). Removing outliers (gray dots) did not change the main result of a knowledge increase through the didactic intervention. n.s. = not significant, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The technical knowledge also changed over time, but much more drastically than the content knowledge, $F(2, 122) = 78.14$, $p < 0.001$, $\omega^2 = 0.71$, 95% CI [0.61, 0.79] (see Figure 3b). Technical knowledge was higher at the post-test (T1: $M = 0.27$, $SD = 1.01$) than at the pre-test (T0: $M = -1.17$, $SD = 0.67$), $p < 0.001$, $d = 1.54$, 95% CI [1.26, 1.96] (T0 vs. T1). Four weeks later, it stayed substantially higher than before the didactic intervention (T2: $M = -0.01$, $SD = 1.14$), although the effect was somewhat smaller, $p < 0.001$, $d = 1.07$, 95% CI [0.81, 1.43] (T0 vs. T2). Excluding two outliers in the follow-up measurement (see Figure 3b) did not change the results ($\omega^2 = 0.75$, 95% CI [0.65, 0.81]).

We further explored differences between the means of the two kinds of knowledge for the different points of measurement (two-sided tests). Excluding the three outliers, technical knowledge was significantly lower than content knowledge before the intervention, $t(58) = 12.29$, $p < 0.001$, $d = 1.60$, 95% CI [1.35, 1.95]. However, directly after the intervention and also four weeks later, the two knowledge types were on a similar level, T1: $t(58) = 0.77$, $p = 0.442$, $d = 0.10$, 95% CI [−0.13, 0.38] and T2: $t(58) = 0.46$, $p = 0.644$, $d = 0.06$, 95% CI [−0.22, 0.33]. Including the outliers did not change the interpretation or significance of the results. Furthermore, as also indicated by the boxplots in Figure 3a,b, the variance in content and technical knowledge is similar at the pre-test, $F(58, 58) = 1.48$, $p = 0.141$, but higher for technical knowledge directly after the intervention, $F(58,58) = 1.82$, $p = 0.025$, and also four weeks later, $F(58, 58) = 2.08$, $p = 0.006$. In other words, there were more individual differences in learning about the technical aspects, leading to a wider range in technical knowledge compared to content knowledge.

Despite some differences in the development of the two knowledge types, we found that they were highly correlated, even before the intervention, with $r_{T0} = 0.70$, which increased to $r_{T1} = 0.89$ directly after the intervention and remained high at follow-up, with $r_{T2} = 0.87$. Put differently, students who have higher content knowledge also tend to have higher technical knowledge. This relationship is even more pronounced after the project day.

Because of this very high overlap between the two constructs, we collapsed the two measures into an overall measure of facade greening knowledge for further analyses by calibrating a unidimensional model for each point of measurement, again linking the pre- and post-test calibration to the follow-up as the reference ($rel_{T0} = 0.59$, $rel_{T1} = 0.77$, and $rel_{T2} = 0.76$). For this composite measure, we extracted knowledge scores for the subsample of all complete cases (n = 71).

5.2. Results to RQ2: How Does the Intervention Affect Students' Attitudes Towards Green Facades?

Again, we conducted repeated measures ANOVA with post hoc t-tests (one-sided and Bonferroni-corrected) to test for changes over time.

We found a significant change in attitude toward green facades through the intervention, $F(2, 140) = 10.65$, $p < 0.001$, $\omega^2 = 0.21$, 95% CI [0.10, 0.33]. Specifically, there was an increase from the pre-test (T0: $M = 2.69$, $SD = 0.82$) to the post-test (T1: $M = 3.06$, $SD = 0.81$), $p < 0.001$, $d = 0.52$, 95% CI [0.29, 0.76] (T0 vs. T1). However, this increase was lost at the follow-up; i.e., attitude values returned to baseline (T2: $M = 2.81$, $SD = 0.85$), $p = 0.210$, $d = 0.18$, 95% CI [−0.05, 0.4] (T0 vs. T2). Removing the three outliers at T0 and one at T1 (see Figure 4) did not change the results. Therefore, their data was maintained.

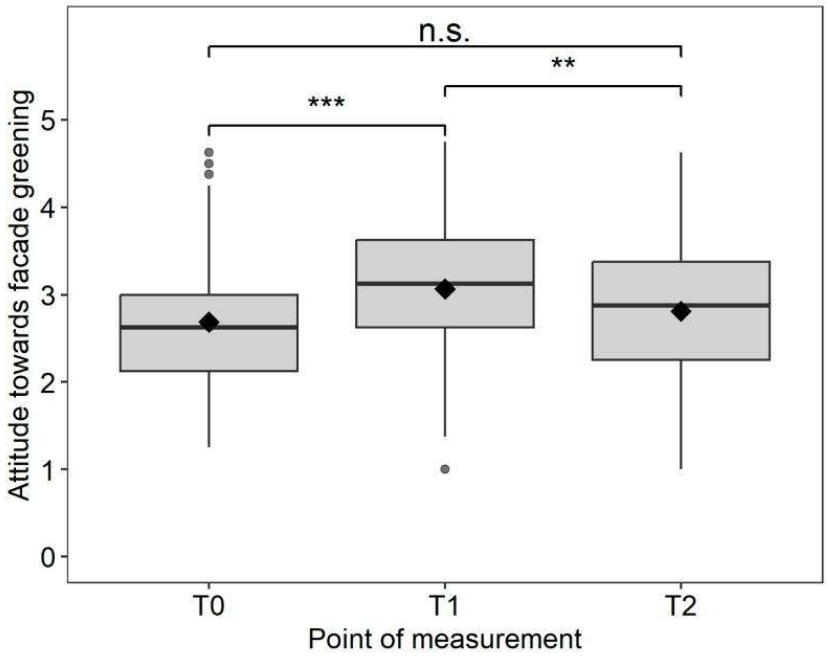


Figure 4. Attitude towards the green facades over time. $n = 71$. Box plots including mean (♦). Removing outliers (gray dots) did not change the results. n.s. = not significant, ** $p < 0.01$, *** $p < 0.001$.

We further investigated which aspects of facade greening students changed their minds. Because most of the items did not meet the criteria for an ANOVA, we conducted the Friedman test as a non-parametric alternative. The results are displayed in Table 1. Although the test indicated small but significant differences between points of measurement for all but item #6, post hoc tests using exact values [53] and Bonferroni correction revealed that the agreement with the facade greening items was increased after the intervention only for items #1 ($p = 0.003$), #2 ($p = 0.004$), and #4 ($p < 0.001$). However, this increase (T0 vs. T1) did not last until four weeks after the intervention (T0 vs. T2: #1: $p = 0.185$, #2: $p = 0.5$, #4: $p = 0.181$).

Table 1. Differences in the level of agreement with specific attitude items (relating to green facades) across three measurement points.

#	Facade Greening Items	*n*	*M* (*SD*)			Chi² (df = 2)	*p*	*W* [95% CI]
			T0	T1	T2			
1 *	The greening of house walls is so important that it should be supported by the government. (*Official measures*)	71	3.39 (1.05)	3.85 (1.19)	3.56 (1.24)	13.67	0.001	0.10 [0.03, 0.24]
2 *	If I had a house, I would green the house walls (facade). (*Personal commitment*)	67	2.57 (1.30)	3.18 (1.22)	2.79 (1.28)	15.86	<0.001	0.12 [0.04, 0.23]
3	Cities would be more beautiful with more green walls/facades. (*Object properties*)	70	3.54 (1.32)	3.80 (1.21)	3.63 (1.31)	6.78	0.034	0.05 [0.01, 0.15]
4 *	For new buildings, facade greening should be mandatory. (*Official measures*)	71	2.13 (1.17)	2.87 (1.26)	2.48 (1.26)	27.30	<0.001	0.19 [0.09, 0.33]
5	I would donate money for the construction of green facades on public buildings. (*Personal commitment*)	69	2.30 (1.11)	2.49 (1.13)	2.24 (1.21)	7.49	0.024	0.05 [0.01, 0.15]
6	I would take part in maintaining a green facade at my school (e.g., cutting back vegetation on the facade). (*Personal commitment*)	70	2.89 (1.27)	2.81 (1.23)	2.70 (1.29)	2.05	0.359	0.01 [0.00, 0.09]
7	It would bother me if I had more spiders around me because of a green facade. (*Object properties*, reverse item)	70	2.72 (1.63)	3.25 (1.63)	3.19 (1.59)	8.42	0.015	0.06 [0.01, 0.17]
8	I would distribute informational flyers in my free time to promote green facades. (*Personal commitment*)	69	1.96 (1.01)	2.20 (1.13)	1.93 (1.20)	10.98	0.004	0.08 [0.01, 0.22]

Note: Sample sizes *n* differ due to missing values. *W* = Kendall's *W*. * = Items for which the post hoc tests (using exact values and Bonferroni correction) revealed a significant ($p < 0.05$), but not lasting, increase in attitude after the intervention (T0 vs. T1: sig., T0 vs. T2: n.s.).

5.3. Results to RQ3: How Do Knowledge and Attitude Correspond to Students' Practices?

We investigated the relation between post-test knowledge and attitude with flyer- and plant-related activities, as summarized in our index (see Section 4.4.3), using ordinal regression. Knowledge and attitude were substantially correlated, with $r = 0.39$ $p < 0.001$ ($r = 0.47$ when corrected for measurement error attenuation). Hence, we calculated separate models for both predictors. We found that knowledge and attitude seemed to correspond to different kinds of behaviors. While post-test knowledge was predictive of the performance of flyer-related activities (*OR* = 2.35, 95% CI [1.29, 4.27], *Nagelkerke's pseudo-*$R^2 = 0.12$), the attitude was predictive of plant-related activities (*OR* = 1.99, 95% CI [1.13, 3.52], *Nagelkerke's pseudo-*$R^2 = 0.09$). Thus, with every unit increase in knowledge, the odds of being in a higher category of flyer-related activities (e.g., performing two instead of one or three instead of two) are 2.35 times higher. Similarly, with each unit increase in attitude, the odds of being in a higher category of plant-related activities increase by 1.99.

We did not find the opposite relations; i.e., knowledge was not predictive of plant-related activities (*OR* = 0.86, 95% CI [0.51; 1.54], *Nagelkerke's pseudo-*$R^2 = 0.00$) and attitude not of flyer-related activities (*OR* = 1.34, 95% CI [0.76, 2.28], *Nagelkerke's pseudo-*$R^2 = 0.02$). See the online Supplementary Material for the full regression models.

6. Discussion

6.1. Answer to RQ1: How Does the Intervention Affect Students' Knowledge?

Both content and technical knowledge showed a significant increase directly after the project day (T0 vs. T1). The extent of this increase, however, varied for content and technical knowledge. The increase in content knowledge was only small and therefore less than expected [29]. An explanation could be that the intervention focused more on practical activities, and students spent more time on experiments than on theory. In addition, it could also be that the content knowledge was not as new to the students as we had anticipated. They may have taken up relevant information from their private life or already learned about the content in class. For technical knowledge, on the other hand, we saw a very strong effect of the intervention. Considering the very low baseline for technical knowledge,

there was a high potential for improvement through the intervention, which ultimately led to an assimilation of both knowledge levels (content and technical-related).

Four weeks after the intervention, a significantly increased knowledge level was still found when compared with the initial value (T0 vs. T2). Thus, not only experiences in nature lead to longer-term knowledge gains [30,31] but also experiences through laboratory experiments.

Despite this longer-term increase in knowledge, some of the newly acquired knowledge was lost again. This loss was higher for technical than for content knowledge. These differences in retention of knowledge can be attributed to the fact that the amount of newly acquired knowledge was lower for content than for technical knowledge, and if less was learnt, less can be forgotten. An alternative explanation could be that content knowledge (which relates to environmental protection and the SDGs) is of general importance and may be addressed in lessons as well as in private life, e.g., when listening to the daily news. This helps to retain knowledge better. In contrast, technical knowledge relates to specific experiments that are unlikely to be repeated or carried out again in class and may therefore be more easily forgotten.

In addition, further differences can be seen in the development of content and technical knowledge: At the pre-test, technical knowledge was significantly less pronounced than content knowledge. This may be related to the fact that there is limited time for experiments at school, and therefore, less technical knowledge is acquired. It must also be considered that the questions in the survey instrument are related to very specific experiments and not to experimental knowledge in general. This specialized knowledge can only be present if experiments have already been carried out in a similar form at school or if their structure has been discussed in theory. While the content knowledge tested was more general, the technical knowledge was specialized.

There was also a difference in (statistical) variance between the two types of knowledge. After the project day, the dispersion of technical knowledge was significantly higher than that of content knowledge. An explanation for this could be inter-individual differences in learning behavior and interest in experimenting. Because of the low baseline level of technical knowledge and, thus, the potential for improvement in technical knowledge, there was also more room for engagement or non-engagement in learning activities.

Despite these differences in their progression, the two kinds of knowledge were highly correlated and could even be calibrated as a unidimensional construct. That is, they indeed represent two subdimensions of the same broader construct. This construct can be described as general facade-greening or project day-related knowledge. However, as the difference between the two dimensions at the pre-test (T0) makes clear, it can also be sensible to distinguish the two forms as knowledge: only the two-dimensional model reveals the differences between these forms of knowledge and may therefore help to design better targeted interventions as well as classroom follow-up activities after a project day.

6.2. Answer to RQ2: How Does the Intervention Affect Students' Attitudes Towards Green Facades?

Regarding attitude towards green facades, there was a large significant increase immediately after the project day. This even exceeded the expectations based on the literature, which assumed a small to medium effect [29]. However, over the following four weeks of our study, there was a significant decrease back to the baseline. Thus, no significant change in attitude towards green facades could be detected when comparing the first and last surveys. This suggests that the issue became more important to the students in the short term as the project day brought the topic to their awareness. However, this positive change in attitude towards green facades receded in the longer term, i.e., over the next four weeks. This could be because green facades do not play a prominent role in the

students' lives, and therefore, other issues that are more important to them right now come forward. Another explanation could be that students responded in terms of social desirability just after the project day because they (unconsciously) felt obliged to do so after the didactic intervention [54].

Looking at the individual items, the omnibus tests indicated that nearly all items (seven out of eight) showed significant changes in the degree of consent (except #6, see Table 1). However, subsequent tests revealed significant changes between pre- and post-tests for only three items (T0 vs. T1). It can be assumed that low statistical power potentially led to insignificant results in the post hoc tests, at least for some of the other items. However, items with the strongest effects (#1, #2, #4), even in the small current sample, have certain characteristics. These items do not require any direct activities from students themselves, and if they do, these activities can be postponed to the future or are not feasible for students at present. Specifically, these items refer to the government, which should support the implementation of green facades (#1) or make green facades mandatory for new houses (#4), thus affecting homeowners but not students. It should also be noted that this last item received comparatively less support from students, which could be due to its mandatory nature, thus restricting personal freedom. In addition, students increasingly agreed that they would green their houses (#2). However, students currently do not own a house. This means that they do not have to take action now. Their agreement only means that they would accept greenery on the house they live in (or will live in the future).

In contrast to the items mentioned above, others did not significantly change, either in general (#6) or just in the post hoc tests. Next to the low statistical power, there may also be content-related reasons. On the one hand, these items (#3 and #7) are not specific measures that lead to a greater prevalence of green facades and, thus, directly contribute to more sustainability. Instead, the items merely refer to opinions on object characteristics (such as beauty and the presence of spiders). On the other hand, there are items (#5, #6, and #8) that refer to specific measures, but these do not come from the state but may concern the young people at the current point in their lives, such as donating money for installing new green facades (#5), maintaining green facades (e.g., at school) (#6), or distributing leaflets about green facades (#8). This means that the more concrete, realistic, and timely certain demands set out in the items are, the less significant a change in the level of agreement will be. There could be different reasons for this assumption: (i) Respondents can better estimate the effort for concrete, timely actions that affect them personally and are therefore less willing to agree with them. This is consistent with findings that the perceived difficulty of actions is a key predictor of behaviors [47,55]. (ii) Respondents consider individual activities to have little impact when it comes to solving problems on a global scale (such as climate change) [56]. Therefore, they may be more in favor of government actions rather than actions by individuals. (iii) Respondents may see the proposed measures (such as distributing flyers or collecting donations) as little help in convincing citizens to green their house facades. On the other hand, government measures may exert more pressure on the public or offer greater incentives and would therefore be more effective [57].

6.3. How to Explain the Differences in the Development of Knowledge and Attitude?

Our project day of just four hours led to significant changes in knowledge and attitude towards facade greening. However, the constancy of these changes varied. While four weeks after the project day, there was still a significant increase in knowledge compared to the pre-test (T0 vs. T2), attitude at the later measurement point (T2) was no longer significantly different from the pre-test.

A possible reason for the different persistence of increased knowledge and attitude could be as follows: Whenever a person consciously perceives something as important (like

what was said or done on a project day), attention is increased, and learning gain will be greater. This gained knowledge will not be quickly overlaid by other knowledge but will remain in the memory, at least for some time [58]. If a change in attitude is to be maintained over a longer period, this is likely to involve more effort for a person. It not only requires a change in agreement with statements in a questionnaire but also more challenging or costly behavioral changes, such as donating money to organizations advocating facade greening. However, if a shift in attitude is rather the result of a momentary (perceived) higher salience of a topic, like during or right after a project day, this shift might not be strong enough to remain over a longer period under decreased salience or to result in changes in more demanding behaviors.

6.4. What Differences Can Be Seen in the Implementation of Voluntary Follow-Up Activities Offered at the End of the Project Day?

Activities that required no extra effort, such as taking a plant or a flyer after the project day, were carried out more often than the proposed time-consuming activities, such as watering and observing the plant or reading the flyer and visiting websites with further information on facade greening. As with the short-term changes in attitude, those follow-up activities that were associated with low personal costs were also favored here. It can be assumed that the number of more demanding activities performed reflects the students' interest in the topic, although the latter was not investigated in this study.

6.5. Answer to RQ3: How Do Knowledge and Attitude Correspond to Students' Practices?

We found positive relations between knowledge and practices, as well as attitude and practices. This is consistent with other studies that show environmental knowledge significantly influences environmental behavior [35–38]. The positive relation between pro-environmental attitude and behavior is also in line with many studies [59,60].

However, knowledge and attitude seemed to correspond to different kinds of behaviors. While post-test knowledge predicted the performance in flyer-related activities, the higher attitude predicted plant-related activities, but not vice versa.

The relation between the level of knowledge and the number of flyer-related activities can be explained by the fact that, apart from taking the flyer, the activities based on it were cognitive in nature. The more people know about a topic, the more interested they may be in further information, and the easier and better they can understand it [61]. Regarding attitude, there was a significant correlation with the number of plant-related activities. Watering and closely observing a plant can both be classified as caring activities. Therefore, if there is a more positive attitude towards green facades, it can be assumed that this goes along with a higher appreciation of the green environment and nature, leading to more plant care.

Moreover, it seems important that didactic interventions focus on knowledge and attitude to enable students to engage in pro-environmental behaviors. This would be consistent with other research findings suggesting that environmental knowledge and attitudes influence behavior through different pathways [62]. However, the observed effect was rather weak for both causal relations (knowledge and flyer-related activities; attitude and plant-related activities). Thus, there must be other important influencing factors (e.g., limited time, other commitments and interests), which were not part of this study.

7. Limitations

As usual, our research does not come without limitations.

First, the intervention was short with only a four-hour project day. Still, we were able to show a longer-term change in knowledge and a short-term change in attitude and to identify a relation between these constructs and students' follow-up activities. A longer or

repeated program would have been desirable to investigate whether such more intensive interventions could also achieve long-term changes in attitude. However, such longer interventions are rather limited in everyday school life (due to the curriculum and limited opportunities to visit out-of-school places), and we wanted to expand the findings on short-term interventions with our study.

A second limitation concerns the timing of the follow-up test. It is not possible to say anything about a truly long-term development of knowledge and attitude, e.g., within six months or a whole year, as the follow-up test took place only four weeks after the project day. However, such a long-term development would have led to the difficulty that other influencing factors independent of the project day would have had greater weight, so the causes of the development would have been unclear.

Third, the structure of the questionnaire followed a fixed pattern, with the questions on technical knowledge at the end. A problem might have been that some students no longer answered the items at the end of the questionnaire with the same care as at the beginning. As a result, some students dropped out before the end and could not be included in comparing content-related and technical knowledge (reduction from $n = 71$ to $n = 62$). Changing the order of the knowledge items for the students would have produced an even more reliable result. Nevertheless, as the Rasch model handles missing values comparatively well, we still achieved overall satisfying person separation reliabilities.

Fourth, the rather small sample of students who completed all three surveys affected the study's statistical power. Still, we were able to find meaningful effects on our constructs of interest, i.e., knowledge, attitude, and practices. In addition, our study lacks a control group. To gain more accurate insights into the effects of our short-term intervention, it would have been helpful to compare the students with other students who learned about green facades but not outside school and/or with other students who did not work with experiments.

Lastly, to measure the effect of a project day on the KAP triad, it would have been advantageous to also measure behaviors (and not just knowledge and attitude) in the pre-, post-, and follow-up tests. However, our indicators did not allow such a longitudinal evaluation of behavior. In addition, we have only assessed behavior in the form of self-reports, which may be biased by social desirability.

8. Conclusions

The topic of green facades is suitable for addressing various SDGs, such as sustainable cities contributing to climate action, better health, and the preservation of biodiversity on land. Even a short-term instructional intervention of only four hours at an extracurricular learning location can lead to longer-term effects on knowledge growth. However, it will only bring about short-term changes in attitude. Regarding attitude, activities that require immediate, concrete action by an individual are more likely to be disapproved. The question is therefore whether extracurricular learning locations should offer not only laboratory activities but also those activities that allow pupils to directly engage with the environment by taking over activities that they otherwise would not do (e.g., promoting facade greening by participating in the installation and/or maintenance of it and/or by informing others about this topic)—an approach that we would like to study in the future. In contrast, voluntary activities at home are likely to be less effective as they are only implemented to a limited extent. Specifically, attitude seems to play a role in implementing plant-related care activities, while knowledge may support subsequent cognitive activities. Therefore, it seems important that didactic interventions focus on knowledge and attitude to enable students to broadly engage in pro-environmental behaviors.

Supplementary Materials: The following supporting information can be downloaded at: https://osf.io/t36w9/ (accessed on 11 March 2025).

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3 Discussion

3.1 Effects of the didactic intervention

The didactic intervention affected differently the various components of the KAP triad. (Pacini et al., 2025). The effects will be discussed below, in the order corresponding to the numbering in the results section (i – xi). A detailed discussion of the study's findings as well as its limitations can also be found in paper 3 (Pacini et al., 2025, pp. 13-17).

Explaining effects on knowledge

An increase in knowledge on facade greening immediately following the intervention (i) and a partial decline in the four weeks afterwards (ii) correspond to the learning curve (Arthur Jr et al., 1998; Ebbinghaus, 1885; Viering & Loog, 2022). Whenever someone experiences something or is taught about it, he or she always takes something away from it. Without repetition, however, some of this newly acquired knowledge is lost (Ebbinghaus, 1885). Possible reasons for certain knowledge being retained may be points of reference in students' memory, particularly memorable information, or repetition of information in class.

When distinguishing between content knowledge and technical knowledge, some differences can be observed. Before the intervention, technical knowledge was significantly less pronounced than content knowledge (iii). This may be because there is limited time for experiments at school, and therefore, less technical knowledge is acquired. It must also be considered that the questions in the survey instrument (referring to technical knowledge) are related to very specific experiments and not to experimental knowledge in general. This specialized knowledge can only be present if experiments have already been carried out in a similar form at school or if their design has been discussed in theory. In addition, it could also be that the content knowledge, which was much more general, was already known by the students from their private lives or in class.

Right after the intervention, there was a very strong positive effect on technical knowledge (compared to a much weaker one on content knowledge) (iv). A possible reason may be the very low baseline of technical knowledge (in comparison to content knowledge), so that there was a higher potential for improvement through the

intervention. In addition, the focus of the intervention was more on practical activities. Thus, students spent more time on experiments than on theory.

There were also differences in retention of knowledge with greater stability for content knowledge (v). This can be attributed to the fact that content knowledge (which relates to environmental protection and the SDGs) is of general importance and may be addressed in lessons as well as in private life, for example, by listening to the daily news. This helps to retain knowledge better. In contrast, technical knowledge relates to specific experiments that are unlikely to be repeated or carried out again in class and may therefore be more easily forgotten.

Explaining effects on attitudes

In the third publication, the focus was only on the specific attitudes towards the green facades. However, general pro-environmental attitudes were also investigated. It was found that no significant changes in general attitudes occurred either immediately after the intervention, or four weeks later (vi). Possible explanations could be related to the type of questionnaire: most of the items of the questionnaire about the general environmental attitudes are from a tool (Kaiser et al., 2007) based on self-reported pro-environmental behaviors (with the behavioral costs indicating the pro-environmental attitude). The self-reported behavior covers various domains like 1) energy conservation, 2) mobility and transportation, 3) waste avoidance, 4) recycling, 5) consumerism, 6) vicarious behaviors toward nature conservation. This means that the items were focused on something other than facade greening. One cannot assume that learning about one aspect of the environment will automatically lead to changes in behavior regarding other environmental issues. That would be too many changes at once, and a student would be overloaded (Baxter et al., 2025; Strother & Fazal, 2011; Toffler, 1970; Wilson et al., 2015).

Looking at changes in the specific attitude towards green facades, there is a significant short-term increase following the intervention, but it does not last (vii). A possible explanation is that the project day made students more aware of the problems raised. The reason for the subsequent reversal of this change in attitude may be that green facades do not play a prominent role in the students' lives, and therefore, other more important problems come forward. Another explanation could be that students respond

in terms of social desirability just after a didactic intervention because they (unconsciously) feel obliged to do so.

Three specific attitude items stood out, when considered individually, because they showed a significant increase in approval following the intervention (viii). These attitude items with the strongest effects have certain characteristics: They do not require any great or long-term efforts from the students at present (but rather by the government or at a later time), which implies that students do not feel compelled to take immediate action. The more realistic and concrete the required tasks are (like donating money, maintaining green facades or distributing flyers), the less the level of agreement changes directly after the intervention. In other words, changes in specific attitudes only occur, if others are responsible, it is something that doesn't have to be done right now and there are no or little costs associated with it.

Explaining effects on practices

When looking at the frequency with which various follow-up activities related to the content of the project day were carried out (ix), a distinction can be made between easier and more difficult activities. Thinking about the project day again or talking to others about it, as well as taking home a flyer or a plant from the project day, are easy activities. It is more difficult or time-consuming to care for the plant students took home (watering and observing it) or to pick up the flyer again and read it and carry out the activities suggested in it. In line with the effort involved, simpler tasks were performed more frequently than those that were more time-consuming and/or cognitively demanding.

It was found that knowledge and attitude correspond to different kinds of practices: Knowledge seems to be predictive for performing flyer-related activities (x). This result can be explained by the fact that flyer-related activities were more cognitive in nature. The more people know about a topic, the more interested they may be in receiving further information (e.g. by reading the flyer and/or by following the links the flyer), the better they can understand this and, therefore, make greater use of information resources (Hidi & Renninger, 2006; Renninger & Hidi, 2022; Tobias, 1994).

Attitude instead seems to be predictive for performing plant-related activities (xi). These results may be explained by the fact that activities like watering and observing

a plant can be considered caring activities. Therefore, if there is a more positive attitude towards green facades, it can be argued that this goes along with a higher appreciation of nature, leading to more attention and care for plants.

These results may suggest that environmental knowledge and attitudes influence behavior through different pathways independently from one another. This conclusion was already drawn by Siegel Levine & Strube (Levine & Strube, 2012). However, their explanation of these different pathways differs from the one in the present study. Highly simplified, in our study we distinguish between the path of knowledge which leads to activities aimed at acquiring further knowledge and the path of attitude/responsibility which leads to more caring activities. In short, it is the motto “I want to know” versus “I want to care.” In contrast, Siegel Levine & Strube (Levine & Strube, 2012) refer to different degrees of consciousness and voluntariness determining behavior. According to their interpretation, attitudes lead individuals to consciously and voluntarily engage in a certain behavior (motto: “I want to do it”). Knowledge, on the other hand, when rooted in traditions, social norms, and formal regulations, is more likely to result in compliance with prescribed behavior (motto: “I have to do it”). Even though this explanation is plausible, it does not align with our study, as all proposed follow-up activities (after the project day) were voluntary for students.

In addition, it must be noted that the observed effects were small for both causal relations in our study (knowledge and flyer-related activities; attitude and plant-related activities). Thus, there must be other important factors affecting the follow-up behavior after the project day.

3.2 Extension of the didactic intervention

The previous chapter discussed the impact of a central component of the teaching concept, namely the natural-scientific research approach. The focus now is on whether the other components of the teaching concept (FIG. 1) could further enhance the positive pro-environmental impact of the intervention. In addition, it will be also addressed whether the inclusion of a preparatory phase prior to the intervention and/or a practical implementation phase after the intervention could further enhance this positive impact. However, the following discussion can only cover presumed (and not actually measured) effects, as the additional phases of the teaching concept had not been tested (due to time restrictions for the doctoral project).

Preparatory phase prior to the intervention

A preparatory phase at school could have preceded the actual intervention to build up students' knowledge about environmental issues, particularly climate-related problems in cities. In having such an additional phase, students would be pre-sensitized to the topics of interest (Manoli et al., 2007, p. 11). In addition, environmental and climate issues would thus be addressed repeatedly in class (and not just on the project day). This is in line with literature showing that there is a need for long term education, by integrating in the syllabus frequent and repeated interventions about environmental issues (Bogner, 1998, p. 26), (Aduse-Poku et al., 2024, p.701).

Descriptive phase

The descriptive phase (inventory of the object of interest) should serve two purposes: (i) It should stimulate students' interest in the topic, as they search for examples, i.e., green facades in their neighborhood and take photos of them. (ii) With the help of these photos, students should learn about different types of green facades and plant species commonly used for them. While the second objective was addressed in the short-term intervention, the first one, i.e. the motivational component, namely the search for and photographic documentation of green facades, was omitted due to time constraints. Such a creative task might have led students to participate in the project with even greater attention and interest, thereby resulting in greater learning gains (Conradty & Bogner, 2019; Harackiewicz et al., 2016; Hidi & Renninger, 2006). The beauty of green facades might also have spoken to students' emotions, provided they appreciate the beauty of nature. This could potentially also have affected their attitudes toward green facades in a positive way and, thus, would demonstrate the positive impact of nature experiences on one's environmental attitude (Bogner, 1998; Kuo et al., 2019; Liefländer et al., 2013; Otto & Pensini, 2017).

Investigative phase – social-scientific research approach

In the social-scientific approach, the focus is on what citizens think about green facades, and whether and where they would support these greening measures (at public and/or private buildings as well as the house they are living in). Literature emphasizes the need for residents' acceptance and appreciation of green facades, to

implement this measure on a larger scale (Magliocco, 2018; Magliocco & Perini, 2015; Molari et al., 2024). That is why it is important for the students to know what citizens think. Based on existing studies (Magliocco, 2018; Magliocco & Perini, 2015; Molari et al., 2024), students could create their own surveys for citizens, for example, residents who live or work in buildings with and without greened walls, to evaluate what they think. Surveys or interviews could address whether residents are aware of the various benefits of green facades, which students had experienced in the natural-scientific sub-phase, as well as drawbacks citizens may associate with these greening measures. Carrying out surveys about environmental issues may be seen as a form of active learning (Felder & Brent, 2009), which will cause an impact on knowledge and attitudes (Granato et al., 2025; Trott, 2019, 2020). There are two reasons why knowledge is influenced by such a socio-scientific survey: Item development requires subject-matter expertise, in order to ask respondents appropriate questions about their perceptions of green facades. Item development thus may serve as a refresher of specialist knowledge. Through item analysis, students are confronted with correct ideas as well as misconceptions of the respondents and must evaluate these answers. This, too, helps to repeat and reflect their own scientific knowledge. Regarding attitudes: During their survey, the students may discover that the respondents do not fully support green facades and, in some cases, even oppose them. This can influence their attitudes in different ways: either positively (as a desire to convince critical individuals) or negatively (as confirmation of their own critical stance). In any case, the survey will prompt students to reflect on their own attitudes as well as those of the survey participants.

Communicative phase

This phase, based on what was done in the previous phases, aims at public outreach. Here, the type of communication can take various forms.

Sharing environmental content with peers is a kind of outreach and an effective way to learn from both sides (Cohen et al., 1982; Topping, 1996). Those who receive the information from peers can do so in a comfortable setting and a familiar language. On the other hand, those who teach can benefit from this approach, since they need to plan and manage this activity. What happens is "learning by teaching" (Duran, 2017; Gartner, 1971) and consequently students improve their knowledge. In addition, those

who explain the topic may enhance their communication skills (Rushton, 2019, pp. 514 and 515), and practice digital methodologies.

Another way to do public outreach may be during open days at school, when students may communicate the topic “green facades” to other students, to teachers of other subjects and parents, showing the results of their school project (including research data of the investigative phase).

Another possibility for communicating to the public is using Photovoice, which means to talk about the topic of interest through digital photos (Trott, 2019, 2020). In fact, this is a qualitative research method (Clandinin & Connelly, 2000), (Creswell & Poth, 2016, p. 10, p. 38), but it can also be effectively used for teaching and/or communication purposes. In our case, students would take photos of various building facades (green, non-green, aesthetically attractive, and unattractive) as well as of their investigations (the natural and social scientific ones) and the experiences associated with them. These photos would then serve as the basis for a discussion with others, a discussion about the pros and cons of green facades and about the question which arguments carry more weight.

These kinds of dissemination are also examples of active learning for students, affecting beneficially not only knowledge, but also attitudes, and consequently practices (Granato et al., 2025; Trott, 2019, 2020). This is because, as students discuss the topic with others, they do not just repeat and defend their knowledge but also get a sense of how their arguments are received. If they find that their arguments are persuasive and effective, this can have a positive impact on their own attitude and willingness to engage.

In fact, involving students in communication activities, also allows to increase their awareness of the social dimension of broader topics (Trott, 2019, p. 44), such as the SDGs and climate change (Pacini et al., 2025; Pacini et al., 2022). Thus, students becoming ambassadors for sustainability and sustainable development (Pacini et al., 2022) – and not just for green facades.

Practical implementation phase

As a culmination of the project, a final hands-on activity could be proposed to students. It should focus on the practical implementation of an environmental/climate protection measure, in this case: setting up a green facade (like an internal or external wall). This includes planning, designing, implementing and maintaining the green facade (plus fundraising, procuring materials, and engaging experts). The installation of the green facade can be done in school or even at another location (if permission has been granted). Thus, not only the participating students but also other members of society benefit from the activity and it becomes a service project. Such kind of projects have been shown to influence students' attitudes and empower them to take action (Monroe et al., 2019).

A further support for hands-on green facades activities is given in a recent book of the UNESCO (UNESCO, 2024). It specifically focuses on counteracting climate change and proposes – among other activities – to set up a vertical garden (UNESCO, 2024, p. 32) as a possible action to implement environmentally friendly infrastructure in a school. From a more general point of view, the ultimate goal would be to end up at a "green school", i.e., a formal or non-formal learning institution that aims to equip learners with the knowledge and attitudes needed to address climate change and to adopt sustainable practices (UNESCO, 2024, p. 4). The installation of a green facade can thus be seen as one step (of several others) in implementing the whole institution approach of getting a "green school".

3.3 Further strategies for achieving pro-environmental changes in the KAP triad

After discussing the results of the didactic intervention (based on the natural-scientific research approach) and exploring ways to improve the intervention‘s effectiveness by adding further phases of the teaching concept, it seems necessary to discuss whether the teaching concept also meets criteria for effective environmental education identified in other studies (independent of those ones in our first publication; see here p. 6). – In addition, two examples of teaching interventions are described, that highlight new, additional criteria that also could influence the effectiveness in achieving pro-environmental changes.

Criteria for effective environmental education

A systematic literature review (Monroe et al., 2019) identified six strategies/criteria to increase the effectiveness of environmental education programs. Effectiveness was measured by assessing the effects of the strategies/criteria on one or more of the three components of the KAP triad. The strategies/criteria are:

1. The **information** given should be **personally relevant** and **meaningful** to the learners.
2. Activities should be designed in a way that **encourages active engagement** by the learners.
3. The use of **deliberative discussions** should enable learners to compare and reflect upon their perspectives and viewpoints with others.
4. **Interaction with scientists** and opportunities to gain (first-hand) **experience with the scientific research process** should be provided.
5. **Misconceptions** should be identified and explicitly addressed.
6. Learners should be involved in **projects** that **affect** the **entire school and/or** the wider **community**.

Several of these six strategies have been already realized in our teaching concept on facade greening, as originally intended (cf. pp. 9, 10; referring to the whole concept and not just the natural scientific research approach):

1. The descriptive phase should encourage students to search for examples of green facades in their direct neighborhoods. This direct connection to the local environment was intended to promote **personal relevance**.
2. All three phases of the teaching concept (the descriptive, investigative, and communicative one) required **active participation**, thereby directly involving the learners in the learning process.
3. **Deliberative discussions** could have emerged through a comparison of the findings from the natural scientific and the social scientific research approach, provided that the results of both approaches would indicate discrepancies (assessment part within the investigative phases). In addition, during the communicative phase, learners communicate with other people and may enter deliberate discussions in which the pros and cons of green facades are weighed against one another.

4. In the investigative phase, students themselves go through the **stages of a research process**. However, they do so in a guided manner and, from a scientific standpoint, they do not discover anything new; rather, they only discover something that is new for them personally. In addition, they do not interact directly with professional scientists, as supervision during the project day was provided by pre-service teachers.
5. **Misconceptions** are not explicitly addressed in the teaching concept; however, they may become apparent when analyzing the results of the social scientific research approach, i.e. the results of the citizen survey (investigative phase), or alternatively, when discussing with citizens (communicative phase). However, in order to argue effectively, students would first need to be aware of these misconceptions and should have already thought of strategies for overcoming them.
6. If an additional practical implementation phase (at the end of the intervention) were integrated into the teaching concept – for example, by establishing a green facade at the school – the final criterion, namely that the project has an **impact on** the entire **school**, would also be fulfilled.

In other words, the current teaching concept already covers many of the strategies/criteria considered essential for effective environmental education.

Two examples of teaching approaches for effective environmental education

In the following, two teaching approaches will be presented which – in comparison to the teaching concept proposed here – incorporate additional strategies/criteria that may also affect the components of the KAP construct.

Example 1: Field research

What makes the following example special is that, on the one hand, contact is established with scientists (cf. criterion 4 of Monroe et al., 2017) and on the other hand, data collection takes place not under artificial laboratory conditions but under real-world environmental conditions.

To address misconceptions and confusion between weather and climate, scientists and staff of a research laboratory on high altitude environments developed a 3-day program

for fifth and sixth grade students of US schools in Colorado (Hallar et al., 2011). The program included classroom lessons on the first day about the chemical composition and layers of the atmosphere, how to use scientific equipment, the mission of the high-altitude laboratory located on a mountain in the region of the school and the key question: “How and why will the weather and particle concentration change as we ascend the mountain”. The second day was a field experience at five specific locations at different altitudes on the way to the laboratory measuring and recording data of various atmospheric parameters and then meeting the scientists at the laboratory to learn about their work there. Day three was again in the classroom where the scientists helped the students to present and interpret their data and discuss them in groups. The effect of this program was assessed with pre- and post-tests, showing a good improvement in students’ knowledge and attitude about climate science.

Regarding data collection, a similar approach to the one described above may also be applied to green facades and sustainability. For example, a program could be designed around green facades present in the city or the neighborhood of a school or at the school itself. For an extended investigative phase (natural scientific research approach), students should be taught how to use scientific instruments to measure various characteristic parameters (temperature, relative humidity) directly on the facade. This allows them to show the effects that such a green facade has on the building where it is placed. Measurements could be taken repeatedly (using common instruments) or even continuously (using data loggers) over a period of time (typically in summer) so that students can notice changes over the course of a day as well as effects of different weather conditions. These “field studies” may help students to see a stronger connection to real-life contexts, and therefore, the data may seem more relevant to them. However, it remains to be investigated whether such field studies will actually have a stronger and more long-lasting effect on students’ attitudes than laboratory experiments.

Example 2: Edutainment

The following example refers to a specific form of knowledge transfer.

The intervention was a fast-paced, one-hour climate science presentation in an assembly format with music and graphics to engage students in understanding the risk

of climate change and highlight the power they have, to make a difference (Flora et al., 2014). The format was developed by the Alliance for Climate Education (ACE) and made available to schools free of charge. This way of combining entertainment and education, is referred to as “infotainment”, “edutainment” or entertainment-education” (E-E) and it incorporates educational messages in entertaining, multi-sensory presentations to engage and capture attention of the learners having a stronger impact as a result. The activity was performed with 2847 high school students of 49 schools, and surveys were administered before and after the assembly to evaluate the changes on the three components of the KAP triad. The ACE intervention resulted quite successful in improving knowledge, attitude, at least in the short term, and selected behaviors (5 behaviors assessed), especially with regard to engaging in interpersonal discussions with family and friends about climate change. Another interesting outcome was that the more dismissive students were shifting to more engaged segments of the assessed population.

This approach could be easily applied by developing an edutainment assembly-format presentation focused on green facades and their positive effects with regard to several sustainability goals. The advantage of such an approach, compared to our comprehensive teaching concept on facade greening with its various phases, is that it would be short and relatively inexpensive and would allow to impact a large number of students from several schools in the same session. Alternatively, edutainment could also be integrated into our teaching concept, namely into the communicative phase. In this case, students would share their knowledge about green facades with others in an entertaining, impressive way. However, this task requires a lot of creativity. Furthermore, it is unclear how such a creative phase affects the components of the KAP framework and whether, for example, the creative ideas (e.g., creating multimedia implementations) become more prominent to students than the actual subject matter.

4 Conclusions

The doctoral project resulted in the following three main conclusions:

1. A review of subject-specific literature can serve as a solid basis for developing a teaching concept for classroom interventions on current topics. The teaching concept presented here (cf. p. 9) is formulated in a general way, making it easy to apply to other topics as well.
2. Even a short intervention of four hours, focused on science-based laboratory experiments, can lead to pro-environmental changes. The knowledge gained remains retained over a period of four weeks, although not all of it is preserved. In contrast, changes in pro-environmental attitudes are only short-term: they occur immediately after the intervention but then disappear again. To increase effectiveness, the intervention could be extended (as suggested in the multi-phase teaching concept). In addition, activities should not only focus on practical-cognitive aspects (such as learning through experiments) but should also include emotional elements. These can be encouraged, for example, through experiences in nature (e.g., during field studies), aesthetic experiences (e.g. through a photo documentary), or edutainment.
3. The project also showed that knowledge and attitudes tend to be predictive for different types of actions. Knowledge is more closely related to cognitive actions, such as seeking further information, while attitudes are linked to more care-oriented behaviors, such as taking care of plants. Therefore, both knowledge and attitudes should be promoted in teaching. Practical activities, however, have also to be included, but they should go beyond gaining knowledge (through experiments or surveys) and refer to actions that benefit society and the environment (like in service projects). Such teaching approaches would combine “head, heart, and hand,” following the idea of Pestalozzi. By this, they should support a holistic development of learners and are therefore considered effective for sustainability education (Sterling & Orr, 2001; Trott, 2019).

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6 Appendixes

6.1 Appendix 1 - Materials of the project days

Description of the didactic intervention

Didactic intervention

The didactic intervention was carried out in a four-hour session which included an introductory phase of verbal explanation about green facades, a practical phase where students worked directly on laboratory experiments and additionally analyzed data from laboratory reports of experiments previously done, and finally a wrap-up phase summarizing the content of the day and proposing follow-up activities. Students were split into small groups during the practical phase and alternated between the experimental stations.

The introductory phase (frontal lecture-style) was meant to introduce the topic "Green Facades" and link it to more general environmental issues, highlighting the most common issues in cities such as global warming and the Urban Heat Island effect, the loss of biodiversity, pollution in the air, along with possible solutions based on nature, such as green facades. We referred to facades plants that may be found easily in the area of North Rhine-Westphalia (state in western Germany) such as *Hedera helix* (Ivy), an evergreen species, *Parthenocissus tricuspidata* (Boston Ivy), deciduous, and *Parthenocissus quinquefolia* (Virginia Creeper), deciduous.

Questions were asked about green facades' effects, to stimulate students to reason autonomously on the presented topics during the next work phase: Are plants used in green facades able to counteract the global warming and the Urban Heat Island effect? If yes, by which mechanism? Do you think green facades may help to preserve biodiversity? Do you think they may help to improve the air quality?

In the **practical phase (hands-on, activity based)** students tried to answer the questions raised in the introductory phase and to learn about the relevant contents through an activity-based approach. The focus of this practical phase was on several specific operating mechanisms of green facades: CO_2 sequestration related to photosynthesis, temperature regulation due to shade and albedo effects, transpiration, and finally the contribution to biodiversity and dust capturing. **The four stations** (three experimental, and one theoretical) being appropriately equipped were set up in the student laboratory of a university.

Station 1 – photosynthesis: Students investigated how green facades plants will capture CO_2 from the air through the photosynthesis process. Different experimental approaches (with leaves or whole plants placed in closed containers (Figure 1); without light, by wrapping aluminum foil around the sample container to simulate darkness, or with light, using a very strong light source such as a LED lamp) were compared to better understand the process. The reduction of CO_2 concentration in the two conditions (non-exposure/exposure to light) was measured by digital sensors. At the same station, the process of respiration could also be demonstrated, leading to an increase in CO_2 concentration in dark conditions. Students were also able to link the experiment to their prior knowledge of photosynthesis and respiration, which are well-established topics in school curricula. In conclusion, pupils were able to understand the environmental impact of green facades, namely the overall reduction of the greenhouse gas CO_2 during daytime.



Figure 1. Photosynthesis and respiration station.

Station 2 - albedo and shade effect: The aim of the second station was to show students a combination of two different effects that occur simultaneously on buildings covered by a Green Facade: the albedo effect and the shade effect. The albedo effect is the reflection of light occurring on a surface, with light-colored surfaces (high albedo) reflecting more light than dark surfaces (low albedo). The shade effect is the interception of light by the plants that constitute a green curtain over a wall. When considering the Urban Heat Island effect in large cities, green surfaces can cool the urban environment more than surfaces made of dark materials, for example, dark gray concrete. Indeed, literature highlights that vegetated areas are generally cooler than sealed surfaces and, therefore, they are useful in an urban context to cope with the UHI effect and climate warming [1].

The experiment (Figure 2) consisted of putting a temperature sensor into boxes irradiated with a lamp, placed 60 cm in front of the box, for 150 seconds. A layer of green facades plants (ivy) was put on the illuminated side of the box, while the temperature sensor was placed inside the box close to the surface illuminated by the lamp. Boxes of two different colors were used: white and black, either with or without the green cover, having in total four different combinations.

Students experimented that dark surfaces heat up more than light-colored surfaces because they have a lower albedo. They also learned that the shading provided by the green cover resulted in a lower inner temperature in the box. In conclusion, students were able to understand the importance of green facades in improving the indoor environment of buildings in hot climates by lowering the internal temperature.



(a)



(b)

Figure 2. Albedo (a) and shade effect (b) station.

Station 3 – transpiration: Here students learned about transpiration of plants, i.e. the release of water vapor from the stomata, when they are open to absorb CO_2.in the photosynthesis process. To increase the transpiration process so to make it more evident, a lamp was used to irradiate the plant for 5 minutes. The experiment was carried out in two ways (Figure 3). (i) In the first case, the humidity was measured directly using a humidity sensor placed in a sealed plastic bag together with an ivy plant. (ii) In the second case, an ivy leaf with a cut stem was placed in a laboratory flask with water. Some oil was added to form an impermeable layer on the surface of the water, preventing it from evaporating directly from the flask. The whole experimental system was weighed with a precision scale before and after illuminating it for 5 minutes. The weight variation indicated indirectly the loss of water by transpiration through the leaves. In doing so, students were able to rely on their prior knowledge from science lessons about heat transfer as latent heat during evaporation and the transpiration process in plants (well-established topics in school curricula).

In conclusion, students were able to understand the importance of these processes for green facades: the heat is used to evaporate water from the leaves, and therefore it is no longer available to raise the temperature of a building wall. For this reason, the temperature inside the building decreases. This phenomenon is called “cooling effect” in the scientific literature of green facades.



(**a**) (**b**)

Figure 3. Transpiration Station: humidity sensor (a), weighing method (b).

Station 4 - biodiversity and dust capturing: At this station, students learn about both the effect of green facades on biodiversity and dust capturing. As these two effects are more difficult to demonstrate (a biodiversity analysis would require an actual green facade outdoor, while the dust capturing effect would require more time than available at the project day and very sophisticated equipment), photos of living creatures in green facades as well as charts of laboratory data were used for students to help them understand these topics.

Literature highlights the effective contribution of green facades to biodiversity [2]. Birds, snails, spiders, and other insects find in green facades nesting habitat, food, and shelter from predators, as well as corridors to move from one green area to another. Flowered facades also attract specialist flower visitors (honeybees, bumblebees, bristle flies, and butterflies) for nectar and pollen [2-5].

In terms of improving air quality, literature says that the greening of a city provides additional surfaces and allows greater deposition rates for airborne particles, pollutants, and dust (compared to bare buildings, pavements, or car parks). While leaf surfaces trap particulate matter, some volatile organic compounds (VOC) can be absorbed directly through the cuticle [6,7], and some gaseous compounds are mainly absorbed through stomata [8].

To make students understand how plants capture dust, laboratory reports of previous complex experiments were presented. Data of two different conditions were

shown: a container without ivy and with an ivy plant inside. The dust level was measured in both conditions showing that it decreased over time in the container with the plant faster than in the other container.

In conclusion, firstly green facades create an oasis for little animals, thereby increasing biodiversity in cities, and secondly, they filter dust and harmful gases from the atmosphere, thereby improving air quality in cities.

The wrap-up phase (interactive, Q&A) was intended to assess whether the students were able to answer the questions raised in the introductory phase and to compare and discuss the results of the experiments.

Subsequently, follow-up activities at home were proposed to keep students engaged with the topic "green facades" after the didactic intervention. For this purpose, a flyer was distributed summarizing important information from the project day and suggesting new activities for students to carry out on their own, with the purpose of stimulating them to recall the experiences gained during the project day and talk about them with parents and friends. The proposed activities in the flyer included: links to websites with more information about green facades (including videos), going on a photo safari of green facades in their neighborhood, and tips for caring for a little ivy plant (watering it, putting it in the right condition for light, and controlling its growth) which students could take home from university if they wished .

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Flyer and follow-up activities (English version)

Experiments

Station 1: Respiration & photosynthesis



During photosynthesis green plants remove CO_2 from the atmosphere and produce O_2. They thus help to counteract climate change, because CO_2 is a greenhouse gas. Theexperiment demonstrates this effect using a model plant in a closed container. Greenfacadeshaveasimilareffect.

Station 2: Albedo & Light interception



Light surfaces reflect more sunlight than dark surfaces. Plants also reflect some sunlight. The reflection corresponds toalbedo. Plants also absorb light, meaning they take it and use it for photosynthesis. The light reflected and absorbed by green facades does not lead to the heating of the house wall.

Station 3: Transpiration



During transpiration plants release water vapor into the air through the stomata in the leaves. This effect lowers the temperature and increases humidity, which is particularly important in dry climates or urban heat islands

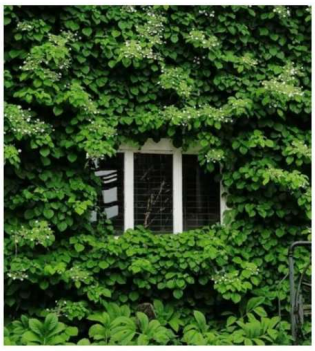
The experiment indirectly demonstrates the evaporation process by measuring the humidity or weight loss of the plants.

Station 4: Biodiversity & Particulate Matter



Green facades absorb dust and harmful gases (e.g. CO_2, NO) from the atmosphere.

This improves air quality. Furthermore, green facades are an oasis for insects and other animals thereby increasing biodiversity in cities.



Project days at the University of Cologne on the topic of facade greening

Universität zu Köln

September/October 2023

Introduction

What is a green facade

A green facade is any way of setting plants on the exterior wall of a building. There are various types of facade greening: surface and modular systems, self-climbing systems (without trellises), climbing systems (with trellises) and hanging plants.

Why should you green a facade?

Green facades can make cities more environmentally friendly. In cities there is often a lack of green areas such as parks, small forests, meadows, vegetable gardens, and flower beds. Green facades provide additional green space: they only require vertical space, not horizontal.

Green facades can be a nature-based solution to several environmental problems. Which problems in cities are we referring to?

- ✓ Climate change and urban heat island effect
- ✓ The lack of green spaces and opportunities to experience nature
- ✓ The loss of biodiversity
- ✓ Air pollution and deterioration of air quality

What are the advantages of a green facade?

Green facades

- ✓ Reduce the increase of temperature in buildings during the summer, among other things, through shading and albedo effect
- ✓ Enable buildings to save energy and emit fewer greenhouse gases into the atmosphere
- ✓ Sequester O_2 from the atmosphere and release O_2
- ✓ Remove dust and harmful gases (e.g. nitrogen oxides)
- ✓ Thus improve air quality
- ✓ Provide habitats for small animals and thus increase biodiversity in cities
- ✓ Increase human well-being
- ✓ Counteract climate change overall



If you **are curious** after the project day, you can find more examples of green facades here:

Get active!

Photo safari

Are there any green facades in your neighborhood? Take photos and share them your classmates to identify the type of plant and the type of green facade.

Let your plant grow

You have received an **ivy plant.** This plant is sometimes found on facades. Place your plant on a small plate or in a bowl in a bright to partially shaded location. Water it only moderately (about twice a week) so that the soil neither dries out completely nor becomes waterlogged. Observe your plant's growth. **Caution:** Ivy is **poisonous** to humans and pets and must **not** be eaten. Skin irritation (when cutting the plant) is also possible.

Flyer and follow-up activities (German version)

Experimente

Station 1: Atmung & Photosynthese



Bei der Photosyn–these entziehen grüne Pflanzen der Atmosphäre CO_2 und produzieren O_2. Sie helfen dadurch, dem Klimawandel entgegenzuwirken, denn CO_2 ist ein Treibhausgas. Das Experiment zeigt diesen Effekt an einer Modellpflanze in einem geschlossenen Behälter. Eine entsprechende Wirkung haben auch grüne Fassaden.

Station 2: Albedo & Absorption



Helle Oberflächen reflektieren mehr Sonnenlicht als dunkle Oberflächen. Auch Pflanzen reflektieren etwas Sonnenlicht. Die Reflexion entspricht der Albedo. Außerdem absorbieren Pflanzen Licht, d.h. sie nehmen es auf, und nutzen es für die Photosynthese. Von Fassadenpflanzen reflektierte und absorbierte Lichtanteile führen nicht zur Erwärmung der Hauswand.

Station 3: Transpiration



Bei der Transpiration der Pflanzen wird Wasserdampf über die Spaltöffnungen in den Blättern an die Luft abgegeben. Dieser Effekt senkt die Temperatur und erhöht die Luft-feuchtigkeit, was besonders in trockenen Klimazonen oder bei städtischen Wärmeinseln nützlich ist. Das Experiment macht den Verdunstungsprozess indirekt sichtbar, indem die Luftfeuchte oder ein Gewichtsverlust der Pflanzen gemessen wird.

Station 4: Biodiversität & Feinstaub



Grüne Fassaden binden Staub und schädliche Gase (z.B. CO_2, NO) aus der Atmosphäre und verbessern so die Luftqualität. Außerdem sind grüne Fassaden eine Oase für Insekten und andere Tiere und können so die Artenvielfalt in Städten erhöhen.



Projekttage an der Uni Köln zum Thema Fassadenbegrünung

Universität zu Köln

September/Oktober 2023

Einleitung

Was ist eine grüne Fassade?

Eine grüne Fassade ist jede Art von Bepflanzung an der Außenwand eines Gebäudes. Es gibt verschiedene Arten von Fassadenbegrünungen: Flächige und modulare Systeme, selbstkletternde Systeme (ohne Gerüst), Rank-Systeme (mit Gerüst) und Hängepflanzen.

Warum sollte man eine Fassade begrünen?

Mit grünen Fassaden kann man die Städte umweltfreundlicher machen. In Städten fehlt es oft an Platz für Grünflächen wie Parks, kleine Wälder, Wiesen, Gemüse-gärten und Blumenbeete. Grüne Fassaden sind zusätzliche Grünflächen: Sie brauchen nur vertikal Platz, nicht horizontal.

Grüne Fassaden können eine naturnahe Lösung für mehrere Umweltprobleme sein. Welche Probleme in Städten meinen wir?

- ✓ Klimawandel und städtischer Wärmeinseleffekt
- ✓ Das Fehlen von Grünflächen und Naturerleben
- ✓ Der Verlust der Artenvielfalt
- ✓ Luftverschmutzung und die Verschlechterung der Luftqualität

Was sind die Vorteile einer grünen Fassade?

Grüne Fassaden

- ✓ verringern im Sommer den Anstieg der Temperatur im Gebäude, u.a. durch Beschattung und Albedo-Effekt
- ✓ ermöglichen bei Gebäuden, Energie zu sparen und weniger Treibhausgase in die Atmosphäre auszustoßen
- ✓ entziehen der Atmosphäre CO_2 und setzen O_2 frei
- ✓ binden Staub und schädliche Gase (z.B. Stickoxide)
- ✓ verbessern so die Luftqualität
- ✓ sind Aufenthaltsort für Kleintiere und erhöhen so die Artenvielfalt in Städten
- ✓ erhöhen das menschliche Wohlbefinden
- ✓ wirken insgesamt dem Klimawandel entgegen



Wenn du durch den Projekttag **neugierig** geworden bist, kannst du hier weitere Beispiele für begrünte Fassaden finden:

Werde aktiv!

Fotosafari

Gibt es grüne Fassaden in eurer Nachbarschaft? Macht Fotos und teilt sie mit euren Mitschüler*innen, um die Pflanzenart und die Art der grünen Fassade zu bestimmen.

Lass deine Pflanze wachsen

Du hast einen **irischen Efeu** erhalten. Diese Pflanze findet man manchmal an Fassaden. Stelle deine Pflanze auf einen kleinen Teller oder in eine Schale an einen hellen bis halbschattigen Ort. Gieße sie nur mäßig (etwa 2 Mal pro Woche), damit die Erde weder austrocknet noch sich Staunässe bildet. Beobachte das Wachstum deiner Pflanze. **Achtung**: Efeu ist für Menschen und Haustiere **giftig** und darf **nicht gegessen** werden. Auch Hautreizungen (beim Pflanzenschnitt) sind möglich.

6.2 Appendix 2 - Questionnaires

Questionnaire administered before the didactic intervention (T0) (English version)

This questionnaire was also used in a slightly modified form for the post-test (T1) and follow-up test (T2).



(#) **Questionnaire on facade greening**

Thank you for taking part in this survey! You are helping us a lot.

On the next few pages we will ask you some questions.
Please note the following points:

- In the **first part of** the questionnaire we ask you about your personal situation and opinion. Therefore, please answer according to your situation and opinion and not according to what you think your parents, your teacher or we think is right.
  - Answer the questions independently, without thinking about them for long.
  - There are questions that are similar. Don't let that confuse you.
- The **second and third parts of** the questionnaire are about knowledge. We are aware that some of these questions are difficult. However, please try to answer all the questions. Please do not copy from the person sitting next to you, as this will distort the results and the research data will no longer be useful.
- You don't have to be afraid of a bad grade, because the evaluation of the questionnaire is of course **anonymous**. This means that we cannot trace who answered which questionnaire.
- **Use a biro** (not a pencil) to fill in the questionnaire.

(#) The questionnaire was developed jointly by Annalisa Pacini, Marie Brüggemann, Maren Flottmann and Kirsten Schlüter. This refers to the sections on knowledge, specific attitudes (regarding green facades) and behavior. Sections taken from other questionaries in literature are marked separately. For some items taken from literature, minor adjustments were made to adapt them to the target group.

Something important in advance: you create your personal code

Today you are filling out the questionnaire for the first time. However, we will ask you again at two later times. This way we want to find out if the project day you will attend at the university changes anything.

In order for us to be able to match your current details with future ones, we would like to ask you to fill in the following code. This way your anonymity is still guaranteed!

CODE - KEY:

Please enter the following in the boxes:

The 2nd and 3rd letters of the street where you currently live (e.g. "Hauptstraße" as "AU").		
Your month of birth as a two-digit number (e.g. "May" as a "05")		
The 2nd and 3rd letters of your father's first name (e.g. "Thomas" as "HO")		
The 1st and 2nd letter of your mother's first name (e.g. "Anke" as "AN")		

If you do not know certain details for the code, enter "NA" in the corresponding boxes.

Part 1: Your personal situation and opinion

Here we go:
First of all, we are interested in your opinion on various topics. Please indicate how much you agree with each of the following statements.

		strongly disagree	somewhat disagree	neither nor	somewhat agree	strongly agree
	The greening of house walls is so important that it should be supported by the government.	☐	☐	☐	☐	☐
	If I had a house, I would green the house wall (facade).	☐	☐	☐	☐	☐
	Cities would be more beautiful with more green house walls (facades).	☐	☐	☐	☐	☐
	For new buildings, facade greening should be mandatory.	☐	☐	☐	☐	☐
	I would donate money for the construction of green facades on public buildings.	☐	☐	☐	☐	☐
	I would take part in maintaining a green facade at my school (e.g., cutting back vegetation on the facade).	☐	☐	☐	☐	☐
	It would bother me if I had more spiders around me because of a green facade.	☐	☐	☐	☐	☐
	I would distribute informational flyers in my free time to promote green facades.	☐	☐	☐	☐	☐
(*)	We do not need to protect areas to preserve endangered species.	☐	☐	☐	☐	☐
(*)	People worry too much about pollution.	☐	☐	☐	☐	☐
(*)	Our planet has unlimited resources.	☐	☐	☐	☐	☐
(*)	We have to clear forests to grow crops (e.g. cereals).	☐	☐	☐	☐	☐
(*)	People are more important than other living beings.	☐	☐	☐	☐	☐
(*)	Environmental protection is holding back economic development.	☐	☐	☐	☐	☐

(*) These items are taken from: Baierl et al., 2022 (p. 9), and from: Bogner & Wiseman, 2006 (p. 251).

(**) **You will find a list of actions here. Please indicate *how often* you perform these actions.**

Always tick *"No information"* (KA) if a question does *not apply to* your current life situation (for example, you cannot give information about your mobile phone if you do not own one).

	never	seldom	some-times	often	very often	KA
I put jumpers or trousers in the wash after I've worn them for a day.	☐	☐	☐	☐	☐	☐
I leave electrical devices (TV, music system, printer) on stand-by.	☐	☐	☐	☐	☐	☐
In winter, I turn down my heating if I leave my room for more than 4 hours.	☐	☐	☐	☐	☐	☐
When it comes to our holidays, I am committed to not going far away if possible. (If you are not going on holiday, please enter "KA" here).	☐	☐	☐	☐	☐	☐
For the way to school I use the bicycle, public transport or walk.	☐	☐	☐	☐	☐	☐
For shorter journeys (10 to 15 minutes) I walk or use the bicycle.	☐	☐	☐	☐	☐	☐
I buy drinks in cans.	☐	☐	☐	☐	☐	☐
I buy drinks in returnable bottles.	☐	☐	☐	☐	☐	☐
If I am offered a plastic bag in the shop, I take it.	☐	☐	☐	☐	☐	☐
On excursions, I take drinks in disposable packs (e.g. hydration packs)	☐	☐	☐	☐	☐	☐
I buy items in refill packs.	☐	☐	☐	☐	☐	☐
At my parties we drink from plastic or paper cups. (If you do not host parties, please enter "KA" here).	☐	☐	☐	☐	☐	☐
I collect waste paper and give it for recycling.	☐	☐	☐	☐	☐	☐
I take used glass to the collection container.	☐	☐	☐	☐	☐	☐
I separate my rubbish.	☐	☐	☐	☐	☐	☐
I save used wrapping paper to reuse it.	☐	☐	☐	☐	☐	☐

(**) All the items on this page are taken from: Kaiser et al., 2007 (pp. 246, 247)

(**)

	never	seldom	some-times	often	very often	KA
When I take notes, I use used paper that is already printed on one side.	☐	☐	☐	☐	☐	☐
I buy food from controlled organic cultivation.	☐	☐	☐	☐	☐	☐
I eat fruit and vegetables according to the season.	☐	☐	☐	☐	☐	☐
When I shop, I prefer products with eco-labels.	☐	☐	☐	☐	☐	☐
I fight insects with a spray.	☐	☐	☐	☐	☐	☐
I eat at McDonalds, Burger King or similar fast food restaurants.	☐	☐	☐	☐	☐	☐
I use notebooks and writing pads made of recycled paper.	☐	☐	☐	☐	☐	☐
I use felt-tip pens and not crayons for painting.	☐	☐	☐	☐	☐	☐
I support getting pizza from the pizza delivery service.	☐	☐	☐	☐	☐	☐
I try to convince my parents to buy a car with the lowest possible fuel consumption. (If your parents do not own a car, please enter "KA" here).	☐	☐	☐	☐	☐	☐
If someone behaves in a way that is harmful to the environment, I make him/her aware of it.	☐	☐	☐	☐	☐	☐
I donate money to environmental organisations.	☐	☐	☐	☐	☐	☐
I ask my parents to buy fruit and vegetables according to the season.	☐	☐	☐	☐	☐	☐
I get books, information pamphlets or other materials that deal with environmental issues.	☐	☐	☐	☐	☐	☐
I inform myself about current environmental issues in the media (social media, newspaper, magazines, books, television).	☐	☐	☐	☐	☐	☐
If I want to go somewhere, I let myself be driven by car.	☐	☐	☐	☐	☐	☐
When I am the last person to leave the room, I switch off the light.	☐	☐	☐	☐	☐	☐

5

(**) All the items on this page are taken from: Kaiser et al., 2007 (pp. 246, 247)

	never	seldom	some-times	often	very often	KA
(*) I take a shower instead of a bath.	☐	☐	☐	☐	☐	☐
I found out about green facades independently of school activities (and independently of the project day).	☐	☐	☐	☐	☐	☐

(**) **The following actions are not about frequency; rather, they are about what is *more likely to be true for you*.**

Always tick *"No answer"* (KA) if a question does *not apply to* your current life situation.

	yes	no	KA
I do not use battery-powered devices.	☐	☐	☐
I am a member of an environmental organisation.	☐	☐	☐
At the hotel, I have the towels changed every day. (If you are not staying in hotels, please enter "KA" here).	☐	☐	☐
After a picnic, I leave the place exactly as I found it.	☐	☐	☐
In winter, it's so warm in my room that you don't freeze even in a T-shirt.	☐	☐	☐
I use shopping bags or sacks several times.	☐	☐	☐
I throw empty batteries into the household waste.	☐	☐	☐

In the following questions we would like to know something about your environment.

	never	seldom	some-times	often	very often	KA
My parents (mother and/or father) use the car every day.	☐	☐	☐	☐	☐	☐
My family spends time together in nature.	☐	☐	☐	☐	☐	☐
In my family we talk about environmental issues.	☐	☐	☐	☐	☐	☐

	strongly disagree	somewhat disagree	neither nor	somewhat agree	strongly agree
Environmental protection is important to my parents (mother and/or father).	☐	☐	☐	☐	☐
My friends are interested in Environmental protection issues.	☐	☐	☐	☐	☐

(*) This item is taken from: Baierl et al., 2022 (p. 9), and from: Bogner & Wiseman, 2006 (p. 251).

(**) All the seven items of this section are taken from: Kaiser et al., 2007 (pp. 246, 247)

Part 2: Knowledge about facade greening

This part is about knowledge relating to planted or greened house walls in cities. This type of planting is also known as facade greening.

leaf

Match the pictures to the correct plant species. Write the respective number next to the illustrations.

1 – Three-pointed wild wine (*Parthenocissus tricuspidata*)

2 – Five-leaved ivy (*Parthenocissus quinquefolia)*

3 – Common ivy *(Hedera helix)*

4 – Common bean (*Phaseolus vulgaris*)

leaf_01 (left) (*)



leaf_02 (right) (**)



This leaf corresponds to the number: _____

This leaf corresponds to the number: _____

leaf_03 (***)



This leaf corresponds to the number: _____

(*) ivy-2421281_1280.jpg by jennyjohansson, pixabay license, source https://pixabay.com/de/photos/ivy-pflanze-green-garten-2421281/

(**) beans-386423_1280.jpg by cocoparisienne, pixabay license, source https://pixabay.com/de/photos/bohnen-bohnenpflanze-gemüse-386423/

(***) wine-1652480_1280.jpg by Leo_65, pixabay license, source https://pixabay.com/de/photos/wein-wilder-wein-weinblätter-1652480/

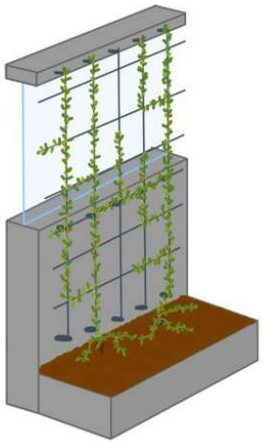
ck_01	What type of facade greening is shown here?

1 ☐ Self-climbing system

2 ☐ Hanging plants

3 ☐ Rank system

4 ☐ Modular system



[Licensed under CC BY-SA 4.0 by Friederike Osterholt & Maik Schössow]

ck_02	Assign the appropriate number from the diagram to the terms or processes below. If you think that no number fits, then write “0”.

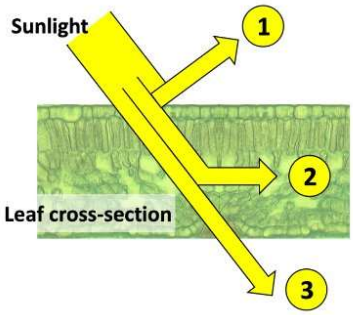
ck_02_1 Albedo
corresponds to the number: _____

ck_02_2 Absorption
corresponds to the number: _____

ck_02_3 Reflection
corresponds to the number: _____

ck_02_4 The proportion of light
that does not lead to shading
of the house wall
corresponds to the number: _____

ck_02_5 The process that is a prerequisite
for the binding of CO_2
corresponds to the number: _____

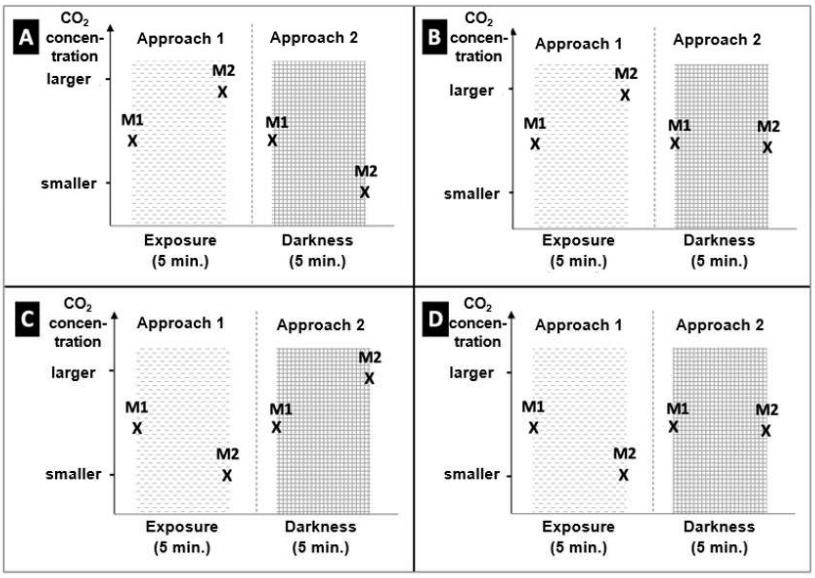


[Modified version of image “Blattquerschnitt” by V44020001, public domain, source: https://de.m.wikipedia.org/wiki/Datei:Blattquerschnitt.jpg]

ck_03

In one experiment, the effect of a plant on the CO_2 concentration in the ambient air is investigated. Two approaches are taken for this purpose: In Approach 1, the plant is exposed to light. In Approach 2, the plant is in the dark. There are two measurement times (M) per approach: M1 at the beginning and M2 at the end of the light or dark phase. The figure shows four possible experimental results (A, B, C, D). Which result is the most realistic?

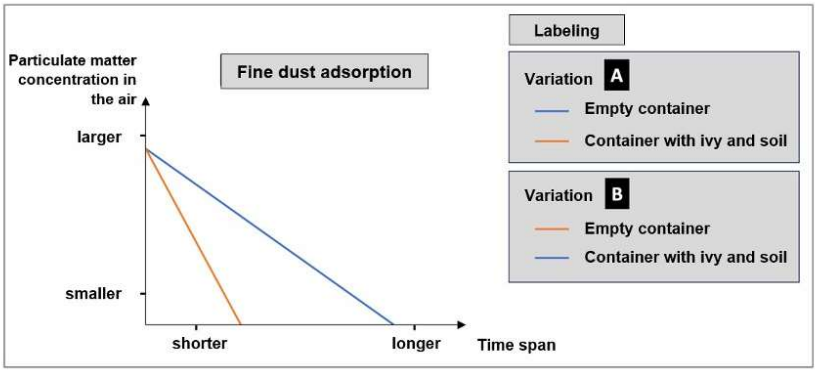
☐ A ☐ B ☐ C ☐ D



ck_04

Select the correct label (A or B) for the following chart.

☐ A ☐ B



<u>Several</u> answers may be correct for the following questions. (However, it can also happen that only one answer is correct!)
Please select the correct answer(s).

ck_MC_01	The illustration shows two different types of leaves: (1) white-green leaves and (2) pure green leaves. Which statement(s) is/are correct when comparing the two leaf types?
1	☐ The pure green leaves have a higher albedo.
2	☐ The white-green leaves bind more CO_2.
3	☐ The white-green leaves have a lower absorption rate.
4	☐ Both leaf types belong to self-climbing plants.



[Composite image created by Friederike Osterholt from: "Hedera helix Leaves" by Derek Ramsey, licensed under CC BY-SA 3.0, source: https://commons.wikimedia.org/wiki/File:Hedera_helix_Leaves_3008px.jpg and "Noordwijk - Klimop (Hedera helix) v2" by Rudolphous, licensed under CC BY-SA 4.0, source: https://commons.wikimedia.org/wiki/File:Noordwijk_-_Klimop_(Hedera_helix)_v2.jpg. Final image licensed under CC BY-SA 4.0.]

ck_MC_02	What do you call plants that do not need or tolerate direct sunlight during the day?
1	☐ Sun plants
2	☐ Part-shade plants
3	☐ Shade plants
4	☐ Dark plants

ck_MC_03	Imagine a house in a big city on a hot day whose walls are covered with a green facade. Which of the following effects helps to lower the temperature inside the house?
1	☐ The “shadow effect”
2	☐ The “cooling effect”
3	☐ The “airflow effect”
4	☐ The “albedo effect”

ck_MC_04	What applies to the transpiration of plants?
1	☐ Transpiration is reduced if the plant does not receive enough water.
2	☐ Transpiration creates an air flow around the wall, which helps to cool the wall.
3	☐ The transpiration process requires energy, which is then no longer available to heat the wall.
4	☐ Transpiration helps to reduce the “heat island effect” in cities.

ck_MC_05	Which of the following statements about CO_2 is/are true?
1	☐ In parks, the CO_2 content in the air is higher in summer than in winter.
2	☐ In a closed room with people, the CO_2 content is higher than outside in the open air.
3	☐ The CO_2 content in the atmosphere is increasing due to the greenhouse gases we produce.
4	☐ In the forest, the CO_2 content in the air does not change over the course of a summer day.
ck_MC_06	What effect(s) do green facades have on air quality?
1	☐ They improve air quality by reducing CO_2.
2	☐ They improve the air quality by producing O_2.
3	☐ They improve air quality by removing dust and harmful gases.
4	☐ They improve air quality indirectly by reducing the consumption of fossil fuels/energy for heating or cooling.
ck_MC_07	What applies to the “albedo effect” in cities?
1	☐ The “heat island effect” can be reduced by increasing the albedo of a city.
2	☐ The albedo of cities is generally very high and it is not necessary to do anything about it.
3	☐ The “albedo effect” in cities relates exclusively to the facades of buildings.
4	☐ The albedo of a building with a green facade depends on the shade of green of the plants (light or dark green).
ck_MC_08	The effect of green facades as a source of shade depends on ...
1	☐ How large the leaves are, regardless of how dense they are.
2	☐ What time of year it is, if the plant is not evergreen.
3	☐ How thick the wall is on which the green facade is located.
4	☐ How much of the surface of the facade is covered by leaves.
ck_MC_09	How much CO_2 is in the atmosphere?
1	☐ 4000 ppm
2	☐ 0.4%
3	☐ 400 ppm
4	☐ 0.04%

ck_MC_10	What does the term “biodiversity” mean?
1	☐ The diversity of different organisms in an ecosystem.
2	☐ The diversity of genetic variation within a species or all species of an ecosystem.
3	☐ The diversity of different habitats in an area.
4	☐ The variety of perspectives from which humans analyze biological processes.
ck_MC_11	What kind(s) of animals can typically be found on or in a green facade?
1	☐ Small birds
2	☐ Insects
3	☐ Bats
4	☐ Hamsters
ck_MC_12	Which of the following statements about air pollutants is/are true?
1	☐ CO_2 is an air pollutant.
2	☐ Particulate matter is an air pollutant.
3	☐ PM10 are particles that are smaller than 10 nanometers.
4	☐ The particles are usually visible to the human eye.
ck_MC_13	What advantage(s) do green facades offer to living creatures?
1	☐ Fire protection
2	☐ Protection from predators
3	☐ Food source (e.g. for birds)
4	☐ Nest building

Please state whether the following statements are <u>true or false</u>:

		true	false
		1	2
ck_RW_01	The energy saved by greening the facade depends on the orientation of the wall to the sun, i.e. whether the wall faces north, east, south or west.	☐	☐
ck_RW_02	The albedo of a black surface is higher than that of a white surface.	☐	☐
ck_RW_03	In principle, any plant can be used for facade greening.	☐	☐
ck_RW_04	Nitrogen oxide is an air pollutant.	☐	☐
ck_RW_05	The “albedo effect” is the storage of heat in buildings.	☐	☐
ck_RW_06	The “heat island effect” describes the phenomenon that cities are often significantly warmer in summer than their rural surroundings.	☐	☐
ck_RW_07	Air at a temperature of 30°C can absorb at least 31 g water/m².	☐	☐

You have already done a lot, but the questionnaire is not over yet. It continues on the next page.

Part 3: Knowledge about experiments

This part is about knowledge in relation to the experiments you will carry out during the project day.

<u>Several</u> answers to the following questions may be correct. (However, it is also possible that only one answer is correct!)

Please select the correct answer(s).

We are aware that these questions are very difficult if you have not yet carried out the experiments. Nevertheless, please try to answer all the questions as best you can.

---

sensor

Assign the correct name to the sensors. Write the respective number next to the illustrations.

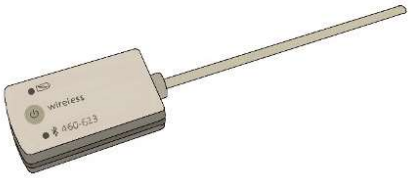
1 – CO_2 sensor

2 – pH indicator

3 – Temperature sensor

4 – Air humidity sensor

sen_01 (left) (*)



sen_02 (right) (*)



This sensor corresponds to the number: _____

This sensor corresponds to the number: _____

sen_03 (*)



This sensor corresponds to the number: _____

(*) Figures created by Simon Meul

tk_MC_01	There is a plant in a sample container. What is suitable for simulating darkness in the sample container?	
1	☐ Aluminum foil	
2	☐ Cling film	
3	☐ Writing paper	
4	☐ Storage in cupboard	
tk_MC_02	If you want to visualize the transpiration of a plant directly, the plant should be in a sealed container. The container must be closed, ...	
1	☐ As a certain pressure must be maintained for the measurement.	
2	☐ To compensate for fluctuations in the room temperature.	
3	☐ To prevent moisture from escaping from the container.	
4	☐ The container does not have to be closed. It can also be open.	
tk_MC_03	Which measuring device(s) belong(s) to the experiment shown in the illustration?	
1	☐ Precision scale	
2	☐ pH indicator	
3	☐ CO_2 sensor	
4	☐ O_2 sensor	
5	☐ Particulate matter sensor	
6	☐ Conductivity meter	
7	☐ Temperature sensor	
8	☐ Water quality test device	

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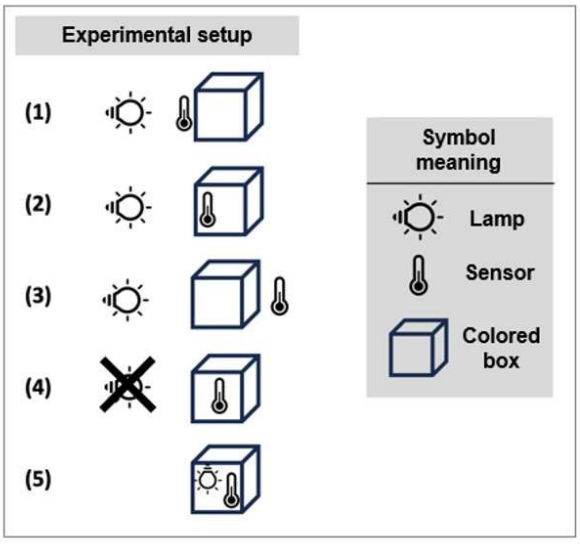
tk_MC_04	The phenomenon of transpiration is to be demonstrated in a plant. For this purpose, there is a control approach in addition to the investigation approach. What does this control approach look like?	
1	☐ Just like the investigation approach to see if both approaches lead to the same results.	
2	☐ Just like the investigation approach, but without the plant.	
3	☐ Just like the investigation approach, but at a higher ambient temperature.	
4	☐ Just like the investigation approach, but there is no water in the container for the plant.	

tk_MC_05	The shading effect is to be demonstrated indirectly in an experiment. What is done with the sensor before the start of each measurement?
1	☐ It is sterilized
2	☐ It is charged
3	☐ It is centered
4	☐ It is set to zero
5	☐ It is cleaned
6	☐ It is brought to room temperature

tk_MC_06	The albedo effect can be made clearly visible with colored boxes. How many or which boxes are needed for this?
1	☐ A single white box
2	☐ A single black or white box
3	☐ One black and one white box
4	☐ Two boxes of the same color
5	☐ A box must be red

tk_MC_07	The aim of the experiment is to demonstrate the impact of the albedo effect. An indirect measurement method is used for this purpose. Which figure shows the appropriate experimental setup? (Note: The control experiment, which is also necessary, is not included in the figures).

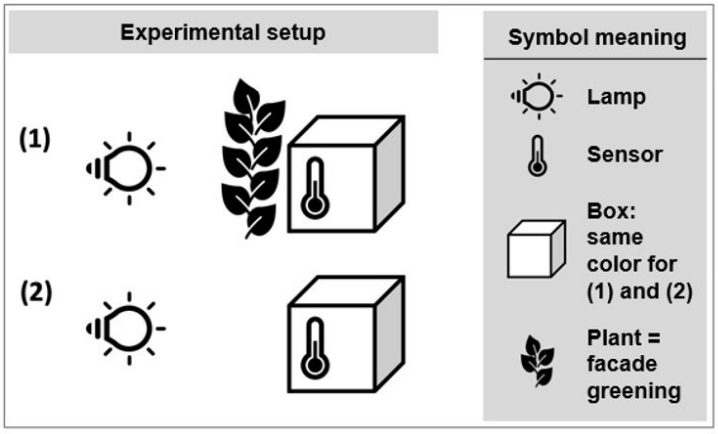
☐ (1) ☐ (2) ☐ (3) ☐ (4) ☐ (5)



tk_MC_08	Why are darkened plants or leaves used for an experiment in which the effects of photosynthesis are to be measured?	
1	☐ To achieve a stronger effect.	
2	☐ So that the plants do not wither.	
3	☐ To prevent (cell) respiration processes in plants, which are the opposite of photosynthesis.	
4	☐ To prevent the green leaf pigment from decomposing.	
5	☐ Because otherwise photosynthesis would not take place during the measurement.	
tk_MC_09	How is the CO_2 content of a person's exhaled air measured?	
1	☐ As volume share	
2	☐ With two measurements: one before and one after exhaling	
3	☐ With two sensors: one for inhaled air and one for exhaled air	
4	☐ In the open air	
tk_MC_10	What is the experiment shown in the illustration supposed to prove?	
1	☐ Albedo effect with plants	
2	☐ Effect of chemicals on plants	
3	☐ CO_2 production in plants	
4	☐ O_2- production in plants	
5	☐ Transpiration in plants	

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tk_MC_11	If the results of the two experimental approaches (1 and 2) are compared, the following effect can be determined:
1	☐ Sole effect of the albedo of the plant
2	☐ Sole effect of the albedo of the box
3	☐ Sole effect of light absorption by the plant
4	☐ Combined effect of albedo and light absorption by the plant
5	☐ Effect of shading by the plant
6	☐ None of the effects mentioned



tk_MC_12	In experiments in which the effect of photosynthesis on the ambient air is to be investigated, very powerful light sources (special lamps) are usually used. What is the reason for this?
1	☐ Prevent incorrect measurements.
2	☐ No reactions take place at temperatures below 15 degrees room temperature.
3	☐ The desired effect is achieved faster.
4	☐ A stronger effect is achieved.
5	☐ Daylight alone is ineffective.

tk_MC_13	The effect of photosynthesis on the amount of greenhouse gas in the air is to be measured. The following is needed for the investigation: a plant, ...
1	☐ Precision scale
2	☐ pH paper
3	☐ Suction pipette
4	☐ CO_2 sensor
5	☐ O_2 sensor
6	☐ Fan
7	☐ Sealable container
8	☐ Volume measuring device

tk_MC_14	What is the function of the dark liquid on the water in the illustration?
1	☐ It serves as a nutrient for the plant.
2	☐ It prevents the water from evaporating from the container.
3	☐ It prevents the plant from wilting.
4	☐ It prevents pollutants from the air entering the plant via the water.



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Now you're almost there! Finally, we would like to ask you for some information about yourself:

When were you born? _____ _____
Month Year

Your gender is? female ☐ male ☐ diverse ☐

Your grade level _____

Let's be honest: Did you answer the questions carefully and sensibly?

no ☐ yes ☐ don't know ☐

Do you have any suggestions or criticism about this questionnaire?

_____

_____

_____

_____

_____

_____

Thank you very much for your cooperation!

Questionnaire administered before the didactic intervention (T0) (German version)



(#) **Fragebogen zu Fassadenbegrünung**

Vielen Dank, dass du an dieser Befragung teilnimmst!
Du hilfst uns damit sehr.

Auf den nächsten Seiten stellen wir dir einige Fragen.
Bitte beachte dabei die folgenden Punkte:

- Im **ersten Teil** des Fragebogens fragen wir dich nach deiner ganz persönlichen Situation und Meinung. Antworte deshalb bitte so, wie es deiner Situation und Meinung entspricht und nicht danach, was du glaubst, was deine Eltern, dein(e) Lehrer(in) oder wir richtig fänden.
  - Beantworte die Fragen selbständig, ohne lange darüber nachzudenken.
  - Es gibt Fragen, die sich ähnlich sind. Lass dich dadurch nicht verwirren.
- Im **zweiten und dritten Teil** des Fragebogens geht es um Wissen. Wir sind uns bewusst, dass einige dieser Fragen schwierig sind. Versuche bitte dennoch, alle Fragen zu beantworten. Bitte schreibe nicht bei deinem/deiner Sitznachbar*in ab, denn das würde die Ergebnisse verfälschen und die Forschungsdaten sind dann nicht mehr brauchbar.
- Du musst keine Angst vor einer schlechten Note haben, denn die Auswertung des Fragebogens ist selbstverständlich **anonym**. Das heißt, dass wir nicht nachvollziehen können, wer welchen Fragebogen beantwortet hat.
- Verwende zum Ausfüllen des Fragebogens einen **Kugelschreiber** (keinen Bleistift).

(#) The questionnaire was developed jointly by Annalisa Pacini, Marie Brüggemann, Maren Flottmann and Kirsten Schlüter. This refers to the sections on knowledge, specific attitudes (regarding green facades) and behavior. Sections taken from other questionaries in literature are marked separately. For some items taken from literature, minor adjustments were made to adapt them to the target group.

Etwas Wichtiges vorab: Du erstellst Deinen persönlichen Code

Heute füllst Du zum ersten Mal den Fragebogen aus. Wir werden Dich jedoch zu zwei späteren Zeitpunkten nochmals befragen. Auf diese Weise wollen wir herausfinden, ob der Projekttag, den du an der Uni besuchen wirst, etwas verändert.

Damit wir deine jetzigen Angaben den künftigen zuordnen können, möchten wir dich bitten, den folgenden Code auszufüllen. Auf diese Weise bleibt deine Anonymität trotzdem gewährleistet!

CODE – SCHLÜSSEL:

Bitte trage in die Kästchen folgendes ein:

Den 2. und 3. Buchstaben der Straße, in der du aktuell wohnst (z.B. „Hauptstraße“ als „AU“)		
Deinen Geburtsmonat als zweistellige Zahl (z.B. „Mai“ als „05“)		
Den 2. und 3. Buchstaben des Vornamens deines Vaters (z.B. „Thomas“ als „HO“)		
Den 1. und 2. Buchstaben des Vornamens deiner Mutter (z.B. „Anke“ als „AN“)		

Falls dir bestimmte Angaben für den Code nicht bekannt sein sollten, trage „NA“ in die entsprechenden Kästchen ein.

1. Teil: Deine persönliche Situation und Meinung

Jetzt geht es los:
Zunächst interessiert uns deine Meinung zu verschiedenen Themen. Bitte gib jeweils an, wie sehr du den folgenden Aussagen zustimmst.

		stimme gar nicht zu	stimme eher nicht zu	weder noch	stimme eher zu	stimme voll zu
	Die Begrünung von Hauswänden und Mauern ist so wichtig, dass sie von der Regierung unterstützt werden sollte.	☐	☐	☐	☐	☐
	Wenn ich ein Haus hätte, würde ich die Hauswand (Fassade) begrünen.	☐	☐	☐	☐	☐
	Städte wären schöner mit mehr begrünten Hauswänden (Fassaden).	☐	☐	☐	☐	☐
	Für neue Gebäude sollte Fassadenbegrünung Pflicht sein.	☐	☐	☐	☐	☐
	Ich würde Geld für die Errichtung von grünen Fassaden an öffentlichen Gebäuden spenden.	☐	☐	☐	☐	☐
	Ich würde mich an der Pflege einer grünen Fassade an meiner Schule beteiligen (z. B. Fassadenbewuchs zurückschneiden).	☐	☐	☐	☐	☐
	Es würde mich stören, wenn ich durch eine grüne Fassade mehr Spinnen in meiner Nähe hätte.	☐	☐	☐	☐	☐
	Ich würde in meiner Freizeit Informationsblätter verteilen, um für grüne Fassaden zu werben.	☐	☐	☐	☐	☐
(*)	Wir müssen keine Gebiete schützen, um bedrohte Arten zu bewahren.	☐	☐	☐	☐	☐
(*)	Die Menschen machen sich zu viele Gedanken über Umweltverschmutzung.	☐	☐	☐	☐	☐
(*)	Unser Planet hat unbegrenzte Ressourcen.	☐	☐	☐	☐	☐
(*)	Wir müssen Wälder roden, um Nutzpflanzen (z.B. Getreide) anzubauen.	☐	☐	☐	☐	☐
(*)	Menschen sind wichtiger als andere Lebewesen.	☐	☐	☐	☐	☐
(*)	Der Umweltschutz hält die wirtschaftliche Entwicklung auf.	☐	☐	☐	☐	☐

(*) These items are taken from: Baierl et al., 2022 (p. 9), and from: Bogner & Wiseman, 2006 (p. 251).

(**) **Du findest hier eine Liste von Handlungen. Bitte gib an, *wie häufig* du diese Handlungen ausführst.**

Kreuze *„Keine Angabe“* (KA) immer dann an, wenn eine Frage auf deine momentane Lebenssituation *nicht zutrifft* (zum Beispiel kannst du keine Angaben zu deinem Handy machen, wenn du gar kein Handy besitzt).

	nie	selten	manch-mal	oft	sehr oft	KA
Pullover oder Hosen gebe ich in die Wäsche, wenn ich sie einen Tag lang getragen habe.	☐	☐	☐	☐	☐	☐
Elektrische Geräte (Fernseher, Musikanlage, Drucker) lasse ich auf Stand-by stehen.	☐	☐	☐	☐	☐	☐
Im Winter drehe ich meine Heizung herunter, wenn ich mein Zimmer für mehr als 4 Stunden verlasse.	☐	☐	☐	☐	☐	☐
Wenn es um unseren Urlaub geht, setze ich mich dafür ein, möglichst nicht weit weg zu fahren. (Wenn du nicht in den Urlaub fährst, gib hier bitte „KA“ an.)	☐	☐	☐	☐	☐	☐
Für den Schulweg benutze ich das Fahrrad, öffentliche Verkehrsmittel oder gehe zu Fuß.	☐	☐	☐	☐	☐	☐
Für kürzere Wege (10 bis 15 Minuten) laufe ich oder benutze das Fahrrad.	☐	☐	☐	☐	☐	☐
Ich kaufe Getränke in Dosen.	☐	☐	☐	☐	☐	☐
Ich kaufe Getränke in Mehrwegflaschen.	☐	☐	☐	☐	☐	☐
Wenn mir im Geschäft eine Plastiktüte angeboten wird, nehme ich sie.	☐	☐	☐	☐	☐	☐
Auf Ausflüge nehme ich Getränke in Einmalpackungen (z.B. Trinkpäckchen) mit.	☐	☐	☐	☐	☐	☐
Ich kaufe Artikel in Nachfüllpackungen.	☐	☐	☐	☐	☐	☐
Auf meinen Partys trinken wir aus Plastik- oder Pappbechern. (Wenn du keine Partys veranstaltest, gib hier bitte „KA“ an.)	☐	☐	☐	☐	☐	☐
Ich sammle Altpapier und gebe es zum Recycling.	☐	☐	☐	☐	☐	☐
Altglas bringe ich zum Sammelcontainer.	☐	☐	☐	☐	☐	☐
Ich trenne meinen Müll.	☐	☐	☐	☐	☐	☐
Gebrauchtes Geschenkpapier hebe ich auf, um es wiederzuverwenden.	☐	☐	☐	☐	☐	☐

4

(**) All the items on this page are taken from: Kaiser et al., 2007 (pp. 246, 247)

(**)

	nie	selten	manch-mal	oft	sehr oft	KA
Wenn ich mir Notizen mache, benutze ich gebrauchtes Papier, das auf einer Seite schon bedruckt ist.	☐	☐	☐	☐	☐	☐
Ich kaufe Lebensmittel aus kontrolliert biologischem Anbau.	☐	☐	☐	☐	☐	☐
Ich esse Obst und Gemüse der Jahreszeit entsprechend.	☐	☐	☐	☐	☐	☐
Beim Einkaufen bevorzuge ich Produkte mit Umweltzeichen.	☐	☐	☐	☐	☐	☐
Insekten bekämpfe ich mit einem Spray.	☐	☐	☐	☐	☐	☐
Ich esse bei McDonalds, Burger King oder ähnlichen Schnellrestaurants.	☐	☐	☐	☐	☐	☐
Ich benutze Hefte und Schreibblöcke aus Recyclingpapier.	☐	☐	☐	☐	☐	☐
Ich benutze Filzstifte und keine Buntstifte zum Malen.	☐	☐	☐	☐	☐	☐
Ich bin für Pizza vom Pizzaservice zu haben.	☐	☐	☐	☐	☐	☐
Ich versuche, meine Eltern davon zu überzeugen, ein Auto mit möglichst wenig Kraftstoffverbrauch zu kaufen. (Wenn deine Eltern kein Auto besitzen, gib hier bitte „KA“ an.)	☐	☐	☐	☐	☐	☐
Wenn sich jemand umweltschädigend verhält, mache ich ihn/ sie darauf aufmerksam.	☐	☐	☐	☐	☐	☐
Ich spende Geld für Umweltschutzorganisationen.	☐	☐	☐	☐	☐	☐
Ich fordere meine Eltern auf, Obst und Gemüse der Jahreszeit entsprechend zu kaufen.	☐	☐	☐	☐	☐	☐
Ich besorge mir Bücher, Informationsschriften oder andere Materialien, die sich mit Umweltproblemen befassen.	☐	☐	☐	☐	☐	☐
Ich informiere mich in den Medien (Social Media, Zeitung, Zeitschriften, Bücher, Fernsehen) über aktuelle Umweltfragen.	☐	☐	☐	☐	☐	☐
Wenn ich irgendwo hin will, lasse ich mich mit dem Auto fahren.	☐	☐	☐	☐	☐	☐
Wenn ich als letzte Person den Raum verlasse, schalte ich das Licht aus.	☐	☐	☐	☐	☐	☐

5

(**) All the items on this page are taken from: Kaiser et al., 2007 (pp. 246, 247)

		nie	selten	manch-mal	oft	sehr oft	KA
(*)	Ich dusche anstatt zu baden.	☐	☐	☐	☐	☐	☐
	Ich habe mich unabhängig von schulischen Aktivitäten (und unabhängig vom Projekttag) über grüne Fassaden informiert.	☐	☐	☐	☐	☐	☐

(**) **Bei den folgenden Handlungen ist nicht die Häufigkeit gefragt; es geht vielmehr darum, was *eher für dich zutrifft*.**

Kreuze *„Keine Angabe"* (KA) immer dann an, wenn eine Frage auf deine momentane Lebenssituation *nicht zutrifft*.

	ja	nein	KA
Ich verzichte auf batteriebetriebene Geräte.	☐	☐	☐
Ich bin Mitglied in einer Umweltschutzorganisation.	☐	☐	☐
Im Hotel lasse ich täglich die Handtücher wechseln. (Wenn du nicht in Hotels übernachtest, gib hier bitte „KA" an.)	☐	☐	☐
Ich verlasse nach einem Picknick den Platz genauso, wie ich ihn angetroffen habe.	☐	☐	☐
Im Winter ist es in meinem Zimmer so warm, dass man auch im T-Shirt nicht friert.	☐	☐	☐
Ich verwende Einkaufstüten oder -taschen mehrfach.	☐	☐	☐
Leere Batterien werfe ich in den Hausmüll.	☐	☐	☐

Bei den folgenden Fragen möchten wir gerne etwas über dein Umfeld erfahren.

	nie	selten	manch-mal	oft	sehr oft	KA
Meine Eltern (Mutter und/oder Vater) nutzen das Auto täglich.	☐	☐	☐	☐	☐	☐
Meine Familie verbringt zusammen Zeit in der Natur.	☐	☐	☐	☐	☐	☐
In meiner Familie sprechen wir über Umweltschutz-Themen.	☐	☐	☐	☐	☐	☐

	stimme gar nicht zu	stimme eher nicht zu	weder noch	stimme eher zu	stimme voll zu
Meinen Eltern (Mutter und/oder Vater) ist Umweltschutz wichtig.	☐	☐	☐	☐	☐
Meine Freunde interessieren sich für Umweltschutz-Themen.	☐	☐	☐	☐	☐

(*) This item is taken from: Baierl et al., 2022 (p. 9), and from: Bogner & Wiseman, 2006 (p. 251).

(**) All the seven items of this section are taken from: Kaiser et al., 2007 (pp. 246, 247)

2. Teil: Wissen über Fassadenbegrünung

In diesem Teil geht es um Wissen in Bezug auf bepflanzte bzw. begrünte Hauswände in Städten. Eine solche Art von Bepflanzung nennt man auch *Fassadenbegrünung*.

leaf	Ordne den Bildern die korrekte Pflanzenart zu. Schreibe dazu die jeweilige Nummer neben die Abbildungen.

1 – Dreispitziger Wilder Wein (*Parthenocissus tricuspidata*)

2 – Fünflappiger Wilder Wein (*Parthenocissus quinquefolia*)

3 – Gemeiner Efeu *(Hedera helix)*

4 – Gartenbohne (*Phaseolus vulgaris*)

leaf_01 (links) (*)



Dieses Blatt
entspricht der Nummer _____

leaf_02 (rechts) (**)



Dieses Blatt
entspricht der Nummer _____

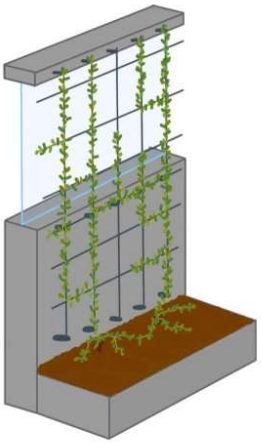
leaf_03 (***)



Dieses Blatt
entspricht der Nummer _____

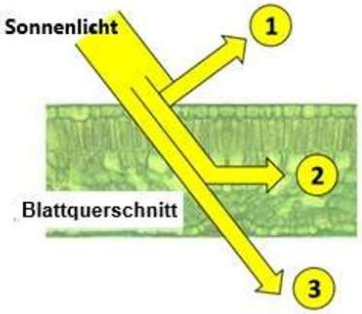
(*) ivy-2421281_1280.jpg by jennyjohansson, pixabay license, source https://pixabay.com/de/photos/ivy-pflanze-green-garten-2421281/
(**) beans-386423_1280.jpg by cocoparisienne, pixabay license, source https://pixabay.com/de/photos/bohnen-bohnenpflanze-gemüse-386423/
(***) wine-1652480_1280.jpg by Leo_65, pixabay license, source https://pixabay.com/de/photos/wein-wilder-wein-weinblätter-1652480/

ck_01	Welche Art der Fassadenbegrünung ist hier abgebildet?
1	☐ Selbstkletterndes System
2	☐ Hängepflanzen
3	☐ Rank-System
4	☐ Modulares System



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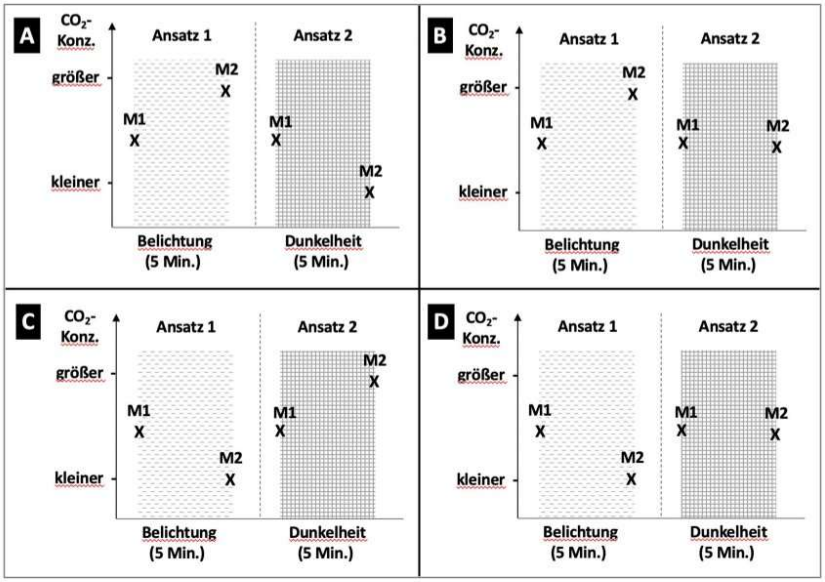
ck_02	Ordne den untenstehenden Begriffen bzw. Prozessen die passende Zahl aus der Abbildung zu. Wenn Du meinst, dass keine Zahl passt, dann schreibe „0“.
ck_02_1	Albedo entspricht der Zahl ____
ck_02_2	Absorption entspricht der Zahl ____
ck_02_3	Reflexion entspricht der Zahl ____
ck_02_4	Der Lichtanteil, der nicht zur Beschattung der Hauswand führt, entspricht der Zahl ____
ck_02_5	Der Prozess, der Voraussetzung für die Bindung von CO_2 ist, entspricht der Zahl ____



[Modified version of image “Blattquerschnitt” by V44020001, public domain, source: https://de.m.wikipedia.org/wiki/Datei:Blattquerschnitt.jpg]

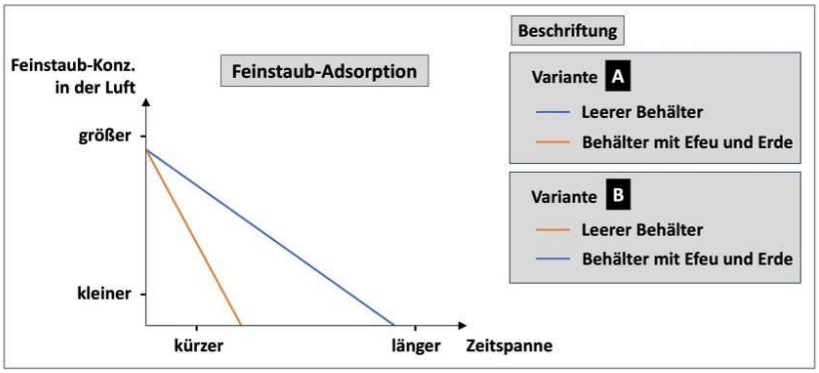
ck_03 In einem Versuch wird untersucht, welchen Effekt eine Pflanze auf die CO_2-Konzentration in der Umgebungsluft hat. Hierzu werden zwei parallele Versuchsansätze durchgeführt: Beim Ansatz 1 wird die Pflanze belichtet. Beim Ansatz 2 steht die Pflanze im Dunkeln. Pro Ansatz gibt es zwei Messzeitpunkte (M): M1 am Anfang und M2 am Ende der Belichtungs- bzw. Dunkelphase. Die Abbildung zeigt vier mögliche Versuchsergebnisse (A, B, C, D). Welches Ergebnis ist am realistischsten?

☐ A ☐ B ☐ C ☐ D



ck_04 Wähle für die folgende Grafik die korrekte Beschriftung (A oder B) aus.

☐ A ☐ B



Bei den folgenden Fragen können <u>mehrere</u> Antworten richtig sein. (Es kann aber auch vorkommen, dass nur eine Antwort richtig ist!)
Bitte wähle jeweils die korrekte(n) Antwort(en) aus.

ck_MC_01	Die Abbildung zeigt zwei verschiedene Blatttypen: (1) weiß-grüne Blätter und (2) rein grüne Blätter. Welche Aussage(n) stimmen, wenn man die beiden Blatttypen miteinander vergleicht?	
1	☐ Die rein grünen Blätter haben eine höhere Albedo.	
2	☐ Die weiß-grünen Blätter binden mehr CO_2.	
3	☐ Die weiß-grünen Blätter haben eine geringere Absorptionsrate.	
4	☐ Beide Blatttypen gehören zu selbstkletternden Pflanzen.	

[Composite image created by Friederike Osterholt from: "Hedera helix Leaves" by Derek Ramsey, licensed under CC BY-SA 3.0, source: https://commons.wikimedia.org/wiki/File:Hedera_helix_Leaves_3008px.jpg and "Noordwijk - Klimop (Hedera helix) v2" by Rudolphous, licensed under CC BY-SA 4.0, source: https://commons.wikimedia.org/wiki/File:Noordwijk_-_Klimop_(Hedera_helix)_v2.jpg. Final image licensed under CC BY-SA 4.0.]

ck_MC_02	Wie bezeichnet man Pflanzen, die im Tagesverlauf kein direktes Sonnenlicht benötigen bzw. vertragen?	
1	☐ Sonnenpflanzen	
2	☐ Halbschattenpflanzen	
3	☐ Schattenpflanzen	
4	☐ Dunkelpflanzen	

ck_MC_03	Stell dir ein Haus in einer Großstadt an einem heißen Tag vor, dessen Wände mit einer grünen Fassade bedeckt sind. Welche(r) der folgenden Effekte trägt dazu bei, die Temperatur im Haus-Inneren zu senken?	
1	☐ Der „Schatteneffekt“	
2	☐ Der „Kühlungseffekt“	
3	☐ Der „Luftstrom-Effekt“	
4	☐ Der „Albedo-Effekt“	

ck_MC_04	Was trifft auf die Transpiration von Pflanzen zu?	
1	☐ Die Transpiration verringert sich, wenn die Pflanze nicht genügend Wasser erhält.	
2	☐ Durch Transpiration wird um die Wand herum ein Luftstrom erzeugt, der zur Abkühlung der Wand beiträgt.	
3	☐ Der Transpirationsprozess benötigt Energie, die dann nicht mehr zur Erwärmung der Wand zur Verfügung steht.	
4	☐ Transpiration trägt dazu bei, den "Wärmeinseleffekt" in Städten zu verringern.	

ck_MC_05	Welche der folgenden Aussagen über CO_2 trifft/treffen zu?
1	☐ In Parks ist der CO_2-Gehalt in der Luft im Sommer höher als im Winter.
2	☐ In einem geschlossenen Raum mit Menschen ist der CO_2-Gehalt höher als draußen in der freien Luft.
3	☐ Der CO_2-Gehalt in der Atmosphäre steigt aufgrund der von uns produzierten Treibhausgase an.
4	☐ Im Wald verändert sich der CO_2-Gehalt in der Luft nicht im Verlauf eines Sommertages.
ck_MC_06	Welche Auswirkung(en) haben begrünte Fassaden auf die Luftqualität?
1	☐ Sie verbessern die Luftqualität durch die Reduzierung von CO_2.
2	☐ Sie verbessern die Luftqualität durch die Produktion von O_2.
3	☐ Sie verbessern die Luftqualität, indem sie Staub und schädliche Gase entfernen.
4	☐ Sie verbessern die Luftqualität indirekt, indem sie den Verbrauch fossiler Brennstoffe/ Energie fürs Heizen oder Kühlen verringern.
ck_MC_07	Was trifft auf den "Albedo-Effekt" in Städten zu?
1	☐ Der "Wärmeinseleffekt" kann durch Erhöhung der Albedo einer Stadt reduziert werden.
2	☐ Die Albedo von Städten ist im Allgemeinen sehr hoch, und es ist nicht notwendig, etwas dagegen zu unternehmen.
3	☐ Der „Albedo-Effekt“ in Städten bezieht sich ausschließlich auf die Fassaden der Gebäude.
4	☐ Die Albedo eines Gebäudes mit grüner Fassade ist abhängig von dem Grünton der Pflanzen (hell- oder dunkelgrün).
ck_MC_08	Die Wirkung von grünen Fassaden als Schattenspender hängt davon ab, ...
1	☐ wie groß die Blätter sind, unabhängig davon, wie dicht sie stehen.
2	☐ welche Jahreszeit es ist, falls die Pflanze nicht immergrün ist.
3	☐ wie dick die Wand ist, an der sich die grüne Fassade befindet.
4	☐ wie viel der Fläche der Fassade von Blättern bedeckt ist.
ck_MC_09	Wie viel CO_2 befindet sich in der Atmosphäre?
1	☐ 4000 ppm
2	☐ 0.4%
3	☐ 400 ppm
4	☐ 0.04%

ck_MC_10	Was beinhaltet der Begriff „biologische Vielfalt“?	
1	☐ Die Vielfalt der verschiedenen Organismen in einem Ökosystem.	
2	☐ Die Vielfalt an genetischer Variation innerhalb einer Art bzw. aller Arten eines Ökosystems.	
3	☐ Die Vielfalt der verschiedenen Lebensräume in einem Gebiet.	
4	☐ Die Vielfalt an Perspektiven, aus welchen der Mensch biologische Vorgänge analysiert.	
ck_MC_11	Welche Art(en) von Tieren kann man typischerweise auf oder in einer grünen Fassade finden?	
1	☐ Kleine Vögel	
2	☐ Insekten	
3	☐ Fledermäuse	
4	☐ Hamster	
ck_MC_12	Welche der folgenden Aussagen über Luftschadstoffe trifft/treffen zu?	
1	☐ CO_2 ist ein Luftschadstoff.	
2	☐ Feinstaub ist ein Luftschadstoff.	
3	☐ PM10 sind Partikel, die kleiner als 10 Nanometer sind.	
4	☐ Die Partikel sind in der Regel für das menschliche Auge sichtbar.	
ck_MC_13	Welche(n) Vorteil(e) bieten grüne Fassaden für Lebewesen?	
1	☐ Brandschutz	
2	☐ Schutz vor Räubern	
3	☐ Nahrungsquelle (z. B. für Vögel)	
4	☐ Nestbau	

Bitte gib an, ob die folgenden Aussagen richtig oder falsch sind:

		richtig	falsch
		1	2
ck_RW_01	Die Energieeinsparung durch Fassadenbegrünung hängt von der Ausrichtung der Wand zur Sonne ab, d.h. ob die Wand nach Norden, Osten, Süden oder Westen zeigt.	☐	☐
ck_RW_02	Die Albedo einer schwarzen Fläche ist höher als die einer weißen Fläche.	☐	☐
ck_RW_03	Grundsätzlich kann jede Pflanze zur Fassadenbegrünung eingesetzt werden.	☐	☐
ck_RW_04	Stickstoffoxid ist ein Luftschadstoff.	☐	☐
ck_RW_05	Der „Albedo-Effekt“ ist die Speicherung von Wärme bei Gebäuden.	☐	☐
ck_RW_06	Der „Wärmeinseleffekt“ beschreibt das Phänomen, dass Städte im Sommer häufig deutlich wärmer sind als ihr ländliches Umland.	☐	☐
ck_RW_07	Luft mit einer Temperatur von 30°C kann mindestens 31 g Wasser /m² aufnehmen.	☐	☐

Jetzt hast Du schon viel geschafft, aber der Fragebogen ist noch nicht zu Ende. Es geht weiter auf der nächsten Seite.

3. Teil: Wissen über Experimente

In diesem Teil geht es um Wissen in Bezug auf die Experimente, die du während des Projekttages durchführen wirst.

Bei den folgenden Fragen können <u>mehrere</u> Antworten richtig sein. (Es kann aber auch vorkommen, dass nur eine Antwort richtig ist!)
Bitte wähle jeweils die korrekte(n) Antwort(en) aus.

Wir sind uns bewusst, dass diese Fragen sehr schwierig sind, wenn man die Experimente noch nicht durchgeführt hat. Versuche bitte dennoch, alle Fragen so gut es geht zu beantworten.

Sensor	Ordne den Sensoren die korrekte Bezeichnung zu. Schreibe dazu die jeweilige Nummer neben die Abbildungen.

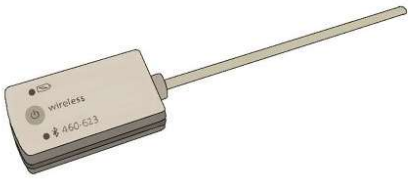
1 – CO_2-Sensor

2 – pH-Indikator

3 – Temperatur-Sensor

4 – Luftfeuchtigkeitssensor

sen_01 (left) (*)



sen_02 (right) (*)



Dieser Sensor entspricht der Nummer: _____

Dieser Sensor entspricht der Nummer: _____

sen_03 (*)



Dieser Sensor entspricht der Nummer: _____

(*) Figures created by Simon Meul

---

tk_MC_01	In einem Probenbehälter steht eine Pflanze. Was eignet sich, um im Probenbehälter Dunkelheit zu simulieren?
1	☐ Alufolie
2	☐ Frischhaltefolie
3	☐ Schreibpapier
4	☐ Abstellen in Schrank

tk_MC_02	Wenn man die Transpiration bei einer Pflanze direkt sichtbar machen will, dann sollte sich die Pflanze in einem verschlossenen Behälter befinden. Der Behälter muss verschlossen sein, …
1	☐ da für die Messung ein bestimmter Druck aufrechterhalten werden muss.
2	☐ um Schwankungen in der Raumtemperatur auszugleichen.
3	☐ um das Austreten von Feuchtigkeit aus dem Behälter zu verhindern.
4	☐ Der Behälter muss nicht verschlossen sein. Er kann auch offen sein.

tk_MC_03	Welche(s) Messgerät(e) gehört/gehören zu dem Versuch, den die Abbildung zeigt?
1	☐ Feinwaage
2	☐ pH-Indikator
3	☐ CO_2-Sensor
4	☐ O_2-Sensor
5	☐ Feinstaub-Sensor
6	☐ Leitfähigkeitsmessgerät
7	☐ Temperatur-Sensor
8	☐ Wasserqualitätsprüfgerät

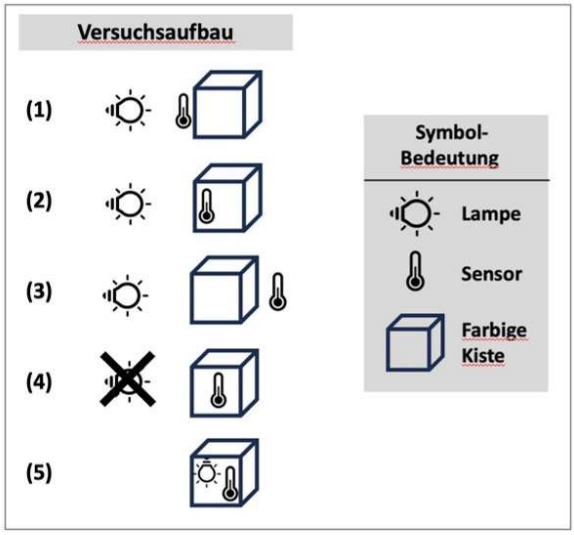


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tk_MC_04	Bei einer Pflanze soll das Phänomen der Transpiration aufgezeigt werden. Hierfür gibt es zusätzlich zum Untersuchungsansatz einen Kontrollansatz. Wie sieht dieser Kontrollansatz aus?
1	☐ Genauso wie der Untersuchungsansatz, um zu sehen, ob beide Ansätze zu gleichen Ergebnissen führen.
2	☐ Genauso wie der Untersuchungsansatz, aber ohne Pflanze.
3	☐ Genauso wie der Untersuchungsansatz, aber bei erhöhter Umgebungstemperatur.
4	☐ Genauso wie der Untersuchungsansatz, aber in dem Gefäß für die Pflanze ist kein Wasser.

tk_MC_05	In einem Versuch soll die Wirkung des Beschattungseffekts indirekt aufgezeigt werden. Was wird vor Beginn jeder Messung mit dem Sensor gemacht?
1	☐ Er wird sterilisiert
2	☐ Er wird aufgeladen
3	☐ Er wird zentriert
4	☐ Er wird auf Null eingestellt
5	☐ Er wird gereinigt
6	☐ Er wird auf Raumtemperatur gebracht
tk_MC_06	Der Albedo-Effekt kann mit farbigen Kisten gut sichtbar gemacht werden. Wie viele bzw. welche Kisten werden dafür benötigt?
1	☐ Eine einzelne weiße Kiste
2	☐ Eine einzelne schwarze oder weiße Kiste
3	☐ Eine schwarze und eine weiße Kiste
4	☐ Zwei Kisten von derselben Farbe
5	☐ Eine Kiste muss rot sein
tk_MC_07	Es soll die Wirkung des Albedo-Effekts aufgezeigt werden. Hierfür wird eine indirekte Messmethode verwendet. Welche Abbildung zeigt den passenden Versuchsaufbau? (Hinweis: Der ebenfalls notwendige Kontrollversuch wird in den Abbildungen nicht berücksichtigt.)

☐ (1) ☐ (2) ☐ (3) ☐ (4) ☐ (5)



tk_MC_08	Wieso werden für einen Versuch, bei dem Effekte der Photosynthese gemessen werden sollen, zuvor verdunkelte Pflanzen bzw. Blätter verwendet?
1	☐ Um einen stärkeren Effekt zu erzielen.
2	☐ Damit die Pflanzen nicht verwelken.
3	☐ Um (Zell-)Atmungsprozesse der Pflanzen, die gegenläufig zur Photosynthese sind, zu verhindern.
4	☐ Damit der grüne Blattfarbstoff sich nicht zersetzt.
5	☐ Weil sonst bei der Messung eine Photosynthese nicht stattfindet.

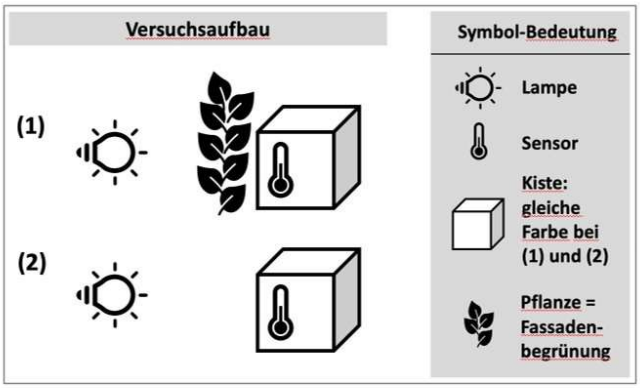
tk_MC_09	Wie wird der CO_2-Gehalt der Ausatemluft einer Person gemessen?
1	☐ Als Volumenanteil
2	☐ Mit zwei Messungen: eine vor und eine nach dem Ausatmen
3	☐ Mit zwei Sensoren: einer für die Einatmungs- und einer für die Ausatmungsluft
4	☐ An der freien Luft

tk_MC_10	Was soll mit dem Versuch, den die Abbildung zeigt, nachgewiesen werden?
1	☐ Albedo-Effekt bei Pflanzen
2	☐ Chemikalien-Wirkung bei Pflanzen
3	☐ CO_2-Produktion bei Pflanzen
4	☐ O_2-Produktion bei Pflanzen
5	☐ Transpiration bei Pflanzen



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tk_MC_11	Wenn man die Ergebnisse der beiden Versuchsansätze (1 und 2) vergleicht, kann man folgenden Effekt ermitteln:
1	☐ Alleiniger Effekt der Albedo durch die Pflanze
2	☐ Alleiniger Effekt der Albedo durch die Kiste
3	☐ Alleiniger Effekt der Lichtabsorption durch die Pflanze
4	☐ Kombinierter Effekt von Albedo und Lichtabsorption durch die Pflanze
5	☐ Effekt der Beschattung durch die Pflanze
6	☐ Keinen der genannten Effekte



tk_MC_12	Bei Versuchen, in denen die Wirkung der Photosynthese auf die Umgebungsluft untersucht werden soll, verwendet man meist sehr leistungsstarke Lichtquellen (Speziallampen). Was ist der Grund dafür?
1	☐ Man verhindert falsche Messungen.
2	☐ Bei Temperaturen unter 15 Grad Raumtemperatur finden keine Reaktionen statt.
3	☐ Der gewünschte Effekt stellt sich schneller ein.
4	☐ Man erzielt einen stärkeren Effekt.
5	☐ Tageslicht allein ist wirkungslos.

tk_MC_13	Es soll die Wirkung der Photosynthese auf die Menge von Treibhausgas in der Luft gemessen werden. Für die Untersuchung wird Folgendes gebraucht: eine Pflanze, …
1	☐ Feinwaage
2	☐ pH-Papier
3	☐ Saugpipette
4	☐ CO_2-Sensor
5	☐ O_2-Sensor
6	☐ Ventilator
7	☐ Verschließbares Gefäß
8	☐ Volumenmessgerät

tk_MC_14	Welche Funktion hat die dunkle Flüssigkeit auf dem Wasser in der Abbildung?
1	☐ Sie dient als Nährstoff für die Pflanze.
2	☐ Sie verhindert das Verdunsten des Wassers aus dem Gefäß.
3	☐ Sie verhindert das Verwelken der Pflanze.
4	☐ Sie verhindert, dass Schadstoffe aus der Luft über das Wasser in die Pflanze gelangen.



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Jetzt hast du es fast geschafft! Zum Abschluss möchten wir dich noch um einige Angaben zu deiner Person bitten:

Wann wurdest du geboren? _____ _____
Monat Jahr

Dein Geschlecht ist? weiblich ☐ männlich ☐ divers ☐

Deine Klassenstufe _____

Jetzt mal ehrlich: Hast du die Fragen sorgfältig und sinnvoll beantwortet?

nein ☐ ja ☐ weiß nicht ☐

Hast du Anregungen oder Kritik zu diesem Fragebogen?

_____

_____

_____

_____

_____

_____

Vielen Dank für deine Mitarbeit!

Answer sheet for the knowledge items

Answer sheet for knowledge questions

Content knowledge	
Question	**Solution(s)**
leaf_01	3
leaf_02	4
leaf_03	1
ck_01	3
ck_02_1	1
ck_02_2	2
ck_02_3	1
ck_02_4	3
ck_02_5	2
ck_03	C
ck_04	A
ck_MC_01	3 and 4
ck_MC_02	3
ck_MC_03	1, 2 and 3
ck_MC_04	1, 3 and 4
ck_MC_05	2 and 3
ck_MC_06	all
ck_MC_07	1 and 4
ck_MC_08	2 and 4
ck_MC_09	3 and 4
ck_MC_10	1, 2 and 3
ck_MC_11	1 and 2
ck_MC_12	2
ck_MC_13	2, 3 and 4
ck_RW_01	true
ck_RW_02	false
ck_RW_03	false
ck_RW_04	true
ck_RW_05	false
ck_RW_06	true
ck_RW_07	false

Technical knowledge	
Question	**Solution(s)**
sen_01	3
sen_02	1
sen_03	4
tk_MC_01	1 and 4
tk_MC_02	3
tk_MC_03	1
tk_MC_04	2
tk_MC_05	6
tk_MC_06	3
tk_MC_07	2
tk_MC_08	1
tk_MC_09	1 and 2
tk_MC_10	5
tk_MC_11	4 and 5
tk_MC_12	3 and 4
tk_MC_13	4 and 7
tk_MC_14	2

Questionnaire administered immediately after the didactic intervention (T1) (English version)

The only difference with the first questionnaire is that students were asked to which experiments they participated during the didactic intervention, hence the first page is modified as follows. In addition, questions about students' personal environment had been removed, as these should not have changed in the short time that had elapsed.

Something important in advance: you create your personal code

Today you are filling out the questionnaire for the second time.
In this way, we want to find out if anything has changed as a result of the project day.

In order for us to be able to match your current details with previous and future ones, we would like to ask you to fill in the following code. This way your anonymity is still guaranteed!

CODE - KEY:

Please enter the following in the boxes:

The 2nd and 3rd letters of the street where you currently live (e.g. "Hauptstraße" as "AU").	☐	☐
Your month of birth as a two-digit number (e.g. "May" as a "05")	☐	☐
The 2nd and 3rd letters of your father's first name (e.g. "Thomas" as "HO")	☐	☐
The 1st and 2nd letters of your mother's first name (e.g. "Anke" as "AN")	☐	☐

If you do not know certain details for the code, enter "NA" in the corresponding boxes.

Please tick all the stations you have worked on today:

Station 1: Respiration and photosynthesis	☐
Station 2: Albedo effect	☐
Station 3: Transpiration	☐
Station 4: Biodiversity and fine dust	☐

2 from 16

Questionnaire administered immediately after the didactic intervention (T1) (German version)

Etwas Wichtiges vorab: Du erstellst Deinen persönlichen Code

Heute füllst Du zum zweiten Mal den Fragebogen aus.
Auf diese Weise wollen wir feststellen, ob sich durch den Projekttag etwas verändert hat.

Damit wir deine jetzigen Angaben den vorherigen und künftigen zuordnen können, möchten wir dich bitten, den folgenden Code auszufüllen. Auf diese Weise bleibt deine Anonymität trotzdem gewährleistet!

CODE – SCHLÜSSEL:

Bitte trage in die Kästchen folgendes ein:

Den 2. und 3. Buchstaben der Straße, in der du aktuell wohnst (z.B. „Hauptstraße“ als „AU“)	☐	☐
Deinen Geburtsmonat als zweistellige Zahl (z.B. „Mai“ als „05“)	☐	☐
Den 2. und 3. Buchstaben des Vornamens deines Vaters (z.B. „Thomas“ als „HO“)	☐	☐
Den 1. und 2. Buchstaben des Vornamens deiner Mutter (z.B. „Anke“ als „AN“)	☐	☐

Falls dir bestimmte Angaben für den Code nicht bekannt sein sollten, trage „NA“ in die entsprechenden Kästchen ein.

Bitte kreuze alle Stationen an, die du heute bearbeitet hast:

Station 1: Atmung und Photosynthese	☐
Station 2: Albedo-Effekt	☐
Station 3: Transpiration	☐
Station 4: Biodiversität und Feinstaub	☐

Questionnaire administered 4 weeks after the didactic intervention (T2) (English version)

In the third questionnaire, some behavioral items related to the follow-up activities were added as follows. They were positioned at the beginning of the questionnaire, directly after the personal code.

Part 1: Your personal situation and opinion

Here we go:
First, please answer a few questions about your behavior since the project day at the university.

	never	seldom	some-times	often	very often
Over the past four weeks, I have been reflecting on what I had learned.	☐	☐	☐	☐	☐
After the project day, I talked to others about the content (e.g., the experiments).	☐	☐	☐	☐	☐

	yes	no
I took a plant home with me from the project day.	☐	☐

If *yes*:

	yes	no
The plant is still alive.	☐	☐
I myself have been watering my plant regularly.	☐	☐
I have been observing the growth of my plant.	☐	☐

	yes	no
I took a flyer from the project day.	☐	☐

If *yes*:

	yes	no
I looked at the flyer again after the project day.	☐	☐
I looked at the examples of other green facades using the videos and websites (QR codes).	☐	☐
I took photos of green facades in my neighborhood.	☐	☐

Questionnaire administered 4 weeks after the didactic intervention (T2) (German version)

1. Teil: Deine persönliche Situation und Meinung

Jetzt geht es los:
Zunächst beantworte bitte ein paar Fragen über dein Verhalten seit dem Projekttag an der Uni.

	nie	selten	manch-mal	oft	sehr oft
Ich habe in den letzten vier Wochen nochmal über die gelernten Inhalte nachgedacht.	☐	☐	☐	☐	☐
Ich habe nach dem Projekttag mit anderen über die Inhalte gesprochen (z.B. über die Experimente).	☐	☐	☐	☐	☐

	ja	nein
Ich habe eine Pflanze vom Projekttag mitgenommen.	☐	☐

Wenn *ja*:

	ja	nein
Die Pflanze lebt noch.	☐	☐
Ich selbst habe meine Pflanze regelmäßig gegossen.	☐	☐
Ich habe das Wachstum meiner Pflanze beobachtet.	☐	☐

	ja	nein
Ich habe einen Flyer vom Projekttag mitgenommen.	☐	☐

Wenn *ja*:

	ja	nein
Ich habe mir den Flyer nach dem Projekttag nochmal angesehen.	☐	☐
Ich habe mir die Beispiele für weitere Fassadenbegrünungen mit den angegebenen Videos und Internetseiten (QR-Codes) angesehen.	☐	☐
Ich habe Fotos von grünen Fassaden in meiner Umgebung gemacht.	☐	☐