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The Objectivization of the Living Green Walls Concept as a Tool for Urban Greening (Case Study: LIKO-S a.s., Slavkov u Brna, Czech Republic)

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Abstract: The improvement of human well-being and the urban environment in cities and towns around the world will always be at the forefront of our interests. After all, the resilience of the urban environment to climate change is very important now. For example, the residents' well-being can be improved in terms of environmental aspects. The opportunities for improving the urban environment are, of course, closely interconnected with other aspects, i.e., economic, technical and social. One of the ways to increase the resilience of cities is by progressive urban greening with small urban greenery elements. Exterior green walls are attractive, often used in urban areas, and are also the key issue of our paper. They represent at first sight (concerning their usual size) only a small instrument, but they can have a significant environmental, techno-economic and socio-cultural impact. Potential stakeholders may not be aware of this consequence. Our research focuses not only on a model exterior green wall (LIKO-S a.s., Czech Republic), where selected environmental aspects were measured for one year to confirm or deny the cooling effect of the exterior green wall on the surrounding environment, but also to objectify the issue of green walls. We also present proposals for tools that consider other aspects (technical-economic and socio-economic aspects): objectivization-decision scheme and guided interview for stakeholders' motivation. These tools can serve future stakeholders in the pre-implementation phase of the intended exterior green wall. Objectivization of exterior green walls is the main goal of the present paper.

Keywords: living walls; vertical green system; air temperature; relative air humidity; objectivization-decision scheme; guided interview for stakeholders' motivation

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1. Introduction

In the beginning, we would like to introduce the story that led us to the creation of this article. In 2020, we became part of the team working on an Interreg Central Europe project called SALUTE4CE. In this project, we cooperated with partner cities Liptovský Mikuláš (Slovakia), Alessandria (Italy), Chorzów (Poland) and Erfurt (Germany) to design strategies for integrating small-scale urban greenery elements into compact city centers to improve the urban climate. Over time, we focused from the general to the specific and started to look at details, such as types, but also awareness of green walls (GW) in the Czech Republic.

In 2021, in the final phase of the SALUTE4CE project, we participated in the development of a handbook and e-learning materials for the public sector, applying lessons learned from the field of urban greenery and urban greening. After the end of the project, we were aware that the functional implementation of urban greenery elements in urban areas could suffer due to problems that can be easily avoided, for example, the lack of awareness of stakeholders when the stakeholder's role is crucial. In particular, the stakeholders may be exposed to conflicting information that affects them. Exterior green walls (urban greenery generally) are not just about the initial investment but more specifically about its subsequent maintenance, and they bring with them both pros and cons in different aspects. Furthermore, we also deal with the question of whether small-scale urban greenery elements, such as exterior green walls, have significance and what that significance is. We have therefore attempted to create a comprehensive study in which the scope is devoted not only to exterior green walls but also to stakeholders.

Negotiations already began in 2020 about the possibility of data collection in one of the companies engaged in the design and construction of exterior green walls in the Czech Republic (LIKO-S, a.s.). Data collection was made possible from May 2021 to June 2022, and this study is based on these data. In cooperation with LIKO-S, we had a unique opportunity to look "into the kitchen" of GW. We were able to verify how GWs work, whether they are functional and to become aware of a whole range of other contexts. In addition, we were also able to refine ideas that would be useful to us and stakeholders in selected European cities in 2020 within the SALUTE4CE project.

In the introductory part of our paper (background of the topic), we want to introduce key concepts related to the objectivization of the living green walls concept. First of all, it is about introducing the already mentioned problem of temperature increase in cities (heat islands) and some selected aspects related to it. In this context, we want to present urban greening as one of the possible tools to deal with this problem, including how to deal with the lack of space for urban greenery in city centers. GW may represent one of the potential solutions to how to use urban greening in dense urban areas. For this purpose, a brief characterization and classification are presented. Equally important, in this sense, is the awareness of potential stakeholders who are interested in the implementation of the green wall, even if they are public or municipal stakeholders. Their role is also briefly presented in the background of the topic, particularly concerning other aspects related to the urban environment. A well-informed stakeholder who recognizes not only the environmental but also the technical, economic and socio-cultural aspects of green walls in the pre-implementation phase can make a significant contribution to the resilience of at least part of the urban environment [1].

1.1. Background of the Topic

Rising global temperatures in the context of climate change is a global issue that requires positions at various levels [2]. One of them is climate change adaptation of cities and also increasing the resilience of cities. Globally, climate change has worsened not only the conditions for human agricultural activities and rural life but also for urban life [3–6]. It is predicted that by the end of the 21st century, global temperatures may increase by 2.1–3.5 °C or by 3.3–5.7 °C according to a more stringent model [7]. Compared to the global average, Europe is warming the fastest, with the average annual temperature increasing by an average of 0.5 °C per decade between 1991 and 2021 [7,8]. In South Asia, the average annual temperature is projected to increase from 1.8 to 4 °C by 2050 [9]. In cities, this temperature increase can lead to the formation of heat islands in prolonged hot weather.

Heat islands in urban environments are also contributing to ongoing climate change [10]. A heat island is considered a location in the urban environment that accumulates more solar energy than its peripheral parts [11]. As a result, this means that the air temperature in this location is approximately 1 to 7 °C higher during a hot summer day and approximately 2 to 5 °C higher at night (known as a "tropical night") [11]. It is also important to note that when hot summer days persist, and in the context of urban heat islands and tropical nights, the most vulnerable residents, such as the ill, the elderly and young toddlers, are negatively affected [12,13]. In the context of heat islands, it is important to note that their existence is also facilitated by the fact that, due to the compactness and sealing of the soil, all rainfall is drained into drains and thus out of the area [14]. Mitigation can be achieved through the use of so-called cool materials, such as cool pavements or cool roofs, the use of vegetation elements (green roofs, green walls, parks, alleys, greenery in general, etc.), the provision of more shading—the so-called old town structure, the increased use of blue infrastructure (water bodies) and minimal use of heat sources (transport, air conditioning, etc.) [14–18].

Heat islands are closely linked to the exposure of building surfaces to direct sunlight, which causes heat accumulation. The capability of accumulating heat is determined by the albedo and emissivity of the surfaces [19]. Albedo is the ability to reflect a specific amount of solar radiation, and emissivity is the ability of a body to radiate energy (relative to a black body of the same temperature) [19,20]. One illustration is a comparison between Portland concrete and greenery. While their albedos are relatively similar (Portland concrete 0.25–0.35; greenery 0.05–0.30 [21]), the difference in utilization and emissivity is evident. In the case of Portland concrete, we cannot talk about the utilization of the received radiation (such surfaces emit all of the accumulated heat), but the greenery utilizes the solar radiation—10–15% is consumed for heating, 5–20% for photosynthesis, 20–40% for evapotranspiration and only 5–30% passes through the leaf (this heat is accumulated) [22–24]. This implies that although the albedo of different materials may be similar, the subsequent use of the received solar radiation can be different—thus, due to the use of solar radiation, there is less heat accumulation by a given surface. The accumulated heat is radiated when the surrounding environment cools down, thus heating the external environment. In this context, it is useful to note that any greening of surfaces can lead to positive changes concerning heat islands. Another physical phenomenon related to heat islands is the thermal conductivity of materials, which can further heat the interior.

Urban greening is one way to improve conditions in cities, and the vision in front of us is an active living city. In such a city, according to the Danish architect Jan Gehl, "vitality, but also calm and quiet are desirable and valued qualities" [25]. However, the placement of new green spaces, especially in the historic centers of European cities, is encountering several problems and is, therefore, practically impossible [26]. The main problem may be the lack of suitable space, the presence of infrastructure, conflicts with conservationists, or the aversion of some citizens [27]. That means that in most European cities, we are still limited (mainly by the lack of space). Implementing small-scale urban greenery elements is one of the options [28].

Urban greening is a combination of strategic planning but also of ecosystem service science and, as such, respects the need for planned land use (agriculture, nature and landscape conservation) and offers methods and tools for identifying needs and opportunities leading to improved environmental function [25]. One of the key roles in this context is the urban greening of cities. The presence or absence of urban greenery is crucial in determining whether our city centers become heat islands. A single-grown tree can reduce the temperature of a wooden facade by up to 9 °C with its shade or up to 12 °C for asphalt surfaces [29,30]. It is important to consider whether it would be appropriate to use solar radiation to "run" ecosystem services in cities (photosynthesis, evapotranspiration, etc.) instead of just accumulating heat in the materials of facades, roofs, roads, etc. The term "urban greening" is a superordinate term to "urban greenery".

Urban greenery, in general, can be classified according to several criteria, e.g., according to size or the ratio of natural and non-natural elements. Nowadays, it is appropriate to view urban greenery as an element of the urban environment, which plays a very important role not only in aesthetic, ecological or economic function but also in social function (e.g., influence on human well-being). The benefits of urban greenery are widely acknowledged, yet they still play a minor role in the heat island problem or climate change resilience [31–33]. However, it is really necessary to take into account the compactness of today's city centers—the installation of new surface elements of urban greenery is almost unrealistic [15,28,34]. In the context of the compactness of urban areas and the placement of new green elements, a project on the implementation of small-scale elements of urban greenery has been established, introducing the concept of "Urban Environmental Acupuncture" (UEA) [28]. This issue also has the potential for use in abandoned or underused areas [28,35]. With the developed publication, using the methodology and examples of action plans, it is possible to design and create a functional network of urban greenery to have a positive impact on urban resilience [28].

Urban greenery also plays an important role in human well-being or biodiversity in urban areas and can also be considered as a set of management measures (greenery management). [31,34,36]. If greenery management is considered functional, then the climate resilience of the urban environment is improved by benefiting from ongoing natural processes [34]. With urban greenery, it is possible to make natural conditions accessible and partially imitate them for city residents [1,34]. A well-designed set of greenery management measures can also protect existing urban green spaces [37].

Due to the aforementioned compactness of today's cities, the optimal solution seems to be the use of free vertical areas. This paper focuses on a specific type of urban greenery, namely exterior green walls. The use of free vertical areas may seem to be the optimal solution. If they are covered with greenery, they can also "insulate the building", which can reduce the cost of interior air conditioning in the summer months [34,38]. Green roofs or green walls are very often an attractive solution for urban spaces, but their further benefits remain questionable. Many studies point to their positive impact on urban climate adaptation, but the additional costs associated with their installation and maintenance are not taken into account. This article focuses not only on the benefits of a particular green wall but also on its objectivization in the context of a case study. By objectivization, we mean decision-making tools that will help potential green wall applicants to better distinguish between a green wall as a way to improve the image of a place and its actual environmental benefits. Covering the vertical surfaces will also reduce the proportion of radiant surfaces that would otherwise contribute to the tropical night effect. For this reason, the use of exterior green walls seems appropriate.

Exterior green walls (GW) as a planned and desired part of a human residence began to appear in the Art Nouveau period (turn of the 19th and 20th century)—climbing plants were to be a natural connection between the garden and the house [39]. This type of urban greenery, or vertical green structures, is traditionally divided into living walls, green facades and combinations of these, among others [40]. One of the key differences lies in the way plants are rooted [40]. While green facades (GF) typically root the plants in soil or in the ground (usually at the base of the building), living walls (LW) use prepared matrices (made of wire or plastic boxes filled with coir or other absorbent material, etc.) to root the plants. Other basic differences are given in the following table (Table 1) [40].

Table 1. An overview of the differences between green facades and living walls [28,38].

	Green Walls (GW)	
	Green Facades (GF)	**Living Walls (LW)**
Method of rooting	substrate, soil, ground	substrate, ground
Construction for plants	trellises, tensioned steel ropes, etc.	wire boxes, plastic boxes
Type of plants	climbing plants (e.g., *Hedera helix* s. l., *Parthenocissus tricuspidata* s. l.)	perennials, rockeries, grasses, climbing plants
Irrigation system	none or mechanical irrigation in dry periods	automatic drip irrigation system
Labor intensity of maintenance	low	high
Expected efficacy	5 years	0–1 year
Approximate lifespan	long (more than 30 years)	short (up to 10 years)
Investment costs	moderate	moderate/high
Energy savings during cooling season	33.8%	58.9%

In developing this article, the following aspects were considered: techno-economic, environmental, and socio-cultural.

Among the techno-economic aspects, the type of exterior green wall (LW or GF), expected efficiency, expected lifetime, acquisition cost, and maintenance intensity were classified. It is necessary to note that the implementation and operation of vertical green structures and the implementation of GW, respectively, can be a very costly affair—in the Czech Republic in 2021, the implementation price of LW ranged between 20,000 and 30,000 CZK/m^2 (approx. 820–1240 EUR), and for GF, the price was around 4000 CZK/m^2 (approx. 165 EUR) [41,42]. It should also be considered that for LW operation, in addition to basic maintenance (e.g., pruning, watering), occasional repair/replacement of water pipes, replacement of matrices, or replacement of plants is required [41]. However, when comparing arbitrary LWs, the cost of operation will vary depending on the exposure to cardinal directions (and associated light conditions), as well as the plant composition of the LW.

The environmental aspect takes into account the climatic function of the exterior green wall, the effect on water management and humidity and the effect on living nature (e.g., nesting, pollination, etc.). It has been found from research that when the greening by VGS is fully functional, it can consume approximately 50% of the solar radiation through vegetation transpiration [34,38]. Plants placed on vertical green structures can filter sunlight through their leaves due to the phototropic effect [43]. Of the solar energy incident on the leaf, 5–30% is reflected, 10–15% is converted to heat, 5–20% is used for photosynthesis, 20–40% is used for evapotranspiration, and only 5–30% of the sunlight passes through the leaf [23,24]. In plants, reflectance is mainly due to the colorant. Depending on the type of colorant, different light frequencies are absorbed. Unused light frequencies are reflected, and plants are colored accordingly (e.g., plants reflecting light with blue, violet or red energy impart blue or violet tones to their flowers) [44]. By having sunlight largely diverted or processed by the greenery on the surface, we can talk about energy, or electrical, savings in summer on air conditioning—each 0.5 °C reduction reduces electricity consumption by up to 8% [23,45]. In a study conducted at HortPark in Singapore, the living green wall studied had a demonstrable effect on the ambient temperature, with up to 3.33 °C at 0.15 m, 1.66 °C at 0.3 m and up to 0.83 °C at 0.6 m [34,45]. Thus, in this case, the wall investigated in Singapore was shown to have a climatic function in its immediate vicinity, thereby having an ecological/environmental function and also an economic function (in cooling season savings). It was also found that vertical green structures have other functions, namely aesthetic, semi-natural (bird nesting), pollutant fixation, noise attenuation, biodiversity increases and maybe some others [28]. It is important to highlight that the environmental aspect of GW can only be functional if other aspects (mainly techno-economic) are also taken into account.

Among the socio-cultural aspects, the expected aesthetic effect, the effect on human health (physical and mental), the participation of citizens in the selection of the site (workshops, public discussions, etc.) or potential health risks (e.g., different types of phobias, allergies, etc.) were taken into account. In this case, implementing vertical green structures can be a burden, although they are properly cared for [1]. It is important to note that greenery, in general, can fulfill so-called ecosystem disservices [46]. These can be allergies (e.g., pollen), feelings of (un)safety or phobias (insects, birds, etc.) [46].

In socio-cultural aspects, it seems appropriate to require public approval for the construction of the GW to avoid its non-acceptance and, therefore, potential damage and loss of functionality.

1.2. Aims of the Objectivization of the Living Green Walls Concept

The paper focuses on the issue of assessing the effect of exterior green walls on their near exterior surroundings (the effect on the interior environment was not investigated). The study aims to investigate whether the use of exterior green walls can be considered an effective part of a strategy in counteracting heat islands in urban environments and, thus, in urban adaptation to climate change.

We explore green walls not only in terms of their environmental aspects but also in terms of techno-economic and socio-cultural aspects. For that purpose, data collection was carried out on an exterior living green wall.

2. Materials and Methods

2.1. Case Study: Living Wall (LIKO-S)

For data collection from a methodology point of view, a GW of small size (as normally offered in the bidding sheets) and in extreme climatic conditions were searched for. A suitable GW was found in LIKO-S company, which enabled us to collect the data (there were several GWs in different types and conditions). Compared to the study in Singapore (where a total of 8 GW types were investigated against one reference in size 8 × 4 m), in our case, only one GW was investigated. Our selected GW represents an extreme example of a GW in location, isolation and conditions.

This model LW is oriented to the southwest, and its size is relatively small (3.6 × 3.5 m). It is only a small part of the facade, and it is located above a parking area made of concrete tiling (Figure 1). This exterior GW is minimally shaded and is influenced by radiant heat from another surface (parking lot, roof, etc.).

Figure 1. View of the model LW in the LIKO-S company (the text above the LW means: "it smells good, it cool, it gives pleasure"). Author: Adéla Brázdová (07/2021).

LW is located in Slavkov u Brna in the South Moravian Region in the Czech Republic. The natural conditions in this site are classified as warm regions with very long, very dry, very warm summers and also very short, warm, dry to very dry winters [47,48]. The average annual air temperature in the area in 1991–2020 was already between 8 and 10 °C [49].

The selected LW is regularly irrigated, oriented to the southwest, and located at a height of approximately 3.3 m above ground level. This LW is constructed by the structural system using a non-load-bearing modular structure of cassettes fixed to a combined load-bearing system, which is attached to the load-bearing elements of the building via waterproofing [50]. LW is automatically irrigated by drip irrigation 4 times per day, and the amount of water is regulated according to the location, season or plants used. For example, during hot summer days in 2021, the daily water consumption at the model wall was calculated to be 62–64 L, while in spring, the daily consumption was around 34 L. The plant's species composition of the LW was composed, among others: *Helleborus viridis*, *Heuchera americana* 'Palace Purple', *Hedera helix*, *Bergenia cordifolia* 'Winterglut', *Lonicera nitida*, *Liriope muscari* and *Pachysandra terminalis*.

A total of 14 dataloggers type LOG210 5005–0210 were used to collect data, which were used to continuously record hourly temperature and relative humidity for 386 days to verify this statement (each datalogger measures temperature within +/−0.5 °C and relative humidity within +/−3.0%). Ten dataloggers were deployed in two layers (at a distance of 0.15 and 0.3 m from the wall) (Figure 2). The remaining four dataloggers were designated as references (Figure 3). All dataloggers were placed in TFA 98.1114.02 radiation shields to maintain the highest accuracy of measurements, protect them from weather conditions and extend their lifetime.

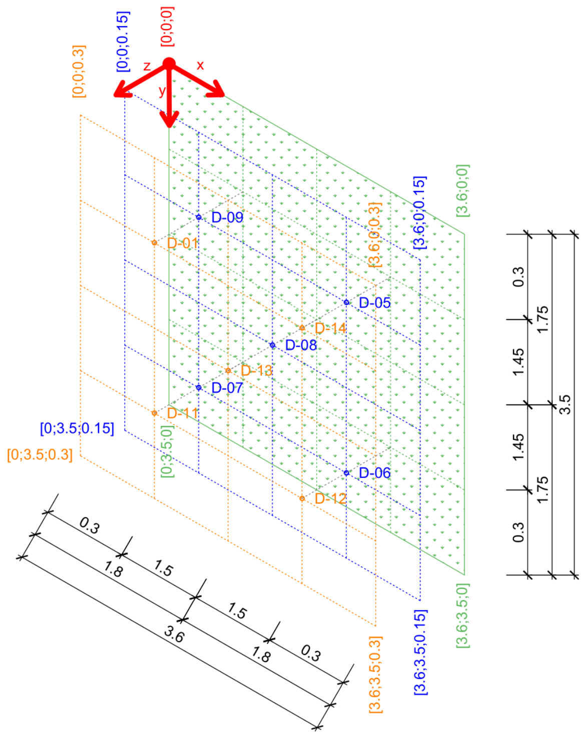

Figure 2. Graphical representation of the positioning of dataloggers on the model LW in the LIKO-S company (into two layers, 5 dataloggers in each layer). Every datalogger on model LW has its own coordinates. Each of the dataloggers on the model wall has its own coordinates, distributed in a grid.

To complete our study, we also realized a single measurement with the FLUKE TI27 thermal imaging camera and a surface temperature measurement of the LW with the FLUKE 566 IR THERMOMETER.

In the conditions of the Czech Republic, the average daily temperature is calculated according to the so-called Mannheim clock, namely Td = (T7 + T14 + 2T21)/4, where Td is the average daily temperature, and Tx represents the temperatures measured in the corresponding hours [51]. In our case (LW orientation to the cardinal directions, sunrise and sunset), the most relevant data were measured from 8:00 to 19:00. The measured daily temperatures were therefore divided into six intervals (zero to 3rd hours—I. interval, 4th to 7th hours—II. interval, 8th to 11th hours—III. interval, 12th to 15th hours—IV. interval, 16th to 19th hours—V. interval, 20th to 23rd hours—VI. interval), and intervals III., IV. and V. were considered the core intervals. In analogy to the Mannheim Clock, the hourly data for each datalogger were then averaged within the selected intervals to achieve a unique value that allows for inter-comparison between and within the intervals of a given day. However, the average daily temperature was not calculated from these data. In the case of the relative humidity data, the same procedure was followed for practical reasons.

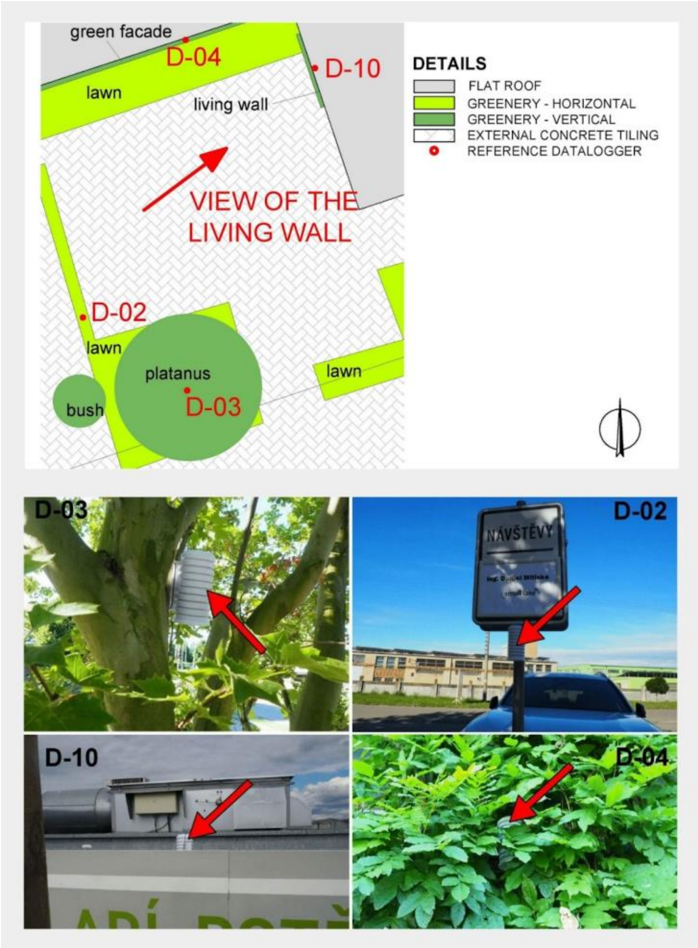

Figure 3. Reference dataloggers (4 in total) were deployed in different conditions in the vicinity of the LW under study. Given the surrounding conditions, two sites were selected that are considered natural—the crown of the Platanus occidentalis (D-03) and a green facade formed by *Wisteria* sp. In addition to these, the two locations where the worst results were expected were selected—a road sign (D-02) and the roof of the building (behind the attic) on which the investigated LW is located (D-10). All reference dataloggers are located within 10 m from the LW.

The individual intervals in the month were also numerically marked as sections. Thanks to this distribution, the individual daily intervals (with the corresponding section number) can be selected, thus facilitating the orientation in the overall amount of data and enabling their comparison with each other. Within each month, peaks with a visible difference between reference and baseline dataloggers were selected. These specific peaks were then analyzed concerning all dataloggers.

2.2. Process of Objectivization of the Concept of Green Walls

The concept and technical design of the GW are very well developed and offer a variety of possible solutions ranging from less investment-intensive to very sophisticated solutions [23,28,38,43,52–56]. Theoretically, it is possible to design a specific variant of GW for any vertical area in an urban environment.

The functionality of a GW does not only depend on its technical design (techno-economic aspect) but also on the stakeholder's efforts and commitment to properly maintain the GW in the future and socio-cultural aspects. For our purposes, the balancing between the function of the GW and GW's "real" functionality has been referred to as the objectivization of the living green walls concept. This objectivization should serve to present (visualize) the GW to a future stakeholder who has expressed a willingness to pay for the GW, especially to avoid future conflicts and misunderstandings related to the operation of the GW. Presenting GW issues in a broader context is crucial for stakeholders who want to implement GW in urban environments [1].

The aim was to find a simple procedure that would give stakeholders a quick insight into the issues. This procedure should help to present all the aspects mentioned and the problems that a stakeholder must expect with this investment. From this point of view, an objectivization-decision scheme based on the stakeholder's current position and a guided interview for stakeholders' motivation containing appropriately selected topics seems to be the most appropriate solution.

The objectivization-decision scheme can significantly simplify the stakeholders' pre-implementation decisions, the division of roles, etc. Stakeholders may not necessarily pay attention in this context [1]. However, tools such as these could be useful for them. Both of these objectivization tools involve techno-economic, environmental, and socio-cultural aspects, and some also intersect. Our proposed tools, "objectivization-decision scheme", which aims to demonstrate the complexity of GW issues, and "guided interview for stakeholders' motivation", are intended to be simple tools for the easy orientation of stakeholders regarding GW in general.

3. Results

3.1. Case Study: Living Wall (LIKO-S)

The placement of the dataloggers on the LW was chosen to cover the entire LW and also to determine if the boundary conditions on the LW are affected by the surrounding facade. It was assumed that air temperature and relative humidity in the centre of the LW would be most similar to other urban greenery features (in the case of this study, conditions in the canopy of the Platanus occidentalis and on the trellis in the *Wisteria* sp.). The number and, therefore, the placing of dataloggers on the LW was limited by financial possibilities. Ten dataloggers were deployed in two layers (at distances of 0.15 and 0.3 m from the wall) for the assumption that the influence of the LW would be detectable at a more distant location.

During data collection, some dataloggers experienced malfunctions or significant anomalies in the data evaluation (e.g., due to faulty equipment, a low battery or a fully discharged battery). Data loggers D-06, D-07 and D-11 were inoperative at some points due to faulty batteries. The battery was replaced during the next data collection (i.e., a failure of a few days). In the case of datalogger D-12, the device malfunctioned, and it was necessary to proceed to a complaint— data collection failures occurred twice, each lasting approximately 25 days. The reference datalogger D-03 also suffered a data collection failure due to a faulty battery—the failure lasted a total of 3 months. In the case of one of the 10 dataloggers located on the living wall, their value was mathematically calculated using the geostatistical kriging method (kriging was not used in the case of data failure of the reference datalogger). A linear variogram was selected for both the air temperature and relative humidity data for the whole time axis, and the data were subject to kriging.

For dataloggers D-06, D-07, D-11 and D-12, where an error was detected, the values could be calculated from another layer of data using kriging. In contrast, the reference datalogger D-03 was not included in the grid system, and the data could not be modeled.

By analyzing all the data, it was found that under these conditions, the LW location suffers from high temperatures in its upper part, although the upper third of the LW is systematically more irrigated than the lower parts. However, even this may not be a sufficient parameter for the quality of life of the planted plants and thus for improving the conditions near the LW. Consequently, the new planting of plants may mean an additional investment.

As expected, the dataloggers located in the middle were observed to display some of the lowest temperatures on the LW. However, dataloggers in the lower corners of the LW also showed comparable temperatures. For the lower corners of the LW, it can be assumed that the lower air temperature and higher relative humidity were caused by more water content (and increased evaporation) due to the gravity irrigation system. Further, analysis of these data shows that although the middle and lower corners recorded the lowest temperatures and highest humidity, these values were in some cases up to several degrees higher and several % lower in the summer months compared to the reference dataloggers located in the canopy of the Platanus occidentalis (D-03) and in the trellis with *Wisteria* sp. (D-04). The middle and lower corners also showed comparable values with a fourth datalogger located on a road sign (D-02; however, this datalogger was shaded by the crown of the American plane tree for most of the day). Comparison of the reference datalogger located on the roof of the building (D-10) with all other 13 dataloggers showed that the location of the reference datalogger D-10 had significantly higher air temperatures and significantly lower relative humidity values during the summer months. The air temperature at the reference datalogger D-10 was, in many cases, comparable to the temperatures at LW only during the night hours.

In one case, the ongoing LW measurement was supplemented by a thermal imager measurement. The thermal imager measurement was performed on the 26th of July 2021 at 17:35 in sunny weather with slight cloud cover. The input parameters for the thermographic camera measurement are listed in Table 2. The result of the thermal imager measurement is the image shown in Figure 4, which shows that the green wall is "cooler" compared to the surrounding facade.

Table 2. The input parameters for the thermographic camera measurement.

Input Parameters	Value
air temperature	29.224 °C (17:00)
relative humidity	52.939% (17:00)
surface temperature of LW	30.3 °C (=set as background temperature for thermal camera)
set emissivity	Ɛ = 0.96 [57]

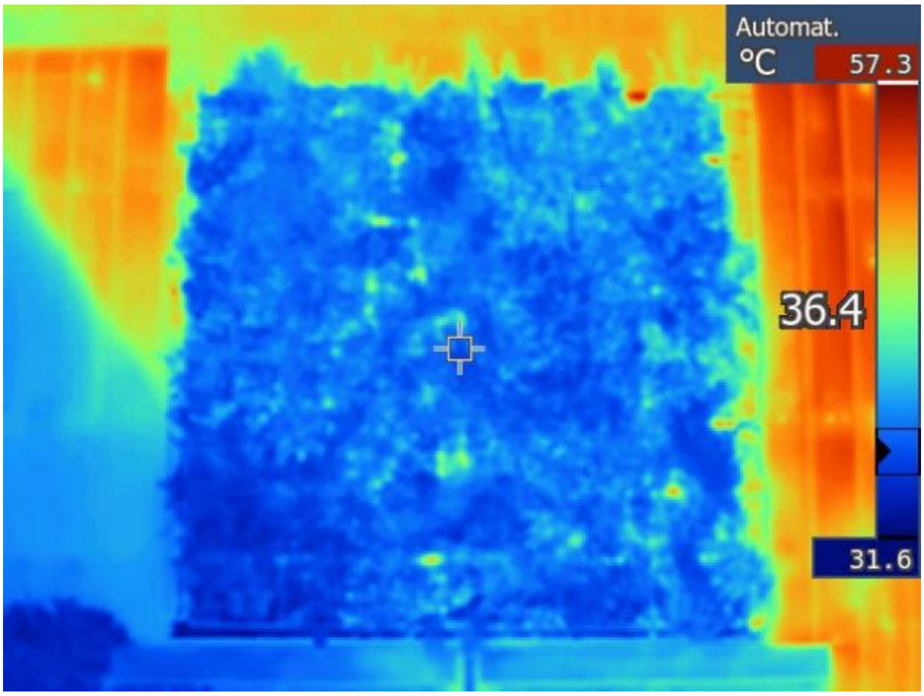

Figure 4. Thermal camera FLUKE TI27 image with accuracy ±2 °C, 26 July 2021. The resulting thermal camera image showed that under the actual measurement conditions, the centre of the LW is almost 20 °C cooler than its surroundings (in this case, the sheet metal facade). In the middle of this LW, 36.4 °C was measured, while the highest temperatures on the surrounding facade reached up to 57.3 °C.

3.2. Process of Objectivization of the Concept of Green Walls

To objectify the GW issues, two simple tools were developed. Namely, a decision-objectivization scheme and a guided interview to motivate stakeholders. The decision-objectivization scheme should enable the stakeholders to better orientate themselves in the issue of exterior green walls and thus provide insight into its complex character. These tools support each other.

The proposed decision-objectivization scheme (see Appendix A) for stakeholders can be a useful tool not only in the pre-implementation phase of an exterior green wall but also for those already built. The diagram is based on the three aspects of GW considered (techno-economic, environmental and socio-economic aspects).

The guided interview for stakeholders' motivation consists of a total of 12 questions, including aspects of GW (techno-economic, environmental, and socio-cultural), the first of them being an introductory question. The effect of this guided interview can also be the motivation for a future stakeholder, which can direct him/her towards a more functional implementation of exterior GWs. In the attached table (Table 3), all the questions used in the questionnaire are recorded and classified into different aspects (see Appendix B).

Table 3. An overview of the questions for the stakeholders: Guided interview for stakeholder's motivation. The questions are designed to guide the stakeholder in making decisions about exterior GW and also provide insight into the relative issues.

<table>
<tr><th>Stakeholder's Main Motivation</th><th colspan="2">Q1: You are a stakeholder. What do you expect from an investment in a green wall? Is your goal a positive change in the urban environment as a tool for urban resilience increase? Is your goal to promote the place, its prestige?</th></tr>
<tr><th>Techno-economic aspect</th><th>Socio-cultural aspect</th><th>Environmental aspect</th></tr>
<tr><td colspan="3">Q2: You want to invest in an exterior green wall. Do you realize that investment has a lifetime, within a few years?</td></tr>
<tr><td colspan="3">Q3: The investment may not bring the expected effect immediately. Have you thought about it? (While the living wall has an immediate effect, the green facade has an effect only after full greening (i.e., min. 3 years).</td></tr>
<tr><td>—</td><td colspan="2">Q4: It is a part of a building, but it is still partly a living organism. Do you realize that green walls can look quite different in the seasons of the year? (e.g., in winter)</td></tr>
<tr><td>Q5: But the investment does not end with the construction. Do you foresee that the green wall requires additional costs in long-term maintenance? (e.g., replanting, pruning)</td><td>Q6: The investment is part of the public space. If your goal is to improve the public space to promote the place—are you aware of the need to involve the public from the very beginning? (Action plan—workshops, discussions)</td><td>Q7: The investment is perceived as a representative element of the site. Have you considered that when GW is fully functional, it can have a significant positive effect on the microclimate in the surrounding area?</td></tr>
<tr><td>Q8: The investment may also require daily maintenance costs (besides long-term). Do you realize that additional energy is needed for the proper functioning of the green wall? (e.g., watering pump)</td><td colspan="2">Q9: Your investment may be causing problems. Are you aware that the implemented green wall will attract insects and vertebrates, which may be a disturbance to some residents? (allergies—insects, pollutants etc.; phobias)</td></tr>
<tr><td>Q10: Choosing a suitable place is very important. Do you realize that not every building wall is suitable for a green wall? Technically, it is possible to place a green wall almost anywhere (if the building design allows it), but orientation to the cardinal points and shading are important considerations. If the wall is poorly chosen, the ecological sense may not be fulfilled. The green wall will suffer in poorly chosen conditions, which will affect the character of the planting.</td><td colspan="2">Q12: Investing in GW is something of a never-ending challenge. Do you realize that urban resilience is an important thing, but one green wall is not enough? More effective and long-lasting and economically beneficial investment in urban land (use of grassed paving, increased permeability..) or investment in a well-designed structure (network) of small urban greenery elements would be more effective?</td></tr>
<tr><td colspan="2">Q11: Your investment may be a threat to the building. Do you realize that GW can interfere with building security? (fire rules, feeling safe, etc.)</td><td>—</td></tr>
</table>

This appendix presents excerpts from an interview with one of the stakeholders (core messages, the guided interview is actually more extensive) as an illustration of the verification of stakeholder awareness of the GW issue. Validation of the guided interview for stakeholder motivation on a larger sample of respondents was not the aim of this study. The result of this control-guided interview indicates that the respondent's perception is primarily initial investment and future prestige. What the stakeholder no longer realizes is that there are many more aspects behind the full functionality of GW.

4. Discussion

The use of urban greenery (e.g., green walls) is often considered a mitigation measure for improving urban resilience. During the summer months, the formation of heat islands in urban environments can be a real problem. However, GW does not only bring benefits but can be the source of many problems. Their current, perhaps sometimes excessive, media coverage can thus appear to be a one-sided promotion of GW. On the one hand, the publicity of GWs is causing an increasing interest in GWs, but on the other hand, awareness of the context of their operation may still be insufficient in many cases. Designing measures to mitigate heat islands, therefore, needs to be approached rationally, responsibly and with a degree of detachment [40].

The model LW selected for this study is located in specific conditions. Its surrounding environment simulated the worst possible conditions in an urban environment. The results of the measurements show that the LIKO-S model GW, despite its small size, fulfills a climate function that can be quantified, and this is essentially consistent with the concept of building GW as a possible tool for climate resilience increase in cities or urban environments. If the GW is not properly maintained, it may, in turn, contribute to a reduction in the aesthetic value of the site, which in extreme cases may lead to its removal and, thus, to the initial investment being lost.

The plant species composition of the model GW (LW) is composed of non-native species. The use of non-native species in urban environments is not uncommon but may be considered problematic itself [58]. On the other hand, the enclosed urban environment represents an extreme environment for plants, which should be reflected in the choice of species A GW is a specific type of artificial ecosystem that can fulfill certain ecological functions (e.g., a source of food or shelter for invertebrates). It is this fact that may be problematic for some citizens of urban environments (e.g., the presence of nuisance insects or allergens).

During spring, for example, a nesting blackbird (*Turdus merula*) was found in the upper part of the LW—see Figure 5. From an environmental point of view, this may be a successful application of a minor urban greenery feature. However, from a socio-economic point of view, it may be an undesirable part of the implementation—increased bird movement means increased bird droppings, and some individuals may also experience health problems because of some allergies or phobias (phobia of birds in general, fear of disease transmission etc.).

Figure 5. Nesting site of a blackbird (*Turdus merula*) on LW: a positive from an environmental point of view, but a possible conflict from a socio-cultural point of view. Author: Adéla Brázdová (05/2022).

In this context, public communication is very important. It is not just a question of identifying the public with the intention of building a GW, but of preventing possible collisions. We aimed to avoid possible conflict situations within the process of objectivization of GW and to enable the potential stakeholders to better orientate themselves in the given issue already in the pre-implementation phase. The aim is then not only to spend the funds for the implementation of the GW efficiently but also to contribute to the climate resilience of cities. For this purpose, a decision-objectivization scheme and a guided interview have been developed for stakeholders.

It is possible that the stakeholder, who usually expects only the implementation costs associated with the vision of good publicity for his person, is often not aware of the additional (future) costs associated with the operation and maintenance of the GW. In addition, this directly follows from the above fragments of answers within the guided interview (the guided interview was further expanded or included our partial answers to its questions). The guided interview was anonymized for the purpose of this study for obvious reasons, pointing out that this is indeed the case. These responses do not represent isolated stakeholder responses to questions but, more precisely, the trend.

The fact that this is not an isolated approach to urban greenery can be illustrated by the example of shopping centers, which generally proclaim their commitment to combating climate change [59–61]. However, if we focus on the issue of their surface car parks, then in the context of the EU directive [62], we find that their green proclamations are more precisely formal (i.e., have a marketing dimension). EU Directive COM/2006/0231 states that, as much as possible, they should be "using construction techniques that allow maintaining as many soil functions as possible", while the next steps should lead to "initiating work to develop best practices to mitigate the negative effects of building cover on soil functions" [62]. The issue of impermeable soil cover or the loss of soil function through soil cover (e.g., water retention) is well known and taking this approach into account will achieve local positive environmental change [63]. In contrast, the approaches of the commercial chains mentioned above only address 'global issues' through marketing tools (e.g., encouraging responsible shopping or green operations) but usually do not take into account the local aspect [40]. For example, by putting solar panels on the roof of a shopping centre, a particular chain may become self-sufficient (which is fine, of course), but at the same time, this solution does not address the issue of local climatic conditions [40].

In urban cores, the situation of residents, especially in the summer months, can be a crucial issue, and therefore, a rational, responsible and forward-looking approach is needed in designing measures to mitigate heat islands. It is important to recognize that elements of small-scale urban greenery (e.g., GWs, green roofs, green pavements) can collectively fulfill their purpose and can be used appropriately by stakeholders for their own benefit, but the key is to objectify the approach. In this context, it is worth mentioning that GFs, where plants are grown from the soil or substrate, could be a more appropriate solution in urban environments because of their low cost.

The proposed outputs (objectivization-decision scheme and guided interview for stakeholders' motivation) should ideally be presented to each potential stakeholder already in the pre-investment phase. However, the question is how to deliver this information to stakeholders. It is necessary to distinguish between a private person or company (who wants to "decorate" their building) and GW as part of the urban greening concept. One option could be an expanded role of the companies that design and build green walls. However, it is worth considering whether the purpose of these companies is only profit or a real ambition to improve the urban climate. Companies should, therefore, not only pay attention to the actual implementation of the product (although of high quality) but also to the stakeholder's awareness. Each stakeholder should be introduced to the complexity of the issue, including the potential problems (this brings us back to the GW aspects of the scheme). We are not saying that this is not happening, but on this point, we often notice a big gap. The second option is to include these tools in the urban-level concept (spatial plan, general greenery plan, etc.).

In the case of the LIKO-S company, it was confirmed that even a small LW could make a contribution. Indeed, in the results of the study, it was presented that LWs, in specific conditions (oriented southwest, only a small part of the facade, minimally shaded, influenced by radiant heat from another surface), have a positive effect on the climate of an urban environment. On the other hand, this concrete LW is energy- and maintenance-intensive, which is, of course, reflected in the purchase price of the GW.

Furthermore, it seems appropriate to combine the exterior GW elements with other small-sized urban greenery and connect them to a suitable irrigation system. From a technical-economic point of view, it must be stated that although the initial investment in the implementation of an exterior GW is already high (at least in the case of LWs), it is necessary to invest additional funds throughout its lifetime (pruning, planting renewal, irrigation, etc.). From this point of view, a functional rainwater recirculation system seems to be very useful, whereby irrigation of the GW (ideally several urban greenery elements at the same time) are carried out by pumping water from a rainwater retention tank. This was the situation in the case of the LIKO-S model GW (LW). On the company's premises, rainwater is channeled into a pond and, from there, pumped through an irrigation system for a total of four green roofs and eight GWs of different types. It should be noted here that LIKO-S might more accurately describe its GW (including the LW model) as a clever GW system (e.g., because of the use of rainwater for irrigation).

5. Conclusions

During the objectivization of the living green walls concept as a tool for urban greening, we tried to present GWs not only as a suitable tool for urban space management but also as a possible tool for increasing the climate resilience of cities.

Our study demonstrated that the LW (in LIKO-S company) detected lower temperatures during the summer months (compared to reference dataloggers located nearby). With a single thermal camera measurement, it was also demonstrated that on hot summer days, the LW is cooler than the surrounding facade. It can be said that although this LW is small compared to the size of the building wall, it can have a positive environmental impact. However, it would be appropriate if the LW was covering most of the facade because the heat from solar radiation is, in other cases, accumulated by the facade of the building and thus reduces the cooling effect of the GW. It is important to note, however, that even from a technical aspect, this may not always be possible. Firstly, this may not be possible in terms of the load-bearing capacity of the building wall (in the case of placement on existing buildings), but also, for example, some fillings of various types of LW (e.g., coir) can be used in the Czech Republic for fire reasons only up to a certain height.

The study of a specific GW in real conditions (LIKO-S) and the cooperation with stakeholders within the SALUTE4CE project have given us a unique insight into the GW issue. During our "journey", we recognized that the crucial factor in the objectivization of GWs, are stakeholders themselves. Their motivation to implement a green wall is crucial. Furthermore, their consideration of the environmental, technical-economic and socio-cultural aspects in the pre-implementation phase so that they form a harmonious whole is very important. We believe that the proposed decision-objectivization scheme and a guided interview to motivate stakeholders can be suitable tools for stakeholders in this sense. One of the challenges that emerged from our study is possible ways of communicating the GW issue to stakeholders and, thus, how our proposed tools (decision objectivization scheme and guided conversation to motivate stakeholders) can reach potential stakeholders. Eventually, this study as a whole may become one of these possible ways.

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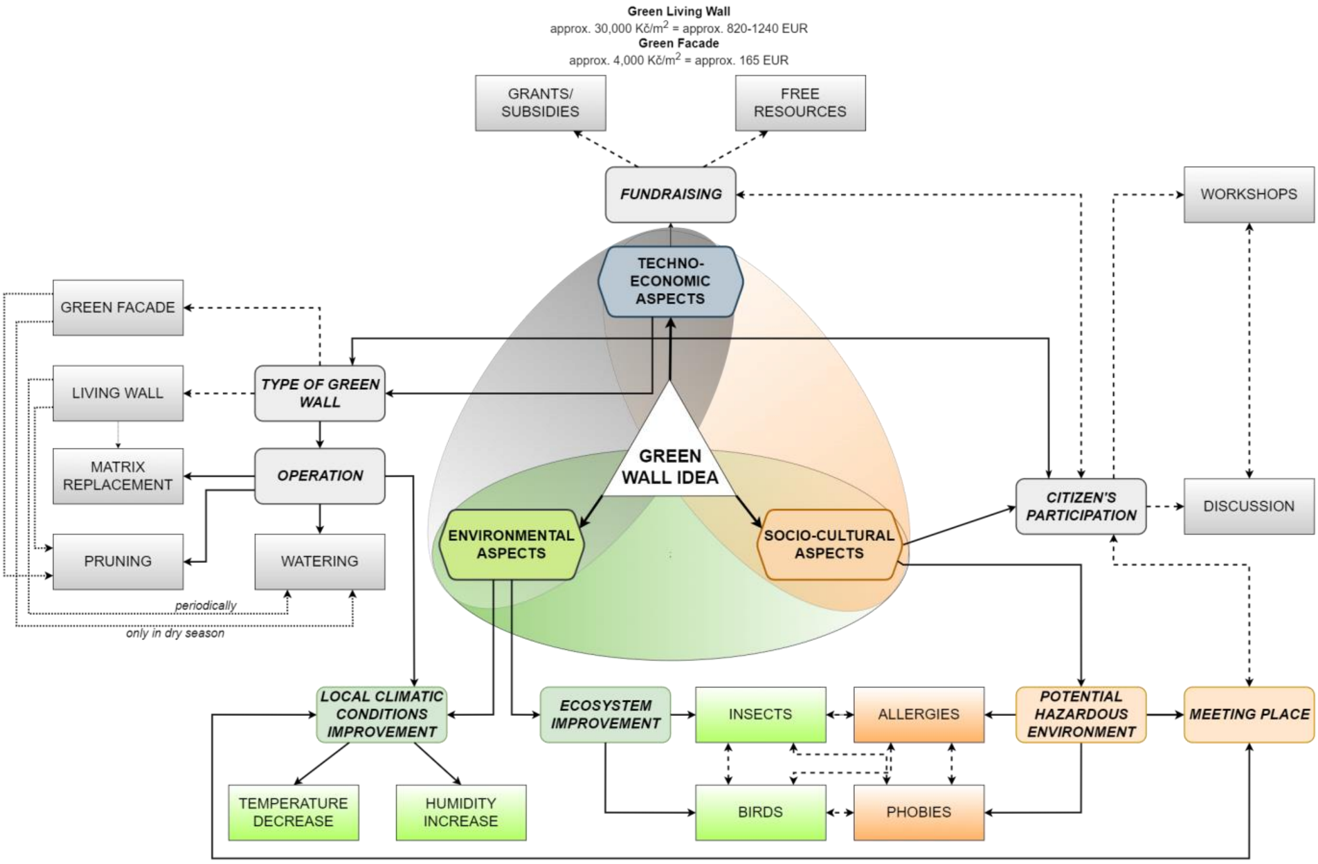
Appendix A. Decision-Objectivization Scheme



Appendix B. Excerpts from a Control-Guided Interview with GW Stakeholder (Anonymized)

Q1: You are a stakeholder. What do you expect from an investment in a green wall? Is your goal a positive change in the urban environment as a tool for urban resilience increase? Is your goal to promote the place, its prestige?

A1: As a city, we received an interesting financial incentive (subsidy), which is tied to the construction of an element of green infrastructure, and we are forced to respond to it. We expect the greening of the urban environment, we have an idea of one place in the city where greenery is completely absent and this could make it visually more attractive.

Q2: You want to invest in an exterior green wall. Do you realize that investment has a lifetime, within a few years?

A2: Yes, nothing is forever, after all, like everything. But can you be more specific? To give you an idea of the time frame we're in.

Q3: The investment may not bring the expected effect immediately. Have you thought about it? (While the living wall has an immediate effect, the green facade has an effect only after full greening (i.e., min. 3 years).

A3: Can you please give me a closer look at the difference between a living wall and a green facade? We expected an immediate benefit.

Q4: It is a part of a building, but it is still partly a living organism. Do you realize that green walls can look quite different in the seasons of the year? (e.g., in winter)

A4: Now I'll admit that we didn't think of that. We expect something that would have a yearlong effect. We want to beautify the place.

Q5: But the investment does not end with the construction. Do you foresee that the green wall requires additional costs in long-term maintenance? (e.g., replanting, pruning)

A5: Yes, we expect that the green infrastructure in the city needs to be looked after. But it occurs to me now that such maintenance of a green wall, given its location, will not be easy, right?

Q6: The investment is part of the public space. If your goal is to improve the public space to promote the place—are you aware of the need to involve the public from the very beginning? (Action plan—workshops, discussions)

A6: Yes, we want to make our intention known to the public. The public will ask about the sense of the investment costs.

Q7: The investment is perceived as a representative element of the site. Have you considered that when GW is fully functional, it can have a significant positive effect on the microclimate in the surrounding area?

A7: If it's done right, then yes. We expect to improve the atmosphere of the place. A green wall can contribute to that aesthetically.

Q8: The investment may also require daily maintenance costs (besides long-term). Do you realize that additional energy is needed for the proper functioning of the green wall? (e.g., watering pump)

A8: Now you've caught me a little unaware. But I think that this aspect of the matter will be dealt with in the contract with the company that will install the green wall. As well as any replanting under warranty. Oh, no, that's actually an extra cost, for the operation. Well, they're probably not too big in this case. Or. . . ?

Q9: Your investment may be causing problems. Are you aware that the implemented green wall will attract insects and vertebrates, which may be a disturbance to some residents? (allergies—insects, pollutants etc.; phobias)

A9: I don't think that in the case of such a small area that we are considering (2×2 m), this could be associated with any of the problems you are talking about.

Q10: Choosing a suitable place is very important. Do you realize that not every building wall is suitable for a green wall? Technically, it is possible to place a green wall almost anywhere (if the building design allows it), but orientation to the cardinal points and shading are important considerations. If the wall is poorly chosen, the ecological sense may not be fulfilled. The green wall will suffer in poorly chosen conditions, which will affect the character of the planting.

A10: This is a matter of who will implement the green wall. I don't think these issues are relevant to me. We have met with a green wall in the interior, I don't think there could be any complications with a green wall in the exterior.

Q11: Your investment may be a threat to the building. Do you realize that GW can interfere with building security? (fire rules, feeling safe, etc.)

A11: Again, I don't think it could be related to any such problems that you mention. I mean, I hadn't thought of it. Are you suggesting that the green wall is some sort of construction?

Q12: Investing in GW is something of a never-ending challenge. Do you realize that urban resilience is an important thing, but one green wall is not enough? More effective and 4long-lasting and economically beneficial investment in urban land (use of grassed paving, increased permeability etc.) or investment in a well-designed structure (network) of small green infrastructure elements would be more effective?

A12: We do not expect too much from the green wall in this context. It can be combined with this in public participation work—it will have a positive impact on the climate in the city, and the public will then be more responsive to the project. We want something interesting and novel in the city. We have more than enough urban greenery in other parts of the city.

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