buildings

MDPI

Article

Barriers and Solutions to Green Facade Implementation—A Review of Literature and a Case Study of Leipzig, Germany

Wiebke Knifka [1], Raphael Karutz [1] and Heinrich Zozmann [2,*]

[1] Department of Urban and Environmental Sociology, Helmholtz Centre for Environmental Research, 04318 Leipzig, Germany; wiebke.knifka@ufz.de (W.K.); raphael.karutz@ufz.de (R.K.)
[2] Department of Economics, Helmholtz Centre for Environmental Research, 04318 Leipzig, Germany
* Correspondence: heinrich.zozmann@ufz.de

Abstract: The expansion of green infrastructure through vertical forms of greenery is an innovative way to address urban sustainability challenges. Despite various social, economic, and environmental benefits, however, facade greening is rarely implemented. This article examines barriers to and solutions for the implementation of green facades through a systematic literature review and a participatory case study of Leipzig, Germany. We found a total of 24 social, political-administrative, economic, practical-technical, and environmental barriers hindering key actors to (successfully) implement green facades. The lack of information and knowledge was found to be an underlying issue. Solutions co-created with local stakeholders and experts include the provision of informative, regulatory, and financial incentives, the adaptation of political-administrative strategies, regulations, and procedures, as well as the support of the practical-technical implementation process through information and experts. To overcome barriers, various measures must be combined, but establishing public relations and advisory services on green facades is of priority in Leipzig. By combining insights from academic literature with applied knowledge of a diverse group of local actors, we identify how barriers to facade greening may be overcome in the specific case of a major German city and provide a blueprint for similar research in other socio-political contexts.

Keywords: green infrastructure; vertical greening; green facade; urban resilience; barrier analysis

Citation: Knifka, W.; Karutz, R.; Zozmann, H. Barriers and Solutions to Green Facade Implementation—A Review of Literature and a Case Study of Leipzig, Germany. *Buildings* **2023**, *13*, 1621. https://doi.org/10.3390/buildings13071621

Academic Editor: Yung Yau

Received: 8 May 2023
Revised: 19 June 2023
Accepted: 23 June 2023
Published: 26 June 2023

1. Introduction

Urban areas account for more than 60% of energy consumption and about three-quarters of CO_2 emissions worldwide [1,2]. Cities thus have a major influence on anthropogenic climate change but are also particularly vulnerable to its impacts [1,3,4]. Negative impacts are expected to increase in light of ongoing urbanization and increasing temperatures, as predicted by the Intergovernmental Panel on Climate Change [5]. Hence, urban areas will increasingly struggle with heat, air and noise pollution, loss of biodiversity and the ensuing implications for their inhabitants' physical and mental health [3]. Expanding urban green infrastructure offers manifold benefits that directly and indirectly address these issues [3]. Considering conflicting interests for land use, vertical forms of greenery are an innovative way to expand green infrastructure on minimal urban space [6,7]. Greening the building envelope, specifically the facades, unfolds a significant spatial potential for the reintegration of vegetation into cities as well as social, economic, and environmental potential benefits [7,8].

Yet, research has shown that such greening systems are rarely (successfully) implemented [7,9,10]. Even though scientific interest in green buildings has increased, stakeholders, such as policymakers, planners, and construction companies, remain reluctant to promote the implementation of green facades in contrast to other climate change mitigation and adaptation measures with similar potentials (e.g., [1,8,11,12]).

There are a number of studies on barriers to the implementation of climate change mitigation and adaptation measures, according to which actor-specific characteristics as well as the socio-economic, institutional, and natural environment are decisive [13,14]. However, there is a lack of studies specifically addressing the implementation of GFs, as emphasized by Sprondel et al. [10]. Individual case studies have been carried out (e.g., [10]), which have identified that insufficient informational material and financial support can impede GF implementation.

To our knowledge, however, a systematic review of the existing literature on GF implementation barriers is missing. Thus, we aim to identify general **implementation barriers**, particularly their origin and relevance, through a comprehensive review and analysis of the related literature. Then, we examine GF implementation barriers in the specific case of Leipzig, Germany, to inform a process of finding locally adapted ways to overcome them. We are aiming at this because the few existing proposed solutions are so far of a quite general nature, e.g., calling for the activation of policy instruments and an improvement in public awareness, knowledge, and participation [7,10,15]. Creating **context-specific solutions** to overcome the barriers present in Leipzig is thus our second and practically relevant objective of this article. Since both barriers and solutions touch upon various fields and actors (see Section 2), it is important to discuss both aspects with a broad group of stakeholders and experts, as will be carried out through a workshop and interviews [16]. In summary, this paper pursues the following two objectives:

1. A systematic literature review to identify general GF implementation barriers.
2. A participatory process with stakeholders and experts in Leipzig, Germany, to identify locally relevant barriers and co-create suitable solutions.

Our analysis is thus based on the literature and supported by an exemplary case study. By doing so, we provide a theoretically and practically evidenced synthesis of GF implementation barriers. We also contribute to shifting priorities from the mere identification of barriers to the development of locally adapted solutions, which is crucial for promoting GF implementation at the city level.

The remainder of this paper is structured as follows. In Section 2, we give relevant background information on GFs, specifically their definition, potential benefits, and implementation process. Section 3 describes the methodological approach of the study. Its results are presented and discussed in Sections 4 and 5. Section 6 concludes and outlines what remains to be assessed in future research.

2. Background

2.1. Definition of Green Facades

Based on a number of varying factors (e.g., plants, supporting elements, and irrigation), different vertical greening systems have been developed [17,18]. Essentially, two categories can be distinguished: living walls and GFs. On living walls, plants and possibly substrate are modularly integrated into a wall structure, with both indoor and outdoor forms of application [17,19]. Plants grow without or only with a small amount of substrate, whereby water and nutrients are supplied by an irrigation system [17,19]. GFs, on the other hand, are greening systems only constructed on the outer wall of buildings, where (climbing) plants naturally grow along a surface, either directly on the wall or indirectly with the help of a structural support system (e.g., rope or trellis system) to cover the building envelope [17–19]. Contrary to living walls, the plants are cultivated ground-based (in-ground or in planters). In comparison, the system technology of GFs is simple and resource-efficient, and maintenance efforts are low [17]. Thus, GFs are easier and cheaper to implement and promise a better scalability than living walls [20].

2.2. Potential Impacts on Urban Sustainability Challenges

Building envelopes provide a considerable spatial potential for GF implementation. In Germany, for instance, the surface area of the facades of all residential and non-residential buildings amounts to approximately 5552 km^2 [21]. This even exceeds the spatial potential for the implementation of green roofs [21,22]. GFs have various environmental, economic, and social potential benefits. This includes the regulation of urban microclimates and the reduction of the urban heat island (UHI) as well as an improvement in air quality through particulate matter and CO_2 sequestration, thereby strengthening cities' climate resilience [23,24]. The greenery further creates habitats and supports urban biodiversity [19]. Due to their shading and insulating properties, GFs reduce buildings' energy consumption and thus mitigate their environmental impact [25,26]. GF can additionally contribute to the value of real estate and urban areas as well as to a reduction in noise pollution and improvement in residents' health and well-being [16,22,27].

2.3. Implementation Process and Involved Actors

Following Mosgaard and Maneschi [28] and Andrić et al. [1], GF implementation can be seen as a three-stage innovation process: from initiation, where actors realize that implementing GF is possible, useful, or even necessary; to planning, where actors work together to find a joint solution; to realization, i.e., installation and maintenance of the GF. The process requires transdisciplinary and cross-actor collaboration between citizens, building owners and managers, professional and scientific experts (e.g., from the fields of landscape architecture and planning, engineering, construction, and horticulture) as well as politicians and public administrators [16,19,29–31]. In the process, these actors are usually confronted with numerous barriers that compromise (successful) GF implementation (see Figure 1).

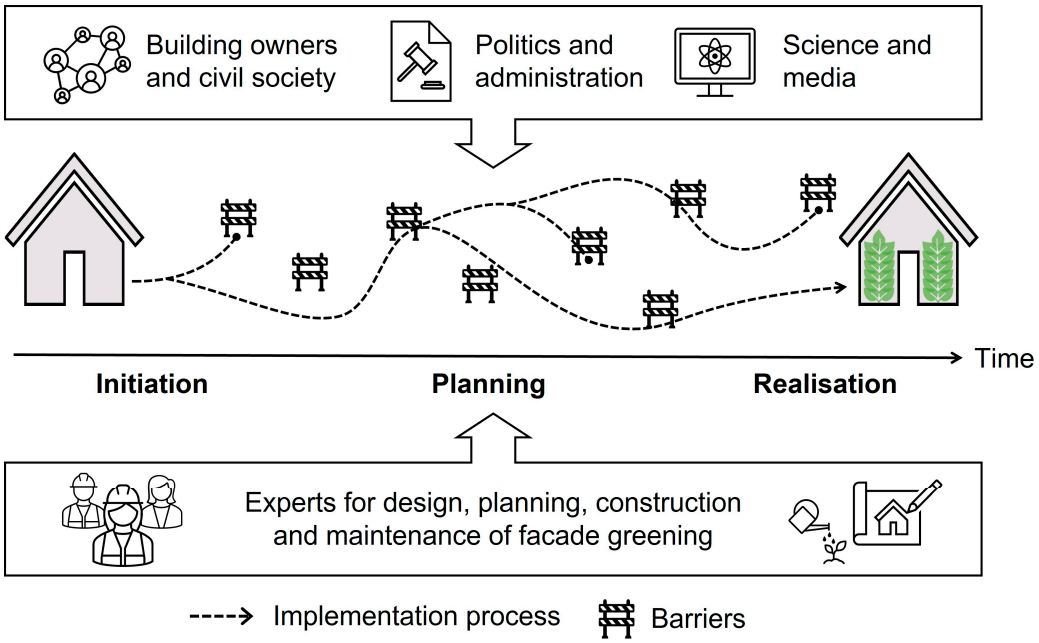

Figure 1. Stages of the implementation process of GFs and actors involved in the process (own illustration based on [1,28]).

3. Research Methods

The analysis of barriers and solutions presented in this study followed the research process illustrated in Figure 2. The study involved a systematic literature review, followed by a stakeholder workshop and subsequent expert interviews. The participatory process was carried out as part of a case study in Leipzig, Germany, to exemplarily confirm and

complement previous literature findings on GF implementation barriers in the local context. To overcome them, context-specific solutions were created in collaboration with various local stakeholders and GF experts.

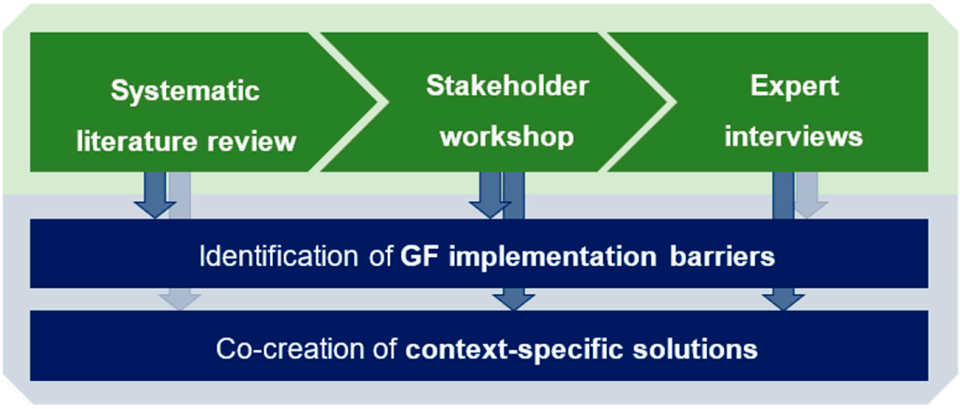

Figure 2. Research concept for the integrated barrier and solution analysis.

The systematic literature review focused on identifying general GF implementation barriers, following the PRISMA guidelines [32]. A search query was developed on Scopus to identify relevant academic publications. The query links three categories of search terms: various keywords for (1) GF, (2) barriers and (3) the implementation process (see Table A1 in Appendix A). The search was conducted within the sections Title, Abstract and Keywords. Resulting publications contained at least one keyword of each category in at least one of the named sections. Due to the increased relevance of the topic in the past twelve years (based on the Scopus results), a date range from 2010 onwards to the search date was added to the query. The abstracts and, if needed, the full texts of the resulting 67 publications were scanned and selected for further analysis if GF implementation barriers were mentioned. To ensure consistent data collection, the remaining 20 papers were systematically assessed using a review protocol based on Artmann and Sartison [33]. Therein, bibliographic data, the objectives and case studies, as well as barriers and solutions named in the publications were recorded. The derived GF implementation barriers were categorized into social, political-administrative, economic, practical-technical, and environmental barriers, based on the work of Andrić et al. [1], Lu et al. [29], and Wong et al. [16], among others, and clustered in each category (for the final results see Table A2 in Appendix B).

Informed by the results of the systematic literature review, a virtual workshop with various Leipzig stakeholders and GF experts was carried out. The meeting focused on the discussion of barriers found in literature and relevant in the local context as well as on the joint creation of locally adapted solutions. Based on their involvement or experience in GF implementation (cf. Section 2), participants were identified, contacted, and invited with the help of an existing network of researchers, administrators, and a housing cooperative from Leipzig. A total of 28 stakeholders and experts took part, including representatives from social associations and housing cooperatives, policymakers and administrators, as well as scientists and GF practitioners (see Table A3 in Appendix C). Based on an input presentation describing the barriers identified through the literature review, the participants were divided into groups to reflect on, specify, add to, and possibly prioritize the found barriers in the Leipzig context. Informed by literature results, three working groups focusing on particular, interrelated barriers, were formed: (G1) political-administrative barriers, (G2) social and economic barriers, and (G3) practical-technical and environmental barriers. Sharing experiences and ideas in small thematic groups allows for a more intensive analysis of a multitude of barriers, as participants can individually discuss specific topics and subsequently make their conclusions available to the entire group [31,34]. The results from

the working groups were consequently summarized and presented to all workshop participants. Subsequently, key implementation barriers selected by each working group were considered by all attendees to jointly create solutions for Leipzig. The plenary situation promotes a comprehensive, diverse, and creative exchange and the exploration of a large amount of ideas [35]. The collection of ideas was supported by a virtual whiteboard where participants could add and sort their suggestions. Both the group and plenary discussions were guided by moderators and key questions. The full agenda of the stakeholder workshop can be found in Appendix D. The meeting lasted around three hours and was recorded, transcribed, and analyzed using qualitative content analysis [36]. Information on GF implementation barriers was extracted from the transcription and summarized using a search grid consisting of the barriers found in literature (deductive categorization). For the elaborated solution paths and their respective measures, inductive categorization was used, i.e., the categories were derived from the text through an iterative procedure [36].

The measures created in the workshop were then specified and complemented in six semi-structured interviews with experts from various fields. The focus of this last step was to discuss the Leipzig-specific measures with domain experts. The selected experts were representatives from a housing cooperative and municipal administration, as well as three GF professionals and a scientific expert (see Table A4 in Appendix E), all with practical experience with GF implementation in Leipzig. Housing cooperatives and municipalities may also act as representatives for tenants and citizens. Based on a pre-test, in which the interview situation and structure was refined, the experts were consulted in guided interviews [36,37]. The questioning was tailored to the respective interviewees' expertise and covered both barriers and solutions from the previous methodological steps while still enabling critical evaluation and complementation (see Appendix F). Analogous to the stakeholder workshop, the interviews were recorded, transcribed, and evaluated using qualitative content analysis. The textual information on barriers and solutions was filtered and summarized from the transcription using a search grid consisting of categories from the previous steps, i.e., through deductive categorization.

4. Results

4.1. Barriers to Green Facade Implementation

The systematic literature review identified a total of 24 (I) social, (II) political-administrative, (III) economic, as well as (IV) practical-technical and environmental barriers that can hinder GF implementation. Apart from (II-v: Lack of uniform standards) and (IV-iii: Extreme weather and climate change), each of these barriers was confirmed as relevant in the Leipzig case by local stakeholders and experts, showing that even though most of the identified barriers may be universal, local differences occur. By identifying locally relevant GF implementation barriers, we enable the development of suitable solutions.

Commonly, a combination of several barriers is relevant during implementation as they are closely linked or interdependent. The barriers must therefore be viewed as a whole. To enable this analysis, the barriers were categorized following the example of previous literature (cf. Section 3), and assessed starting from one **central implementation barrier** in each of the four categories:

- **(I-i)** Lack of acceptance and motivation to implement GF on the social level;
- **(II-i)** Lack of ambition in politics and administration to adequately support GF;
- **(III-i)** Lack of the means or willingness to pay for the costs of GF;
- **(IV-i)** Unsuccessful practical-technical execution of GF.

These barriers were identified as central since they are linked to, i.e., preceded or followed by, all barriers in their respective category and beyond, hence playing a key role during GF implementation. The barriers' interdependencies, which are based on the case study, are depicted and described in the following. The 24 barriers are

each labeled with a capital Roman number from (I) to (IV) for the category, followed by a lowercase Roman number from (i) to (ix) for distinction. For the description, we draw on results both from the literature and the case study. In Appendix B, we further provide a detailed breakdown of the analyzed publications and resulting barriers.

(I) Social (Actor-Specific) Barriers (Figure 3)

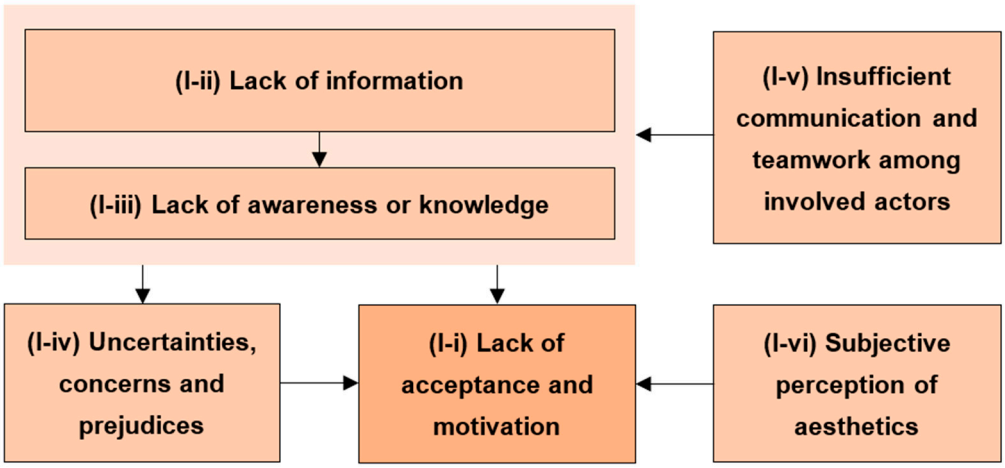

Figure 3. (I) Social (actor-specific) barriers.

Social (actor-specific) barriers are mentioned in 17 of the 20 analyzed publications and by various Leipzig stakeholders and experts, confirming that these are among the most significant GF implementation barriers. First and foremost, there is a (I-i) lack of acceptance and motivation for GF implementation, as mentioned both by the literature and in Leipzig [38,39]. This central barrier is also reflected in the central barriers in category (II) and (III), respectively, highlighting the insufficient political and financial support for GF. The case study confirms, that (I-i) is primarily influenced by the (I-ii) lack of (objective) information and consequently (I-iii) awareness or knowledge about the existence, cost and benefit, and practical-technical execution of GF [1]. A GF consultant from Leipzig substantiated this by claiming that the public has frequently internalized false information. This is due to insufficient public relations and many improperly implemented GF, which negatively influences the perception of the involved actors [16,38]. Thus, (I-iv) uncertainties, concerns, and prejudices regarding the practical-technical execution of GF and potential hazards for buildings and residents arise, as was also reflected by Leipzig stakeholders [16,29,40]. Particularly, the practical-technical complexity as well as the cost and maintenance effort are perceived as a hurdle for GF implementation [16,20]. According to the literature, as well as local stakeholders and experts, (I-ii) and (I-iii) are therefore major barriers (ibid.). Since the involved actors have very different occupational environments, knowledge, and goals, the (I-v) communication, coordination, and teamwork between them are often insufficient [1,38]. The case study confirmed that this hinders the flow of information on GFs, thereby not only negatively influencing social acceptance but also the proper practical-technical execution of GFs (cf. I-i, IV-i; [38,41]). The literature and case study findings show that, irrespective of the informational situation, the (I-vi) subjective perception of aesthetics can also act as a barrier because some actors see the greening as abnormal or messy [16,40].

(II) Political-Administrative Barriers (Figure 4)

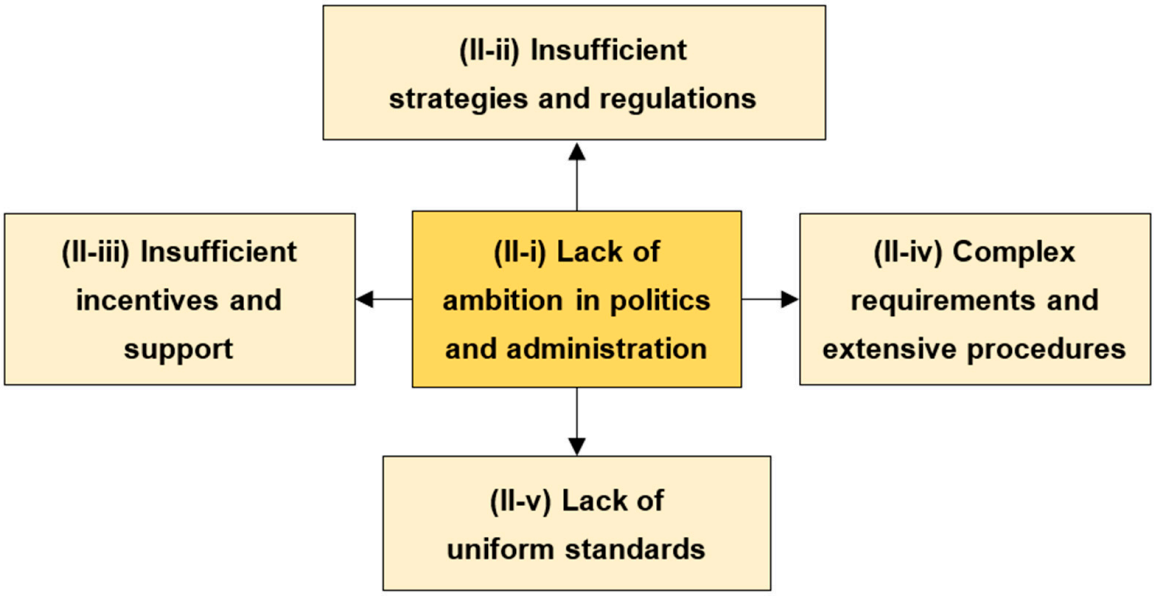

Figure 4. (II) Political-administrative barriers.

Political-administrative barriers are addressed in 12 of the 20 assessed papers. The central barrier reported both in the literature and the Leipzig case is the (II-i) lack of ambition in politics and administration, which is strongly influenced by the lack of information as well as social acceptance and motivation itself (cf. I-i, I-ii). This results in an institutional environment that not only inadequately promotes GF but may even raise social concerns (cf. I-iv). Firstly, this refers to (II-ii) insufficient strategies and regulations—there is a lack of distinct guiding principles specified within policy strategies and put into practice through binding regulations [8]. This involves both self-imposed obligations (e.g., greening of municipal buildings) as well as external obligations (e.g., stipulations in urban land use planning). Leipzig stakeholders and experts added that difficulties in the monitoring implementation of, and compliance with, regulations occur. There is also a lack of adequate (II-iii) incentives and support for GF implementation from the government [9,12]. Both regulatory incentives, e.g., the achievement of certain targets in building projects through GF implementation, and financial support through funding programs and tax relief are missing (see III; [8,12,20]). Even if such offers exist, they are often insufficiently advertised, as stated by a Leipzig expert. (II-ii) and (II-iii) are the political-administrative barriers most often addressed in the literature and have also been confirmed in the Leipzig case. A barrier whose particular relevance only became apparent in the case study was the (II-iv) complex requirements and extensive procedures in politics and administration. Local stakeholders and experts emphasize that, during GF implementation, a multitude of public and civil law requirements must be taken into account [42]. The accompanying procedures can require a great deal of bureaucratic, temporal, personnel, and financial effort, also affecting barriers on the economic and practical-technical level (see III, IV). This occurs, for example, when a GF installation is planned for landmark buildings or when it is required to repeatedly obtain permission from authorities for maintenance work. Hence, (II-iv), particularly fire protection regulations, are a major barrier in Leipzig. A further barrier mentioned in the literature, e.g., in certain case studies from Singapore, Australia, and Great Britain, is the (II-v) lack of uniform constructional, technical, and design standards since these are important for proper GF implementation (see IV) and warranty claims [12,20,22,40]. Yet, (II-v) could not be confirmed in the Leipzig or even German case because a respective German directive exists. The results suggest that the barriers in category (II) are highly context-dependent, i.e., they vary between different

countries and even municipalities. While GF guidelines and strategies are still lacking enforcement in Leipzig, for instance, they are already being enforced more effectively in Hamburg, another German city, as pointed out by a consulted expert.

(III) Economic Barriers (Figure 5)

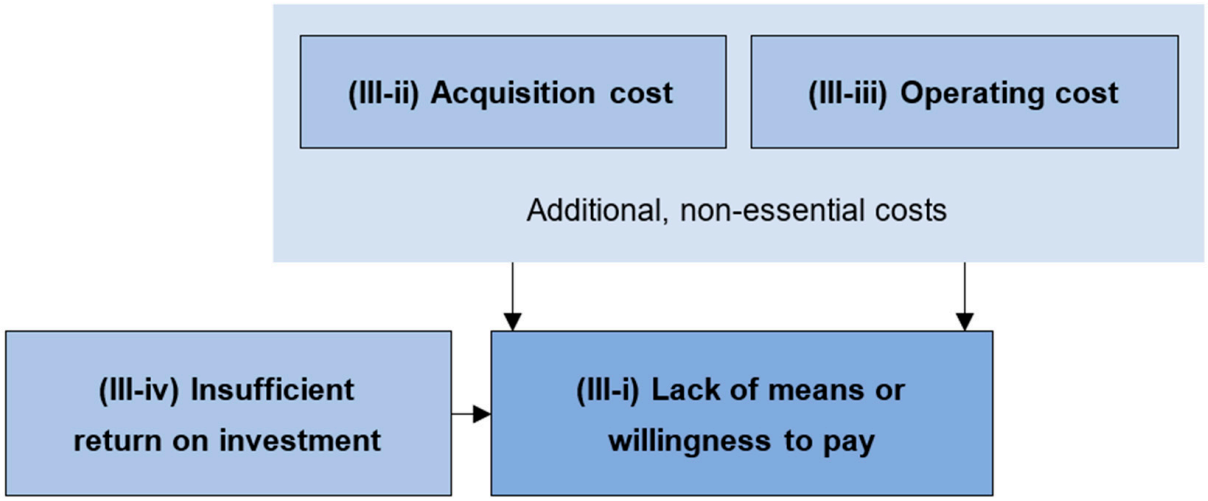

Figure 5. (III) Economic barriers.

Together with social aspects, financial aspects are the most frequently mentioned barriers to GF implementation, as they were addressed in 17 of the analyzed papers. Local stakeholders and experts confirmed that, along with social barriers, financial obstacles are key in Leipzig. According to the literature and the case study, actors mainly lack the (III-i) means or willingness to pay for GFs [10,20,39]. (III-i) may be a universal barrier but is strongly dependent on social and political-administrative framework conditions (cf. I-I, II-iii). Leipzig stakeholders and experts add that, apart from financial resources, actors' expectation that others will bear the costs incurred limits implementation. This conception especially persists between landlords and tenants. Altogether, costs are often overestimated while the potential benefits of GFs are underestimated (cf. I-ii to I-iv). However, the literature and case study confirm that additional, non-essential costs are linked to GF implementation [12,40,43]. This concerns, on the one hand, the (III-ii) acquisition costs, i.e., the costs for planning and installation (e.g., system, plants and labor), and, on the other hand, the (III-iii) operating costs, i.e., the costs for plant care and system maintenance (e.g., water, electricity and possibly time-consuming maintenance work), both addressed in over ten publications and by various local stakeholders and experts [1,9,18,31,41,44]. The costs can be increased by political-administrative framework conditions, e.g., monument conservation requirements and approval procedures during planning (cf. II-iv), but are dependent on the context, especially market conditions, as well as on the system and on proper execution (see IV; [8,18,22]). Irrespective of financial expenses, the (III-iv) insufficient return on investment (ROI) of GFs can act as a barrier [9,18]. GFs have a lower ROIs than other measures and a relatively long payback period, which is why, e.g., yield-oriented companies are not willing to pay for them [9,18]. Hence, depending on their priorities, not all actors can be convinced by the non-monetary benefits of GFs (cf. Section 3; [10]). This barrier could also be confirmed in the Leipzig case.

(IV) Practical-Technical and Environmental Barriers (Figure 6)

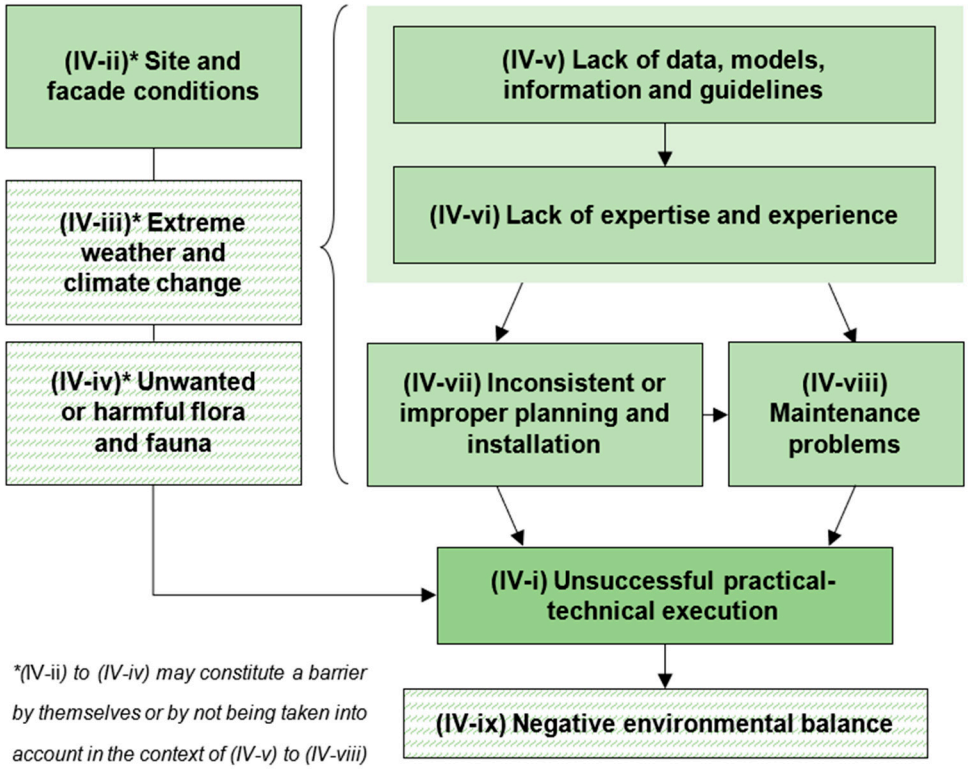

Figure 6. (IV) Practical-technical (fully colored) and environmental barriers (shaded).

In total, 13 publications and various Leipzig stakeholders and experts addressed barriers to the practical-technical implementation of GFs. While eight papers also address environmental barriers, these were hardly a concern in the case study. Due to their close interconnection, practical-technical and environmental barriers are considered together. The central consequence of the barriers in category (IV) is the (IV-i) unsuccessful practical-technical execution of GFs, meaning that the greening fails, i.e., the facade is not or only sparsely covered, or that it has negative effects on the system, the building, or its residents, as frequently experienced by Leipzig stakeholders and experts. Successful execution can initially be hindered by three barriers, all of which are highly dependent on the study area. The first barrier consists of the (IV-ii) site and facade conditions, for not all facades are suitable for GF installation [9,10]. This was confirmed by local stakeholders and includes, according to the consulted GF experts, e.g., sites above a geographic height of 600 m above sea level and facades with a complicated wall structure. Secondly, (IV-iii) extreme weather and climate changes can affect the success of GFs, yet this was not brought up in Leipzig [12,41]. Lastly, (IV-iv) unwanted or harmful flora and fauna can cause trouble at the site or facade [22,40,41]. Leipzig stakeholders and experts underlined the problem of potentially invasive species. However, the case study showed that (IV-ii) to (IV-iv) primarily become a barrier if not taken into account during the implementation process. GFs are complex systems with multiple components that need to be well thought through. This is why the (IV-v) lack of data, models, information, and guidelines as well as of (IV-vi) expertise and practical experience in GF implementation are major barriers in this context [9,16,43]. This pertains to specialist information and knowledge about political-administrative requirements (cf. II-iv) and about proper planning, installation, care, and maintenance of GFs [8,12,22]. Together, (IV-v) und (IV-vi) are addressed in over half of the reviewed publications and were also emphasized in the case study. The two barriers depend, e.g., on the flow of information on the social level (cf. I-ii, I-v) and on the market conditions, respectively, as well as the availability of corresponding experts, as noted by respective GF experts [20]. Both barriers can lead to (IV-vii) inconsistent or improper

planning and installation as well as to (IV-viii) maintenance problems [41]. These problems include the negligence of maintenance requirements, either due to lack of know-how (cf. IV-v, IV-vi) or due to high effort and actors' lack of willingness (cf. I-i, III-I; e.g., [12,41]. The maintenance effort can also be increased by (IV-vii), reinforcing economic barriers (cf. III-iii; [41]). (IV-vii) and (IV-viii) were not only repeatedly confirmed in the case study but are, according to the consulted stakeholders and experts, significant barriers in Leipzig, as they cause GFs to fail. As per the literature and the case study, this can not only reduce actors' willingness to implement and support GFs in the future (cf. I-i, II-i, III-i) as well as the return on investment (cf. III-iv) but can also have a (IV-ix) negative impact on the environment because the preceding consumption of resources for installation and maintenance can no longer be balanced out by the environmental benefits provided by the GF [1,18,41].

4.2. Solutions to Promote GF Implementation in Leipzig

Through the participatory process in the Leipzig case study, we were able to identify locally relevant barriers and develop respective, context-specific solutions. Along with Leipzig stakeholders and experts from various fields, **three solution paths**, each defined by a set of measures, to overcome present GF implementation barriers were created:

(A) Establishment of an incentive system to motivate actors to voluntarily implement GFs;
(B) Adaption of the political-administrative framework conditions, aiming at obligations and simplifications regarding GF implementation;
(C) Support of the practical-technical implementation process of GFs.

The categorization from (A) to (C) is a result of the stakeholder workshop. The solutions comprise a total of eight measures to overcome the four central implementation barriers (cf. Section 4.1), i.e., to activate social and political will as well as financial resources and to ensure the successful practical-technical execution of GF. In Table A5 in Appendix G, an overview of the barriers primarily targeted by the solution paths is presented.

In the following, each solution path will be discussed briefly. Where similar measures have been mentioned in the literature, corresponding references have been added to the case study results. The results show that, to promote GF implementation, a combination of different measures is required, and that the solutions' focus and specifications will vary depending on the context, especially the relative importance of the locally present barriers [22]. In Leipzig, the priority lies in the transfer of knowledge through public relations and advisory services.

(A) Establishment of an Incentive System

Activating the social and political will to implement GFs, i.e., overcoming barriers (I-i) and (II-i), requires the establishment of incentives. An incentive system consisting of informational, regulatory, and financial incentives also addresses the central economic barrier (III-i). Acceptance and motivation on the social level, and hence the political-administrative and economic levels, are not only a basic prerequisite for GF implementation but crucial for its long-term success (cf. IV-i), as stated by Leipzig experts and the literature [10,39].

According to the case study, the creation of (A.1) informative incentives is essential. This primarily includes the acquisition of well-founded information through scientific research (cf. I-ii, IV-v) and the strengthening of information flows within the scientific community and beyond, i.e., between all actors involved in the implementation process (cf. I-v) [1,16,38]. Leipzig stakeholders and experts underlined the significance of communicating a distinct guiding principle regarding the actual cost and benefit of GFs [45]. This requires transfer and public relations work, and possibly information policy [40]. Various print and online formats as well as (participatory) events, e.g., lectures, workshops, and walking tours, were mentioned as suitable for this purpose in the workshop [1]. It became clear in the case study that best practice examples in public spaces hold a particularly high potential for communicating relevant information to different actors [16]. Through the

comprehensive education and participation of actors, knowledge on GFs is strengthened as concerns are addressed and realistic expectations are raised (cf. I-iii, I-iv) [22,43]. Thus, acceptance problems can be overcome and the willingness to initiate and pay for GFs as well as the implementations' success can be promoted (cf. I-i, III-i, IV-i), as stated by Leipzig experts and echoed in the literature [29,38]. Scientifically based information and public awareness and mobilization for GFs also positively influence the ambition and agenda-setting at the political-administrative level (cf. II-i) [8,10,39].

A further step is the introduction of (A.2) regulatory incentives (cf. II-iii). Firstly, this refers to the recognition of GFs as a compensation measure as per the German Conservation Act, i.e., as a compensatory planting for interventions into the natural environment during construction projects. Building owners may also green their buildings' facades to "stockpile" compensation measures for future interventions or may rent them out for the compensation of others' construction projects, as suggested in the stakeholder workshop. Secondly, the establishment of locally adapted rating systems and labelling programs for green building along the lines of BREEAM (Building Research Establishment Environmental Assessment Methodology) and LEED (Leadership in Energy and Environmental Design) can act as an incentive [15]. This measure not only recognizes GFs as a beneficial measure but also recognizes building companies' and owners' efforts [22]. Case study results and literature findings indicate that this recognition is associated with an increase in image and value of properties, and can thus also increase the willingness of yield-oriented actors (cf. III-iv; [8,22]).

According to Leipzig stakeholders and experts as well as the literature, (A.3) financial incentives (cf. II-iii) may also be useful or necessary, especially for private actors or small businesses with limited financial resources (cf. III-ii, III-iii) [29,31,38]. This comprises the development of funding programs and the provision of funding by the public sector as well as government subsidies in the form of tax relief [10,12,29]. Another way to indirectly promote the implementation financially is to increase government subsidies for research and development in the field of GFs [22]. According to literature, financial incentives increase the likelihood of GF implementation [10,31].

However, it was emphasized in the case study that, depending on the context, the establishment of incentives may be accompanied by implementation difficulties regarding the effort, the legal framework, and the availability of funds.

(B) Adaptation of the Political-Administrative Framework Conditions

Since the political-administrative framework has a great influence on GF implementation and has so far only inadequately supported the process, it was found in the case study that it is necessary to identify instruments and establish institutional structures in Leipzig that adequately promote GF implementation (cf. II) [10].

One measure is the (B.1) establishment of strategies and regulations which, contrary to incentives (cf. A.2), do not build on voluntary action but oblige actors to implement GFs. According to the stakeholder workshop and expert interviews, GFs need to be considered, promoted and, if necessary, enforced more ambitiously within political goals, reports and regulations at federal, state, and municipal levels. This measure is also frequently suggested in the literature [1,8,39]. It includes the consideration of GFs within well-founded policy strategies (including specific implementation plans and enforcement mechanisms) as well as the establishment of binding regulations (e.g., guidelines, statutes, and provisions in urban land use planning) for the consistent implementation of the developed strategies and commitment of actors. Leipzig stakeholders and experts propose that, as a building owner, the city itself can take on a pioneering role by greening municipal buildings. Yet, in Leipzig, many building owners are investors who do not live in Leipzig themselves, thus usually paying little attention to environmental aspects. This is why, according to one expert opinion, they in particular must be held accountable. It was illustrated in the case study that this requires politics and administration to provide resources for the monitoring and implementation of, and compliance with regulations. Alternatively to an incentive system, (B.1) can positively influence GF implementation where actors are not willing to do

so, firstly through information and a respective political statement and secondly through legal obligations [10,22,40].

Of particular importance in the Leipzig case, however, is the (B.2) simplification of requirements and procedures in politics and administration (cf. II-iv). This involves the clarification and facilitation of political-administrative requirements, especially regarding historic preservation and fire protection, as well as of the application and approval procedures in connection with GF installation, care, and maintenance [10]. Local stakeholders and experts propose maintenance operations to be simplified by municipalities through a permanent permission. This will increase actors' acceptance and motivation by reducing concerns (cf. I-ii) as well as downstream economic (cf. III-ii, III-iii) and practical-technical obstacles (e.g., IV-viii).

(C) Support of the Practical-Technical Implementation Process

As GF implementation often fails due to practical-technical barriers, different possibilities to support the process and promote successful GF execution were discussed in the Leipzig case study. The following measures comprise a theoretical and practical support of the process to overcome the central barrier (IV-i) and, hence, overcome ensuing social, political-administrative, economic, and environmental obstacles as well (cf. IV).

Since guidelines and expertise have a great influence on the success of GFs, the provision of (C.1) information on the implementation process can be an important theoretical support (cf. IV-v), as stated by local stakeholders and experts. According to the case study and the literature findings, it is firstly key to provide expert information on the practical process, i.e., on initial questions (e.g., Who is allowed to implement GFs and where?), the course of the process, political-administrative aspects of consideration, and different approaches in planning [1,9,20]. Secondly, information on the technical execution must be provided, i.e., technical aspects that must be considered from the start for successful planning, installation, and maintenance [12,41]. The Leipzig stakeholders emphasized that the information must be provided in a low-threshold and adequate manner. Possible formats include catalogues or manuals with guidelines, specifications, and recommendations for action, as well as other working aids such as checklists, sample forms and greening plans [43]. Visual and participatory formats such as walking tours are recommended by Leipzig experts as well. Insofar, the formats of (A.1) and (C.1) can be integrated.

However, the consulted stakeholders' and experts' experiences show that a theoretical overview of the practical-technical requirements is usually not sufficient to overcome the central barrier (IV-i). Therefore, an advanced measure, the (C.2) support of the implementation process through experts (cf. IV-vi), is proposed [1]. This primarily requires the (further) education of experts, especially in the fields of landscape architecture, engineering, and horticulture (cf. Section 2) [43]. This can be accomplished through input from research and teaching, or consultation of the specialist literature and colleagues, as suggested in the Leipzig case study. A GF expert added that the German federal association for green buildings (BuGG) already offers a GF-specific further training and certification [46]. Subsequently, advisory services as well as other service offers supporting the implementation process, either through theoretical advice (e.g., answering questions, providing guidance) or active assistance (e.g., mediation of actors, administrative tasks), can be established. As noted by a Leipzig expert, however, active implementation support, especially taking over administrative tasks, is not always possible from a legal point of view. According to the case study, contact points or persons who take on a sort of "pilot" function in the implementation process are of utmost importance to support the practical-technical execution of GFs and remove corresponding obstacles in Leipzig. While there already are respective counselling centers in Leipzig, they are still inadequately represented throughout Germany and beyond, as noted by a local GF counsellor.

According to the Leipzig case study, this is because many GFs fail due to problems with plant care and system maintenance; hence, a final yet important measure is the generation of a (C.3) contractually defined maintenance offer (cf. IV-viii). Maintenance

work should be bundled, i.e., offered from one source, either by the public sector (e.g., fire brigade) or private service providers (e.g., gardening and landscaping companies). According to the consulted experts, however, municipalities will hardly take care of private green spaces. Leipzig stakeholders and experts made clear that maintenance should be carried out by qualified personnel. By signing a service and maintenance contract with a respective implementation partner at an early stage in the process, it can be ensured that the greenery is not only installed properly but maintained consistently and professionally in the long term. As there already exists a number of appropriate service providers in Leipzig, actors' willingness to pay for respective services (cf. III-i) also plays a major role in this context, as brought up in the workshop and interviews.

5. Discussion

Based on a review of existing literature, this study identified general barriers that hinder GF implementation, investigated them in the local context of Leipzig, Germany, and developed specific solutions to overcome them.

A total of 24 social, political-administrative, economic, practical-technical, and environmental barriers were identified. The results are consistent with those of previous research, according to which actor-specific characteristics as well as the institutional, socio-economic, and natural environment are key variables for the implementation of climate protection and adaptation measures (cf. Section 1). With two exceptions (cf. II-v, IV-iii), all barriers resulting from the literature review have proven relevant in the Leipzig case. Central obstacles are the lack of acceptance and motivation to implement GFs on the social level as well as the lack of ambition to support GFs on the political-administrative level. Additionally, actors' means and willingness to pay for GFs are insufficient. Finally, GF implementation fails due to unsuccessful practical-technical execution.

Within this study, previous findings on GF implementation barriers were systematically reviewed and assessed for the first time. There is a strong and partially reciprocal correlation between the identified barriers, e.g., between barriers on the social and political-administrative level. The consultation of GF stakeholders and experts within the Leipzig case study allowed us to not only identify local constraints but to determine how central barriers arise. The results confirm the findings of Mosgaard and Maneschi [28] and Andrić et al. [1] on the importance of information in innovation processes (cf. Section 2). The four central barriers are in many respects caused by a lack of (objective) information, knowledge, and experience on GFs. Of key relevance is the information that involved actors bring into the implementation process (cf. Figure 3). Even though a combination of several obstacles usually comes into play, this turns out to be the underlying issue and, hence, the major barrier to GF implementation—not only in Leipzig but also in other municipalities, as stated by an experienced GF counsellor interviewed within this study. In addition, there are mainly political-administrative and economic aspects standing in the way of (successful) implementation. The results of this work are thus in line with Biesbroek et al. [13] and Lehmann et al. [14], according to whom the implementation of GFs is primarily influenced by information, incentives, and resources.

Within the Leipzig case study, it was possible to gather new, particularly locally relevant insights into GF implementation barriers. There is a fundamental consensus among local stakeholders and experts about the high relevance of information for (successful) GF implementation. Contrary to literature findings, however, political-administrative requirements and procedures, especially fire protection regulations, as well as the overall complexity of GF implementation, turned out to be major barriers in Leipzig. By involving various actors familiar with GF implementation, a specific focus could also be put on failures during implementation processes. Thus, new insights into the interconnections of barriers on the practical-technical level could be gathered. The case study indicates that, apart from specialist planning, proper plant care and system maintenance are the biggest hurdles for Leipzig actors.

The multitude of identified barriers and interconnections suggests that an integrative solution consisting of different measures will be necessary to overcome them. In the case study, three solution paths with a total of eight different measures were created in collaboration with local stakeholders and experts. The findings confirm that barriers may, in turn, also be an opportunity for GF implementation, as the measures are in many respects complementary to the identified barriers [13]. Chan et al. [15], e.g., list possible solutions for implementing green building technologies such as GFs, which could be confirmed and substantiated in the context of this study. The establishment of an incentive system, consisting of informative, regulatory, and financial incentives, is essential to motivate actors to implement GFs voluntarily. Another solution path is the adaptation of the political-administrative framework, particularly the strategies and regulations, making GF obligatory. These measures are in line with the results of previous studies (cf. Section 1). Complementarily, it was determined as crucial in Leipzig to simplify political-administrative requirements and procedures for GFs. Thirdly, there is a substantial need for informational or expert support, e.g., contact points or persons, during practical-technical implementation. While a combination of various measures will be effective to promote GFs, the initial and biggest task in Leipzig and beyond is to address knowledge gaps among key actors through information provision, i.e., public relations and advisory services on GFs. This will raise acceptance and motivation, and also enable other measures, especially on the political-administrative level.

The barriers to GF implementation identified in the literature stem from a variety of regional contexts. By expanding the pool of existing case studies to Leipzig, we were able to substantiate that almost all barriers from the literature translated into the assessed local context, albeit with differences in their relative importance. Especially political-administrative but also financial and practical-technical aspects are highly dependent on the local framework conditions and may change over time, e.g., with the economic framework [13]. The solutions created with local stakeholders and experts are accordingly context specific, i.e., they apply primarily within Leipzig. Depending on the context and, hence, the present and most important barriers, different solutions may need to be developed and prioritized. In addition, while some measures, e.g., (A.1) and (C.2), have already been applied in Leipzig and other cities, their realization may prove difficult or inapplicable in other contexts, as stated by a GF expert. This must be considered when transferring the results of this research to other German municipalities and beyond. However, given the broad agreement among the findings from the literature review and the case study, it is assumed that the solutions are also applicable in other contexts to promote GF implementation.

Considering the number of actors involved in the implementation of GFs and the variety of interconnections within barriers and solutions, it is necessary to assess both aspects in an interdisciplinary and holistic way. The methodological approach of this study, whereby a literature review was complemented by a local case study including a diverse group stakeholders and experts, proved effective in identifying both general and local barriers as well as underlying issues and major constraints, and in developing context-specific solutions. However, a holistic barrier and solution analysis is vast and complex, thus not every issue can be considered equally. There is a need for analytical reduction, e.g., through the categorization and observation of central obstacles, as carried out in this study. Due to this, as well as the local focus of the case study and the limited number of consulted actors, it cannot be ruled out that there are further barriers and solutions that do not appear in our results. The found causal relationships between and within barriers and solutions are, too, dependent on the local case study and were derived from the participants' subjective contributions.

For future research, we recommend following the approach of our case study and apply it to other locations and specific actors. A transfer to other contexts is important to confirm and complement the results of this research and to evaluate the relevance of barriers and solutions in light of different contexts. The research concept may be supported by other

methods to foster discourse with involved actors. According to Zinia and McShane [39], an analysis of social acceptance and motivation is key. Potential GF initiators and supporters, e.g., the civil society, politics and administrations, may therefore be involved in the barrier and solution assessment from the beginning, e.g., through a public opinion survey, as suggested by a Leipzig administrator. Understanding the perception of different actors can help with creating acceptance [16]. Complementing our approach with methods such as AHP or those applied in Wilkinson et al. [31] and Sprondel et al. [10] will, too, be useful for weighting barriers and solutions. We also recommend to assess their interrelationships in a more structured and comprehensive manner, e.g., by adapting modeling techniques such as ISM or cognitive mapping. Furthermore, it must be assessed whether and how the measures can be realized in different contexts. They should be practically tested and critically evaluated in terms of effectiveness. To promote the implementation and use the full potential of GFs, both scientific and macrosocial efforts are required [8,12,45].

However, it became apparent in our study that, regardless of their potential, GFs should not be considered standalone but as one of many elements to address urban challenges. It is crucial to consider circularity principles and other green-infrastructure elements as well as mitigation and adaption measures additionally or compared to GFs, e.g., through cost-benefit analyses—especially if there are conflicts of use on the facade, like with photovoltaics [18]. This was remarked by Leipzig stakeholders in previous work [47]. Hence, it also remains to be assessed how GFs can holistically be integrated into cities, not as a competitor but as a complement to other sustainability measures.

6. Conclusions

In light of ongoing social, economic, and environmental challenges, GFs offer manifold potential benefits to create livable and resilient cities. As GFs are rarely (successfully) implemented, this study assessed both barriers and solutions to GF implementation by means of a systematic literature review and a participatory case study in Leipzig, Germany. We were able to identify general implementation barriers, confirm their local relevance in an exchange with Leipzig stakeholders and GF experts, and co-create locally adapted solutions.

We identified that, while various social, political-administrative, economic, practical-technical, and environmental barriers are relevant, GF implementation mostly fails due to information and knowledge gaps, resulting in motivational and practical problems. Barriers and their interdependencies need to be comprehensively assessed in order to detect underlying issues. The case study demonstrates that many barriers may apply universally but that context-specific particularities and local differences in the barriers' relevance persist.

To overcome barriers in Leipzig, three solution paths were created. The measures include the establishment of informative, regulatory, and financial incentives, the adaption of the political-administrative strategies, regulations, and procedures, as well as the informational and expert support of the practical-technical implementation process. While a combination of different measures will be effective in overcoming present barriers, the transfer of knowledge on GFs through public relations as well as advisory services is of priority.

Our analysis contributes a general overview of GF implementation barriers and a set of context-specific solutions to overcome them. To promote GFs on a city level, local barriers must be explored so suitable solutions can be developed and prioritized. We provide a blueprint for similar research in other socio-political contexts which is needed to evaluate the relevance of barriers and solutions with respect to different actors and locations. Subsequently, research on whether and how the measures can be put into practice across various contexts is needed.

Author Contributions: Conceptualization, W.K. and H.Z.; methodology, W.K.; formal analysis, W.K.; writing—original draft preparation, W.K.; writing—review and editing, W.K.,R.K. and H.Z.; visualization, W.K.; supervision, H.Z.; funding acquisition, R.K. and H.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Sächsische Aufbaubank (SAB) with tax funds on the basis of the budget passed by the state parliament of Saxony, Germany.

Data Availability Statement: The data underlying the analysis presented in this study are available on request from the corresponding author.

Acknowledgments: We would like to thank Sophia Dietrich at UFZ for her support in the preparation of this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Search strategy: development of the Scopus search query.

Combination of Key Words on (1) Green Facades and (2) Barriers	# Publications	
	1 March 2022	
(TITLE-ABS-KEY **("vertical greenery" OR "vertical greening" OR "green wall" OR "facade greening" OR "green facade")** AND TITLE-ABS-KEY **(challenge OR barrier OR hindrance OR constraint OR obstacle OR rejection OR acceptance)**)	137	
(1) Based on the definition of "green facades" in Section 2, following the terminology applied in Palermo and Turco (2020); (2) Synonyms from Biesbroek et al. *(2013) and Lehmann* et al. *(2013), extended by a focus on actor-specific barriers (rejection and acceptance)*		
Limitation of the Results by Adding Key words on the (3) Implementation Process *(Final Search Query)*	**# Publications**	
	5 April 2022	**PUBYEAR > 2009**
(TITLE-ABS-KEY ("vertical greenery" OR "vertical greening" OR "green wall" OR "facade greening" OR "green facade") AND TITLE-ABS-KEY (challenge OR barrier OR hindrance OR constraint OR obstacle OR rejection OR acceptance)) AND TITLE-ABS-KEY **(initiate OR initiating OR initiation OR plan OR planning OR implement OR implementing OR implementation OR maintenance)**	68	**67**
(3) Based on the steps of the implementation process according to Mosgaard and Maneschi (2016), cf. *Section 2*		*Increased relevance of the topic*

Appendix B

Table A2. Analyzed publications and identified GF implementation barriers.

Author	Year	Title	Case Study	GF Implementation Barriers				
				Social	Political-Administrative	Financial	Practical-Technical	Environmental
Adegun et al. [45]	2021	Urban green infrastructure in Nigeria: A review	Urban green infrastructure in Nigeria	I-ii, I-iii				

Table A2. *Cont.*

Author	Year	Title	Case Study	GF Implementation Barriers				
				Social	Political-Administrative	Financial	Practical-Technical	Environmental
Andric et al. [1]	2019	A review of climate change implications for built environment: impacts, mitigation measures and associated challenges in developed and developing countries	Developed and developing countries	I-i, I-ii, I-iii, I-v	II-ii, II-iii	III-i, III-ii, III-iv	IV-v	IV-ix
Ascione et al. [43]	2020	Green Walls, a Critical Review: Knowledge Gaps, Design Parameters, Thermal Performances and Multi-Criteria Design Approaches	Different climate (locations) and system compositions		II-ii, II-v	III-ii, III-iii	IV-v, IV-vi	IV-ix
Carmichael et al. [44]	2020	The wallbot: A low-cost robot for green wall inspection	Sydney (Australia)	I-iv		III-iii		
Conejos et al. [41]	2019	Green maintainability assessment of high-rise vertical greenery systems	Singapore, i.e., tropical climate and spatial conditions of Singapore (VGS application on high-rise buildings, residential buildings, educational institutions, commercial building, mixed-use development)	I-iv, I-v		III-iii	IV-i, IV-vi, IV-vii, IV-viii	IV-iii, IV-iv, IV-ix
Henseke and Breuste [38]	2015	Climate-change sensitive residential areas and their adaptation capacities by urban green changes: Case study of linz, Austria	Linz (Austria)	I-i, I-ii, I-iii, I-v			IV-ii	
Hong et al. [9]	2019	Urging green retrofits of building facades in the tropics: A review and research agenda	Malaysia (office building retrofitting)	I-i, I-iii	II-iii	III-i, III-ii, III-iv	IV-ii, IV-v, IV-vi	
Iligan and Irga [20]	2021	Are green wall technologies suitable for major transport infrastructure construction projects?	Sydney (Australia)	I-iii, I-iv	II-ii, II-iii, II-v	III-i, III-ii, III-iii	IV-vi	
Leong et al. [22]	2021	The initial study on implementation of vertical greenery in Malaysia	Malaysia	I-iv	II-ii, II-v	III-i, III-ii, III-iii	IV-i, IV-vi, IV-vii, IV-viii	IV-iv

Table A2. *Cont.*

Author	Year	Title	Case Study	GF Implementation Barriers				
				Social	Political-Administrative	Financial	Practical-Technical	Environmental
Lu et al. [29]	2020	Can the dual identity of policy entrepreneur and policy implementer promote successful policy adoption? Vertical greening policymaking in Shanghai, China	Urban vertical greening in Shanghai, China	I-ii, I-iii, I-iv	II-ii, II-iii, II-iv	III-i, III-ii, III-iii		
Magliocco [40]	2018	Vertical greening systems: Social and aesthetic aspects	Case studies in Singapore, Genoa (Italy), Sydney (Australia), London (UK)	I-i, I-ii, I-iii, I-iv, I-v	II-ii, II-v	III-i, III-ii, III-iii		IV-iv
Mohandes et al. [12]	2020	Hindrances to the adoption of green walls: A hybrid fuzzy-based approach	Hong Kong	I-iv	II-ii, II-iii, II-v	III-i, III-ii, III-iii, I-iv	IV-i, IV-ii, IV-v, IV-vi, IV-vii, IV-viii	IV-iii, IV-iv, IV-ix
Murphy et al. [30]	2016	Growing green: Developing industry guidelines for green infrastructure	Melbourne (Australia)	I-iii, I-v			IV-vi	
Oberti and Plant-matura [8]	2018	Greenery systems for urban sustainability: State of the art and perspective in Italy	Italy	I-ii, I-iii, I-iv	II-ii, II-iii	III-i, III-ii, III-iii		
Perini [18]	2021	Greening the Building Envelope	-			III-ii, III-iii, III-iv	IV-v, IV-vi	IV-ix
Rek-Lipczynska [42]	2019	Purification of the Air in the Historic Cities of Towns	Poland		II-iv	III-i		
Sprondel et al. [10]	2016	Urban climate and heat stress: how likely is the implementation of adaptation measures in midlatitude cities? The case of façade greening analyzed with Bayesian networks	Berlin (Germany)	I-i	II-i, II-ii	III-i, III-iv		

Table A2. *Cont.*

Author	Year	Title	Case Study	GF Implementation Barriers				
				Social	Political-Administrative	Financial	Practical-Technical	Environmental
Wilkinson et al. [31]	2021	Towards smart green wall maintenance and Wallbot technology	Sydney (Australia)	I-iii, I-iv		III-iii	IV-ii, IV-v	
Wong et al. [16]	2010	Perception studies of vertical greenery systems in Singapore	Singapore	I-i, I-ii, I-iii, I-iv, I-vi	II-iii, II-v	III-ii, III-iii	IV-viii	IV-iv
Zinia and Mc Shane [39]	2018	Ecosystem services management: An evaluation of green adaptations for urban development in Dhaka, Bangladesh	Dhaka (Bangladesh)	I-i		III-i	IV-i, IV-v, IV-vi, IV-viii	

Note: The 24 barriers are each labeled with a capital Roman numeral from (I) to (IV) for the category, followed by a lowercase Roman numeral from (i) to (ix) for distinction. Table A2 is followed by a list of abbreviations, i.e., Roman numerals and their associated implementation barriers.

List of abbreviations (Roman numbers and associated implementation barriers):

(I-i)	Lack of acceptance and motivation
(I-ii)	Lack of information
(I-iii)	Lack of awareness or knowledge
(I-iv)	Uncertainties, concerns and prejudices
(I-v)	Insufficient communication and teamswork among involved actors
(I-vi)	Subjective perception of aesthetics
(II-i)	Lack of ambition in politics and administration
(II-ii)	Insufficient strategies and regulations
(II-iii)	Insufficient incentives and support
(II-iv)	Complex requirements and extensive procedures
(III-i)	Lack of means of willingness to pay
(III-ii)	Acquisition cost
(III-iii)	Operating cost
(III-iv)	Insufficient return on investment
(IV-i)	Unsuccessful practical-technical execution
(IV-ii)	Site and façade conditions
(IV-iii)	Extreme weather and climate change
(IV-iv)	Unwanted or harmful flora and fauna
(IV-v)	Lack of data, models, information and guidelines
(IV-vi)	Lack of expertise and experience
(IV-vii)	Inconsistent or improper planning and installtion
(IV-viii)	Maintenance problems
(IV-ix)	Negative environmental balance

Appendix C

Table A3. Background of the stakeholder workshop participants.

No.	Domain	Institution
1	Civil society	DMB Mieterverein Leipzig e.V. (tenants association)
2	Civil society	Wir im Quartier (WiQ) (civil network, urban district work)
3	Housing cooperative	Leipziger Wohnungs- und Baugesellschaft (LWB)
4	Housing cooperative	Leipziger Wohnungs- und Baugesellschaft (LWB)
5	Housing cooperative	Leipziger Wohnungs- und Baugesellschaft (LWB)
6	Professional	Fassadengrün e.K. (distribution of GF elements)
7	Professional	Ökolöwe, Kletterfix project (GF educational/advisory service)
8	Public administration	City of Leipzig—Office for Building Management; Subject area: conservation of value (climate protection manager)
9	Public administration	City of Leipzig—Office for Building Regulations and Preservation of Historical Monuments
10	Public administration	City of Leipzig—Office for Environmental Protection
11	Public administration	City of Leipzig—Office for Housing and Urban Renewal; Dept. for Construction of Housing
12	Public administration	City of Leipzig—Office for Traffic and Civil Engineering, Dept. of Road Administration, Subject area: Road Cadaster
13	Public administration	Climate protection management of the city of Plauen, KlimaKonform project
14	Public administration	Federal Agency for Nature Conservation
15	Scientific expert	Helmholtz Centre for Environmental Research (UFZ), project on GF
16	Scientific expert	Helmholtz Centre for Environmental Research (UFZ), project on GF
17	Scientific expert	Helmholtz Centre for Environmental Research (UFZ), project on GF
18	Scientific expert	Helmholtz Centre for Environmental Research (UFZ), project on GF
19	Scientific expert	Helmholtz Centre for Environmental Research (UFZ), project on GF
20	Scientific expert	Helmholtz Centre for Environmental Research (UFZ), project on GF
21	Scientific expert	Helmholtz Centre for Environmental Research (UFZ), project on GF
22	Scientific expert	Helmholtz Centre for Environmental Research (UFZ), project on GF
23	Scientific expert	Helmholtz Centre for Environmental Research (UFZ), project on GF
24	Scientific expert	UFZ, Leipzig BlauGrün project (blue-green infrastructure)
25	Scientific expert	UFZ, projects on green roofs, urban green-blue infrastructure
26	Scientific expert	UFZ, projects on green roofs, urban green-blue infrastructure
27	Scientific expert	UFZ, public relations
28	Scientific expert	University of Leipzig, Institute of Biology

Appendix D

- **WELCOMING** *(approx. 5 min.)*
  by the head of the GF project at UFZ

- **INTRODUCTION ROUND** *(approx. 15 min.)*
  - Who am I? Where do I work? Why am I interested in GF?

- **INSIGHT INTO THE STATUS QUO OF FACADE GREENING IN LEIPZIG** *(approx. 5 min.)*
  by a representative of Ökolöwe—Umweltbund Leipzig e.V., project Kletterfix

- **PRESENTATION ON POTENTIALS AND BARRIERS** *(approx. 10 min.)*
  by research assistant in the GF project at UFZ
  - Overview of diverse potentials of GFs
  - Insight into the implementation process of GFs (initiation – planning –implementation)
  - Overview of social, political-administrative, economic, practical-technical, and environmental barriers

- **EXCHANGE IN THREE WORKING GROUPS FOR BARRIER ANALYSIS** *(approx. 30 min.)*
  Moderation by two researchers and a research assistant in the GF project at UFZ
  1) Political-administrative barriers
     Focus: Funding, administrative requirements, obligations
  2) Social and economic barriers
     Focus: Acceptance/motivation problems, information flows, willingness to pay
  3) Practical-technical and environmental barriers
     Focus: Planning, installation, and operational challenges and problems

  Goal: Discussion, completion and prioritization of barriers

- **BREAK** *(approx. 10 min.)*

- **SUMMARY OF THE RESULTS FROM THE WORKING GROUPS** *(approx. 10 min.)*

  Important barriers: Lack of acceptance and motivation, lack of information and knowledge, high effort for GF implementation, public law requirements, limited funding, problems with planning and maintenance

- **PLENUM DISCUSSION FOR CO-CREATION OF SOLUTIONS** *(approx. 25 min.)*
  Moderation by two researchers in the GF project at UFZ
  - Focus: Solutions for the most important barriers according to the working groups
  - Interactive and visual support using a whiteboard

  Goal: Collaborative development of solutions

- **CONCLUDING ROUND AND FEEDBACK** *(approx. 20 min.)*

Appendix E

Table A4. Expertise of the Interviewees.

No.	Domain	Institution/Position
1	Housing cooperative	Leipziger Wohnungs- und Baugesellschaft (LWB); experience with GF implementation on own buildings
2	Public Administration	City of Leipzig—Office for Building Regulations and Preservation of Historical Monuments; work in construction consultancy
3	Professional	Fassadengrün e.K. (distribution of GF elements)
4	Professional	Ökolöwe, Kletterfix project (educational and advisory service for GF); certified GF counsellor
5	Professional	Vertiko GmbH (advisory, planning, installation, and maintenance service for GF); GF consultant
6	Scientific Expert	Helmholtz Centre for Environmental Research (UFZ), GF project; special expertise: micrometeorological modeling and microclimatic measurements on GF

Appendix F

General Guidelines for Expert Interviews

(1) **Thematic Introduction**, i.e., personal and occupational background and connection to GF, expert opinion on GF implementation barriers

- *a.* *Why are you interested in GFs?*
- *b.* *Which experience/expertise do you have in the field of GFs?* OR *Where do you see occupational connecting factors to GFs?*
- *c.* *Which GF implementation barrier(s) do you consider particularly important?*

(2) Questions on **specific GF implementation barriers** identified in the literature review and the stakeholder workshop for critical evaluation based on the interviewees' experience and expertise

(3) Addressing the **identified solutions paths** and questions on **specific measures** developed in the stakeholder workshop for critical evaluation and further refinement based on the interviewees' experience and expertise

(4) **Complementation of the measures** already identified

- *a.* *Which additional measures can be taken to reduce present barriers and to promote (successful) implementation of GFs?*

Appendix G

Table A5. Solution paths and primarily addressed barriers.

Solution Paths	Primarily Addressed Barriers																						
Three solution paths, each defined by a set of measures, were developed to overcome present GF implementation barriers: **(A)** Establishment of an incentive system to motivate actors to voluntarily implement GF; **(B)** Adaptation of the political-administrative framework conditions, aiming at obligations and simplifications regarding GF implementation; **(C)** Support of the practical-technical implementation process of GFs.	**I** (social)						**II** (pol.-adm.)					**III** (econ.)				**IV** (prac.-tech. | env.)								
	i	**ii**	**iii**	**iv**	**v**	**vi**	**i**	**ii**	**iii**	**iv**	**v**	**i**	**ii**	**iii**	**iv**	**i**	**ii**	**iii**	**iv**	**v**	**vi**	**vii**	**vii**	**ix**
	Lack of acceptance and motivation	Lack of information	Lack of awareness or knowledge	Uncertainties, concerns and prejudices	Insufficient communication and teamwork among actors	Subjective perception of aesthetics	Lack of ambition in politics and administration	Insufficient strategies and regulations	Insufficient incentives and support	Complex requirements and extensive procedures	Lack of uniform standards	Lack of means or willingness to pay	Acquisition cost	Operating cost	Insufficient return on investment	Unsuccessful practical-technical execution	Site and facade conditions	Extreme weather and climate change	Unwanted or harmful flora and fauna	Lack of data, models, information and guideline	Lack of expertise and experience	Inconsistent or improper planning and installation	Maintenance problems	Negative environmental balance
(A.1) **Informative incentives** (Scientific research, strengthening of information flows, guiding principle, transfer and public relations work, best practice examples)	×	×	×		×		×													×				
(A.2) **Regulatory incentives** (Recognition of GF as a compensation measure as per the German Conservation Act, rating systems and labelling programs for green buildings)	×								×			×			×									
(A.3) **Financial incentives** (Funding programs, tax relief, subsidies for research and development in the field of GF)	×								×			×	×	×										
(B.1) **Establishment of strategies and regulations** (Consideration within well-founded policy strategies, enforcement of binding regulations)	×	×	×					×				×												

Table A5. *Cont.*

Solution Paths		Primarily Addressed Barriers												
(B.2)	**Simplification of requirements and procedures** (For installation, care, and maintenance of GFs)	×			×			×	×		×			
(C.1)	**Information on the implementation process** (Provision of information on the practical process and the technical execution of GFs in low-threshold formats)	×	×	×							×	×		
(C.2)	**Support of the process through experts** (Further education of experts on GFs, advisory services, active support in the implementation process)	×	×	×		×					×	×	×	
(C.3)	**Contractually bundled maintenance offer** (Public or private service providers, qualified personnel, service and maintenance contract throughout the whole lifespan of the GF)	×									×			×

Note: Due to the interconnectedness of barriers, the presented solution paths may also have secondary effects on barriers not marked here.

References

1. Andrić, I.; Koc, M.; Al-Ghamdi, S.G. A review of climate change implications for built environment: Impacts, mitigation measures and associated challenges in developed and developing countries. *J. Clean. Prod.* **2019**, *211*, 83–102. [CrossRef]
2. United Nations. Sustainable Development Goals. Available online: https://www.un.org/sustainabledevelopment/cities/ (accessed on 5 May 2021).
3. Revi, A.; Satterthwaite, D.; Aragón-Durand, F.; Corfee-Morlot, J.; Kiunsi, R.; Pelling, M.; Roberts, D.; Solecki, W.; Pahwa Gajjar, S.; Sverdlik, A. Urban areas. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC, Ed.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 535–612.
4. Henninger, S.; Weber, S. *Stadtklima*; utb: Paderborn, Germany, 2019; ISBN 9783825248499.
5. Intergovernmental Panel on Climate Change. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2014.
6. Meili, N.; Manoli, G.; Burlando, P.; Bou-Zeid, E.; Chow, W.T.L.; Coutts, A.M.; Daly, E.; Nice, K.A.; Roth, M.; Tapper, N.J.; et al. An urban ecohydrological model to quantify the effect of vegetation on urban climate and hydrology (UT&C v1.0). *Geosci. Model Dev.* **2020**, *13*, 335–362. [CrossRef]
7. Douglas, A.N.; Morgan, A.L.; Rogers, E.I.; Irga, P.J.; Torpy, F.R. Evaluating and comparing the green wall retrofit suitability across major Australian cities. *J. Environ. Manag.* **2021**, *298*, 113417. [CrossRef] [PubMed]
8. Oberti, I.; Plantamura, F. Greenery Systems for Urban Sustainability: State of the Art and Perspective in Italy. *WIT Trans. Built Environ.* **2018**, *179*, 113–121.
9. Hong, W.-T.; Ibrahim, K.; Loo, S.-C. Urging Green Retrofits of Building Façades in the Tropics: A Review and Research Agenda. *Int. J. Technol.* **2019**, *10*, 1140–1149. [CrossRef]
10. Sprondel, N.; Donner, J.; Mahlkow, N.; Köppel, J. Urban climate and heat stress: How likely is the implementation of adaptation measures in mid-latitude cities? The case of façade greening analyzed with Bayesian networks. *One Ecosyst.* **2016**, *1*, e9280. [CrossRef]
11. Mann, G.; Gohlke, R.; Wolff, F. *BuGG-Marktreport Gebäudegrün 2020*; Dach-, Fassaden-und Innenraumbegrünung Deutschland: Berlin, Germany, 2020.
12. Mohandes, S.R.; Mahdiyar, A.; Sadeghi, H.; Tabatabaee, S.; Hosseini, M.R. Hindrances to the adoption of green walls: A hybrid fuzzy-based approach. In Proceedings of the International Conference of Architectural Science Association, Auckland, New Zealand, 26–27 November 2020; pp. 541–550.
13. Biesbroek, G.R.; Klostermann, J.E.; Termeer, C.J.; Kabat, P. On the nature of barriers to climate change adaptation. *Reg. Environ. Chang.* **2013**, *13*, 1119–1129. [CrossRef]
14. Lehmann, P.; Brenck, M.; Gebhardt, O.; Schaller, S.; Süßbauer, E. Barriers and opportunities for urban adaptation planning: Analytical framework and evidence from cities in Latin America and Germany. *Mitig. Adapt Strateg. Glob. Chang.* **2015**, *20*, 75–97. [CrossRef]
15. Chan, A.P.C.; Darko, A.; Ameyaw, E.E. Strategies for Promoting Green Building Technologies Adoption in the Construction Industry—An International Study. *Sustainability* **2017**, *9*, 969. [CrossRef]
16. Wong, N.H.; Tan, A.Y.K.; Tan, P.Y.; Sia, A.; Wong, N.C. Perception Studies of Vertical Greenery Systems in Singapore. *J. Urban Plan. Dev.* **2010**, *136*, 330–338. [CrossRef]
17. Palermo, S.; Turco, M. Green Wall Systems: Where do we Stand? In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2020; Volume 410. [CrossRef]
18. Perini, K. Greening the Building Envelope. In *Bioclimatic Approaches in Urban and Building Design*; Chiesa, G., Ed.; Springer Nature AG: Cham, Switzerland, 2021; pp. 401–414, ISBN 978-3-030-59328-5.
19. Francis, R.A.; Lorimer, J. Urban reconciliation ecology: The potential of living roofs and walls. *J. Environ. Manag.* **2011**, *92*, 1429–1437. [CrossRef]
20. Iligan, R.; Irga, P. Are green wall technologies suitable for major transport infrastructure construction projects? *Urban For. Urban Green.* **2021**, *65*, 127313. [CrossRef]
21. Kaltschmitt, M.; Streicher, W.; Wiese, A. *Erneuerbare Energien—Systemtechnik, Wirtschaftlichkeit, Umweltaspekte*, 6th ed.; Springer Vieweg: Berlin/Heidelberg, Germany, 2020; ISBN 978-3-662-61189-0.
22. Leong, B.T.; Yeap, P.S.; Ang, F.L. The initial study on implementation of vertical greenery in Malaysia. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2021; Volume 685, p. 12017. [CrossRef]
23. Price, A.; Jones, E.C.; Jefferson, F. Vertical Greenery Systems as a Strategy in Urban Heat Island Mitigation. *Water Air Soil Pollut.* **2015**, *226*, 1–11. [CrossRef]
24. Marchi, M.; Pulselli, R.M.; Marchettini, N.; Pulselli, F.M.; Bastianoni, S. Carbon dioxide sequestration model of a vertical greenery system. *Ecol. Model.* **2015**, *306*, 46–56. [CrossRef]
25. Pérez, G.; Coma, J.; Sol, S.; Cabeza, L.F. Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect. *Appl. Energy* **2017**, *187*, 424–437. [CrossRef]
26. Coma, J.; Pérez, G.; de Gracia, A.; Burés, S.; Urrestarazu, M.; Cabeza, L.F. Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades. *Build. Environ.* **2017**, *111*, 228–237. [CrossRef]

27. Grinde, B.; Patil, G.G. Biophilia: Does visual contact with nature impact on health and well-being? *Int. J. Environ. Res. Public Health* **2009**, *6*, 2332–2343. [CrossRef] [PubMed]
28. Mosgaard, M.; Maneschi, D. The energy renovation journey. *Int. J. Innov. Sustain. Dev.* **2016**, *10*, 177–197. [CrossRef]
29. Lu, H.; Mayer, A.L.; Wellstead, A.M.; Zhou, S. Can the dual identity of policy entrepreneur and policy implementer promote successful policy adoption? Vertical greening policymaking in Shanghai, China. *J. Asian Public Policy* **2020**, *13*, 113–128. [CrossRef]
30. Murphy, S.M.; Rayner, J.P.; Hall, G.; Francis, J. Growing green: Developing industry guidelines for green infrastructure. *Acta Hortic.* **2016**, *1108*, 291–296. [CrossRef]
31. Wilkinson, S.; Carmichael, M.; Khonasty, R. Towards smart green wall maintenance and Wallbot technology. *Prop. Manag.* **2021**, *39*, 466–478. [CrossRef]
32. Shamseer, L.; Moher, D.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: Elaboration and explanation. *BMJ* **2015**, *350*, g7647. [CrossRef] [PubMed]
33. Artmann, M.; Sartison, K. The Role of Urban Agriculture as a Nature-Based Solution: A Review for Developing a Systemic Assessment Framework. *Sustainability* **2018**, *10*, 1937. [CrossRef]
34. Kusay-Merkle, U. *Agiles Projektmanagement im Berufsalltag—Für Mittlere und Kleine Projekte: Die Gestaltung von Meetings und Workshops*; Springer Gabler: Heidelberg, Germany, 2018; ISBN 978-3-662-56800-2.
35. Henseling, C.; Hahn, T.; Nolting, K. *Fokusgruppen-Methode als Instrument in der Umwelt-und Nachhaltigkeitsforschung*; Institut für Zukunftsstudien und Technologiebewertung (IZT): Berlin, Germany, 2006.
36. Gläser, J.; Laudel, G. *Experteninterviews und Qualitative Inhaltsanalyse als Instrumente Rekonstruierender Untersuchungen*, 3rd ed.; VS Verlag für Sozialwissenschaften: Wiesbaden, Germany, 2009; ISBN 978-3531156842.
37. Kaiser, R. Qualitative Experteninterviews. In *Konzeptionelle Grundlagen und Praktische Durchführung*, 2nd ed.; Springer VS: Siegen, Germany, 2021; ISBN 978-3-658-02479-6.
38. Henseke, A.; Breuste, J.H. Climate-Change Sensitive Residential Areas and Their Adaptation Capacities by Urban Green Changes: Case Study of Linz, Austria. *J. Urban Plan. Dev.* **2015**, *141*, A5014007. [CrossRef]
39. Zinia, N.J.; McShane, P. Ecosystem services management: An evaluation of green adaptations for urban development in Dhaka, Bangladesh. *Landsc. Urban Plan.* **2018**, *173*, 23–32. [CrossRef]
40. Magliocco, A. Vertical Greening Systems. In *Nature Based Strategies for Urban and Building Sustainability*; Pérez, G., Perini, K., Eds.; Elsevier: Amsterdam, The Netherlands, 2018; pp. 263–271, ISBN 978-0-12-812150-4.
41. Conejos, S.; Chew, M.Y.L.; Azril, F.H.B. Green maintainability assessment of high-rise vertical greenery systems. *Facilities* **2019**, *37*, 1008–1047. [CrossRef]
42. Rek-Lipczynska, A. Purification of the Air in the Historic Cities of Towns. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2019; Volume 471, p. 102029. [CrossRef]
43. Ascione, F.; de Masi, R.F.; Mastellone, M.; Ruggiero, S.; Vanoli, G.P. Green Walls, a Critical Review: Knowledge Gaps, Design Parameters, Thermal Performances and Multi-Criteria Design Approaches. *Energies* **2020**, *13*, 2296. [CrossRef]
44. Carmichael, M.; Khonasty, R.; Wilkinson, S.; Schork, T. The Wallbot: A Low-cost Robot for Green Wall Inspection. In *Australasian Conference on Robotics and Automation*; ACRA: Singapore, 2020.
45. Adegun, O.B.; Ikudayisi, A.E.; Morakinyo, T.E.; Olusoga, O.O. Urban green infrastructure in Nigeria: A review. *Sci. Afr.* **2021**, *14*, e01044. [CrossRef]
46. Bundesverband GebäudeGrün, E.V.; German Federal Association for Green Buildings. BuGG-Seminarübersicht zur Fort- und Weiterbildung Gebäudebegrünung. 2022. Available online: https://www.gebaeudegruen.info/aktuelles/seminare-veranstaltungen-messen/bugg-veranstaltungen/fortbildung (accessed on 1 June 2023).
47. Karutz, R.; Zozmann, H.; Wollschläger, N.; Schlink, U. Fassadenbegrünung als multifunktionales Anpassungsinstrument gegen Hitze: Ergebnisse des Leipziger Pilotprojekts „Lebendige Wände". In *Die resiliente Stadt: Konzepte, Konflikte, Lösungen*; Kabisch, S., Rink, D., Banzhaf, E., Eds.; Springer Spektrum: Heidelberg, Germany, 2023; *in press*.