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From Intention to Implementation of Vertical Green: The Case of Ljubljana

Damjana Gantar *, Jana Kozamernik, Ina Šuklje Erjavec and Simon Koblar

Urban Planning Institute of the Republic of Slovenia, SI1000 Ljubljana, Slovenia; jana.kozamernik@uirs.si (J.K.); ina.suklje@uirs.si (I.Š.E.); simon.koblar@uirs.si (S.K.)

* Correspondence: damjana.gantar@uirs.si; Tel.: +386-51-395-176

Abstract: This article examines the need and opportunities to implement vertical green in Ljubljana as a case of a medium-sized European city with a relatively green feel. Sustainability-oriented urban development supports the introduction of nature-based solutions in principle; however, there is a lack of vertical green as well as actual legislative and administrative support. Therefore, several methods were applied in the present study to link this idea to execution, starting with semi-structured interviews and a workshop for selected city officials. Legislative and formal backgrounds for implementation were then assessed. An inventory of green façades and other structures (e.g., noise barriers and retaining walls) in Ljubljana was prepared, and a geographic information system-based decision support system was developed to identify the potential areas in the city where additional green space elements would be most favourable for humans, the environment, and climate indicators. The results reveal a gap between opportunities and the actual situation. The general opinion that there is never too much green space in urban areas is confirmed by direct information from the city administration and strategic documents. There are many potential sites for implementation; however, this is hindered by ownership, management, and economic issues. The study concludes with some suggestions for following the best practices in other central European capitals, such as Vienna and Berlin.

Keywords: vertical green; green infrastructure; sustainable city; urban planning

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1. Introduction

A vertical greenery system is a nature-based solution in contemporary architecture and urban planning that contributes to the ecological, environmental, mezzo- and micro-climatic, and aesthetic conditions of a city. The introduction of vertical green in cities is in accordance with strategies that support climate change resilience, nature-based solutions (NbS), green infrastructure (GI), and restoration ecology as well as the improvement of living conditions and wellbeing of the inhabitants of densely populated urban areas. The decision for implementing a green façade on a building is based on multiple factors, including economic or budgetary reasons, social and health aspects, and environmental or ecological needs such as increasing the urban green and biodiversity. In this article, we discuss the implementation process of vertical green, from an assessment of needs and legislative and administrative support to an inventory of the existing green façades and walls and a subsequent assessment of locations with green infrastructure deficit in Ljubljana, the capital city of Slovenia.

Ljubljana is renowned as a green city, and it received the European Green Capital award in 2016. Categorised as a medium-sized European city, it combines the offer of a metropolis with the approachable feel of a small town [1]. Ljubljana's development over the last decades has supported its transition from a post-socialist city to a contemporary capital that successfully integrates cultural heritage restoration with the refurbishment of open spaces in the city centre [2]; however, the share of green spaces and consideration of green system development goals are not consistent. The wider city area (urban centre and hinterland) is reported to have a high proportion of green spaces per inhabitant [3]. Although the city has a clear concept of a green system, containing five green wedges, a system of parks, and other types of green spaces, the urban fabric is mainly characterised by two broad green wedges in the urban city centre and small parks. In recent decades, the city has experienced a shrinking of green areas due to the pressure to build on both green spaces and private plots; there is also a trend towards occupying open green spaces for other uses (parking, temporary buildings, etc.) or even transforming them into paved areas, sometimes without vegetation (squares, parking spaces).

The present research was thus oriented to resonate with the middle-sized and relatively green feel of Ljubljana as well as the actual needs and potential for implementing a certain type of NbS, namely façade greening, to improve local living and environmental conditions. Ljubljana, similar to any other city, faces a variety of challenges in terms of climate change, economic transition, and demographic change. Quality of life and sustainable development have received attention from the research society, practitioners such as architects, civil engineers, and urban planners, as well as policy in the last decades. Accordingly, several documents and agendas to promote the development and inclusion of nature-based solutions and green infrastructure in urban planning and management have been formed [4,5]. The most important task for sustainable urban development is resource- and efficiency-oriented planning, which includes sustainable mobility, sustainable housing, and nature-based solutions to mitigate the consequences of climate change as well as to improve water, air, and overall living quality in urban areas. Vertical greenery systems (VGS) constitute a "promising contemporary green infrastructure element which contribute to the provision of several ecosystem services both at building and urban scales" [6]. Further, NbS have a number of beneficial impacts on the urban environment [7]: they help lower building façade temperatures in the summer, e.g., via passive cooling, and thus lower the effect of thermal heat islands [8–10], reduce surface water runoff [11], reduce noise by absorbing sound [6,12], and improve biodiversity [13] as well as improve the aesthetics and perception of urban open spaces [14,15].

This article is based on the hypothesis that the viewpoints of the decision-makers and key stakeholders, the legislation, and the planning framework in the current situation of Ljubljana have some drawbacks that contribute to the lesser implementation of VG in the city than in other European capitals. We also presume that some of the factors that hinder the implementation could be improved by following good practices from other capitals such as Vienna and Berlin. The low use of VGS compared to other capitals can be attributed to the indirect definition of responsibilities and goals, economic reasons, and the historically scarce VG development or not-so-rich tradition of façade greening in the past.

This article looks at when and how VG implementation should be addressed in the process of urban planning to benefit the city. Does it need to be planned at all, or is it better to support investors who are willing to implement vertical greenery systems in their building projects? Which legislation or document types are the most established and appropriate in promoting this type of GI at the city level? Last but not least, how to define the most spatially appropriate locations for VG implementation to improve the overall city's appearance and social, ecological, and climatic conditions?

In comparison to a classically built façade, green façades affect not only their own buildings but also their immediate and wider surroundings. The impacts and benefits of VG are much broader than the direct impact on the building itself. If carried out in appropriate locations and on a large-enough scale to have cumulative benefits, green façades and other VG elements can have positive impacts on the city as a whole. Since they are vertical, these green structures also occupy other types of urban spaces or surfaces than ordinary green spaces. Therefore, as a type of urban green space, VG is especially important in urban environments that have no potential for implementing typical green spaces or elements such as treelines, and in circumstances where no other types of green spaces can address the environmental problems or improve the quality of living. Such urban environments are very densely built urban areas or city areas that are kept or need to be greener due to previous planning decisions such as green wedges and green corridors. Moreover, VG and other green spaces are important as additional improvement measures as well as sustainable planning and design approaches for regenerating or initiating new development in cities and other built-up areas.

Several challenges arise in providing appropriate conditions for the desired development of VG at the city level or in certain areas and individual buildings. The values, opinions, and motivations of stakeholders have a strong impact on urban governance issues, including the establishment of appropriate links and synergies among the various sectors' activities, planning levels, and document topics as well as within the decision-making, financing, and management processes of VG. In addition, the historical presence of VG in the city is also important; in cities where façade greening has previously occurred or is a custom practice (e.g., inner courtyards in Berlin and Vienna), citizens are used to the development, and new VG spaces are not questioned in principle. With respect to a city, it is of key importance to determine the areas most appropriate and in need of improvement before adding GI to existing structures.

The present research has been conducted within the scope of the Urban Vertical Green 2.0 project implemented under the Joint Programming Initiative Urban Europe.

2. Materials and Methods

This research was aimed at assessing the possibilities for VGS implementation in Ljubljana based on the intentions expressed and possible locations in need of new green infrastructure. Accordingly, the methodology consisted of the sequence of methods described below (see Figure 1 for the process diagram). The methods were chosen based on the broader project framework, seeking to provide comprehensive and complementary information with the aim of analysing the state of the art and the possibilities for improving the implementation of VG in urban areas. The selected methods presented in this article are directly relevant for the case of Ljubljana.

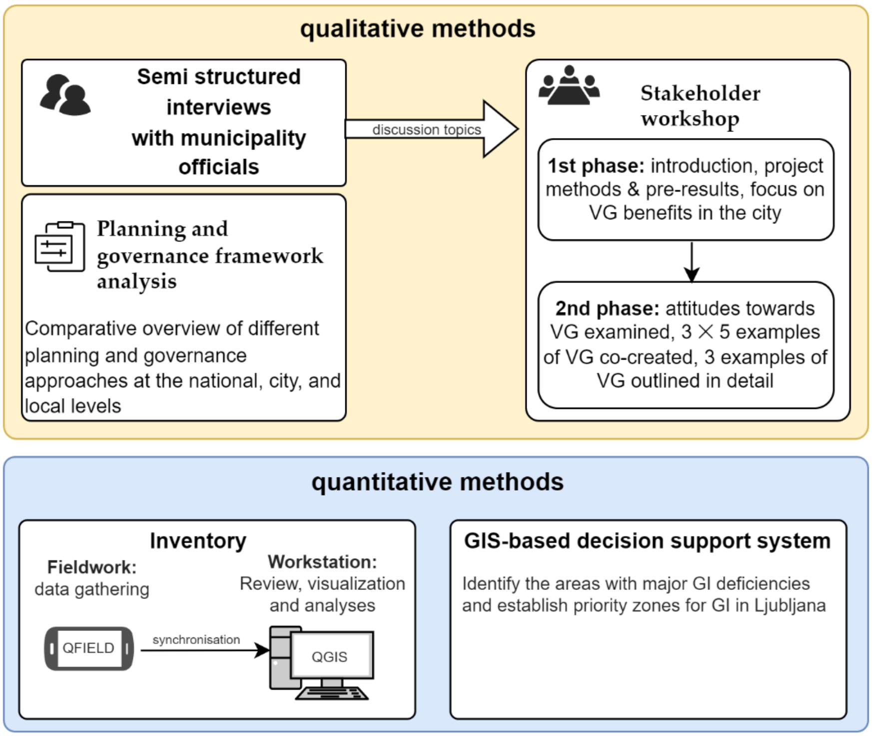

Figure 1. Schematic representation of the research process and applied methods (author: Simon Koblar).

First, we conducted semi-structured interviews with municipality officials who lead certain relevant departments and public services, namely the Head of Department of Urban Planning, Head of Emergency (Protection and Rescue) Management, Director of the City of Ljubljana's Public Housing Fund, Head of Department for Environmental Protection, Head of Office for Investments, Head of Pre-School Education and Schooling Department, and Head of City Energy Management. Seven interviews were performed in January 2019: five were administered in person at the interviewer's headquarters at a pre-arranged time, and two were administered by e-mail; the questionnaire was the same for both interview types. All interviews, except the written interviews, were recorded. The recordings were used exclusively for transcription and then deleted. Each interview lasted 30–60 min and followed a protocol that involved a short introduction of the project and a preset questionnaire with five sets of questions on the following:

- Attitudes towards green spaces in the city and knowledge of green walls;
- General attitudes towards green walls and the advantages and disadvantages of green walls;
- Knowledge of and attitude towards VGS implementation in Ljubljana;
- Key stakeholders for the implementation of VGS in Ljubljana;
- Key departments and their roles in the implementation of VGS in Ljubljana.

During the interviews, some of the answers stimulated further interest among the researchers, and additional questions related to the specific content of the previous answers were asked. In some interviews, certain sets of questions were answered in more detail than others, depending on the interviewee's field of work and/or personal interest. The aim was twofold—to get better insight into experiences and attitudes on VG of people leading relevant departments and to raise their awareness and interest of the relevant departments to participate further in the following workshop, where the gathered information was used to better adapt the next steps to the needs and experiences of different departments.

As the next step of the research process, a stakeholder workshop was organised based on the interview analysis. The interviews revealed insights into the topic of VG implementation in the city from the point of view of each individual department. So, the following step was to strengthen their knowledge of VG and encourage a conversation between these diverse departments and implement a co-creation of case studies. The workshop was held in February 2019 and led by a professional moderator; the group discussions and concluding sessions were led by the authors of this article. The workshop participants were not the same as interviewees (with one exception); they were chosen for their operational and executive roles in their respective departments. Accordingly, 14 participants from relevant departments of city administration and public services were present, namely the Department of Urban Planning, Department for Environmental Protection, Department for Commercial Activities and Traffic, Office for Development Projects and Investments, Office for Local Self-Government, Public Housing Fund, City Energy Manager, Public Services of Waste Management, and Public Space Management.

The workshop consisted of two parts. The first part aimed at presenting in detail the potential and possibilities of green walls in urban areas. The project facts and contextual background were briefly explained, including the different forms and characteristics of green walls and the potential costs of implementation, based on data from case studies. This was followed by a presentation of the methods and results of past VGS research, with a focus on measuring the benefits of green walls in the city. The first part of the workshop was concluded by the city administration's representative, who presented the implementation process for the green wall next to the children's playground "Mala ulica Family Centre" in Ljubljana.

The aim of the second part of the workshop was to examine the attitudes of the representatives of different departments and public services towards green walls, to encourage interdepartmental cooperation and to co-define the comprehensive process of implementing a green wall in Ljubljana. The participants were divided into three groups, with each group consisting of representatives from different departments. Each group prepared five examples of green wall initiatives and defined the rationale for the same; they summarised all the initiatives and justifications in the form of a table. Each group then chose one example from the five and further defined it according to the benefits for the initiator, concerns and fears of the initiator, overall benefits of the green wall under consideration, and overall risks of the green wall under consideration. For each selected case (surface mounted urban equipment, school renovation, and re-use centre), the groups co-created and presented the process from initiative to decision and the process of planning, implementation, and maintenance. Necessary activities for each stage of the process as well as the steps and drivers of implementation were defined, including the department responsible for each part of the process and with whom everyone should connect and cooperate. This part of the workshop resulted in an increase in the awareness of the needs, possibilities, and opportunities of establishing green walls in Ljubljana among the city service departments as well as the co-design/simulation of the necessary joint process.

As the interviews and workshop with representatives of the city administration brought knowledge of some implemented cases and the aspirations at the city level, the next step of the research was to analyse the general occurrence of green walls in Ljubljana by performing a field inventory. The analysis consisted of the preparation phase, fieldwork, preparation of the gathered data, and geographic information system (GIS) analysis. The fieldwork was carried out in the Slovenian capital city Ljubljana. To get relevant results for urban context, only densely populated urban areas were mapped. The inventory included green walls covering 2 m^2 and larger vertical green surfaces.

The preparation phase included the development of an inventory sheet to define the characteristics of each object. All the objects were first classified as one of the three main types of green walls (as part of building façades or other structures e.g., retaining walls):

- Green façade—a ground-based structure in which plants growing from the ground are supported directly by the wall or by using a net/other support systems.
- Living wall—a wall-based structure (planting media, plants, supporting structures) that is attached to the façade, with plants growing "out of the façade".
- Combination system—the structure is mounted on the façade, with plants rising from the structure instead of the ground, e.g., troughs on the façade usually potted with climbers.

The fieldwork was carried out during the growing season in July and August 2020. The inventory was carried out by two students of urban planning using a tablet and the open-source mobile GIS application Q-field 1.6. The tablet was used to plot the location of the green wall as a linear feature, enter attribute data, and take photographs; the photos were then linked to each object via a relational table.

The following data on object characteristics were collected: the type of building on which the vertical greening is growing on or is attached to (considering the detailed European Classification [16] of construction types); dimensions of the green area (height, width, ground clearance); an estimation of the green coverage of the entire façade; type of surrounding space (adjacent to a traffic area, green area, etc.); the presence of high vegetation (trees) along the green wall; the position of the green façade on the building, i.e., frontal, side, or courtyard (only for buildings); visible exposure (very to less exposed); the accessibility (private or public access); type of vertical green in relation to the embeddedness; the construction material and method of anchoring on the wall; distance of the structure from the wall; type and density of vegetation; texture and particular features such as the presence of a special green design motif. Certain data related to the condition of the VG were also collected and assessed, such as the planned or spontaneous/natural growth, state of greenery, and state of maintenance. After the fieldwork was completed, a cabinet review of the collected data was carried out using QGIS 3.14. As the field inventory was carried out by two students with limited knowledge of vertical greening systems, the data quality was checked by the co-author of this article, who is an expert in the field. The quality analysis was enabled by the availability of photographs; they were accessible from within the QGIS software and were linked to each object entered. The completeness of the inventory was also checked via street view on Google Maps.

Following the inventory phase, GIS and statistical analysis were conducted. The gathered data, which included the location and size of green walls, enabled further analysis of the contribution of green walls to green areas in certain parts of the city, the type of object with green walls, and the spatial contexts of green wall implementation (assessment of the purpose of the green wall). Inventory data were compared with other relevant spatial information such as land use, buildings, district areas, etc.

The next research stage focused on determining the need for green infrastructure, including VG. Based on different spatial data, the city was evaluated and a geoinformation decision support system was developed.

The aim of the geoinformation decision support system was to identify the areas with major GI deficiencies and establish priority zones for GI in Ljubljana.

To evaluate GI deficit in an urban area, a homocentric indicator was developed from the user's perspective to show the areas where it would be suitable to introduce GI for its potential benefits, considering the current presence of GI and intensity of the urban heat island. The GI deficit areas or priority areas for future GI implementation would potentially be those with more people present in outdoor spaces, higher urban heat island intensity, and less existing GI. The following input data were used:

- Number of inhabitants and locations of long-stay and short-term activities;
- Environmental data of the soil sealing and street tree layer;
- Climate-related data on the urban heat island (see Appendix A for details).

In line with the above-described methods, the planning and governance framework was analysed to gain insights into the associated practices for vertical green implementation in Austria (Vienna), Germany (Berlin), Slovenia (Ljubljana), and Taiwan (Taipei), which are all involved in the project. A common framework for analysis was established, with several sets of questions related to the inclusion of VG content in the established forms of formal and informal planning, legislation, and governance. A comparative overview of different planning and governance approaches at the national, city, and local levels were obtained for all four cases. In accordance with the article's goal, only the results for Ljubljana are indicated here. The analysis was performed in September and October 2021. The survey (see Appendix B for a summary) addressed how VG is included in the statutory, formal, and legally binding strategy, implementation, and planning practices at the national, regional, and city/local levels. The survey also investigated whether and how VG is included in informal, non-statutory planning at the city and local levels (which is supported by city or state administrations or other stakeholders but is not officially biding). Furthermore, the survey helped identify the international guidelines and documents that are considered in the planning and legislation systems of different countries and cities as well as determine whether vertical greening is already addressed as a nature-based solution in various national documents and legislative acts. This planning and governance framework analysis proved to be a substantial part of the methodology, as legislation, planning issues, and stakeholders' roles, involvement, and opinions were defined as key factors of urban governance related to VG.

3. Results

The sequence of qualitative methods used in this research was important for the overall coverage of diverse information gained from stakeholders, literature and documents, fieldwork, and GIS analysis (see Table 1). The broad spectrum of information and knowledge gained allowed for a comprehensive overview of the state of the art and future possibilities for VG in Ljubljana and also a better understanding of the support and process necessary for VG implementation in general. The following four subsections present the results according to the primary source of information.

Table 1. Methods applied, purposes, and outcomes.

Method Applied	Goal/Purpose	Outcomes
Semi-structured interviews	- Attitude/acceptance towards VG in general - Knowledge of and attitude towards the implementation of VG in the city - Key stakeholders for implementation of VG	Elaboration of (personal) viewpoints of city administration; main concerns regarding implementation; most acceptable locations for implementation; and key stakeholders/departments to promote the implementation of VG. Developing a suitable approach and raising awareness and interest in the workshop for further cooperation from different municipality stakeholders.
Stakeholder's workshop	- Presentation of project and results to Ljubljana city administration - Upgrade of insights on VG from the city administration - Co-creation of VG case studies (process mapping) for possible implementation	Elaboration of 15 initiatives for implementing green walls in Ljubljana (5 per group); further development of 3 selected cases (process map, including responsible persons, funding, and timing). Co-creation of the VG implementation process simulation for the city of Ljubljana.
Inventory of implemented green walls	- To analyse the state of VG for Ljubljana (type of VG, location/part of the city, type of the building, contribution to green spaces) as a basis for future monitoring	Elaboration of state of the art of VG for Ljubljana (including an image, description, and spatial representation).
GIS decision support system for new GI development	- To determine the green space and GI deficit areas and priority areas for additional GI implementation, including VG elements) based on human, environmental, and temperature criteria	Map of the GI deficit index for Ljubljana.
Planning and governance framework analysis (survey)	- To gain insights into governance practices and documents to support the implementation and management of vertical greening in the participating cities (relevant information on regional and national level included)	Elaboration of VG-related planning and government practices and legislation at the city level.

3.1. Stakeholders from City Administration: Aspirations and Drawbacks of Vertical Green

The research commenced with an assessment of the aspirations and viewpoints of key city officials in the Ljubljana City Municipality. Municipal officials are part of the public administration and perform administrative and legislative roles. The most competent or relevant municipal officials for implementing spatial development and investments, i.e., chairpersons and representatives of spatial planning, environmental, investment, and other key departments, were included in the research as participants in the interviews and workshop.

Only a few of the interviewed individuals had direct professional experience with the process of green wall implementation (2 of 7). Nevertheless, all but one of the interviewed individuals expressed their enthusiasm for green walls and were keen on exploring the potential of integrating green walls into the urban fabric. They are aware of the benefits of green walls, including the following: reduction in the urban heat island effect, reduction in the number of fine particles, general improvement in air quality, increase in rainwater retention, improvement in noise protection, and contribution to the diversity of green areas in the city. The main concerns related to green walls that were raised in the interviews are the maintenance costs and aesthetic characteristics during the winter months as well as the maintenance requirement (especially watering) during summer. However, most of the opinions and experiences were personal rather than professional. The risk of VG implementation being used by developers to gain permission to increase the density of buildings—i.e., the addition of a green wall could be seen as an opportunity to reduce open green space—was one of the more pronounced professional concerns. Additionally, an aesthetic-related constraint was pointed out, particularly that VG cannot be placed on any façade or in any urban setting without consulting expert architects. High-density urban areas (such as the commercial area of BTC City) have been characterised as most appropriate for implementing green walls. Publicly owned buildings have been identified as most suitable and can set a good example for private investors. Particularly, façades with no windows on lower buildings, such as production halls, gyms, schools, and kindergartens, were identified for didactic and social benefits. The possibility of using a VG structure as a noise barrier in settled areas was also mentioned. Further, areas parallel to the comprehensive (including static) renovation of multiapartment buildings could also be considered for VG implementation.

During the workshop stage of the research, each participant group conducted a case study analysis (see Section 2). The selected case was analysed in terms of the benefits and risks for the initiators and at the city level. Five benefits, five concerns and fears, and the general benefits and risks of the considered green wall were elaborated upon in a group discussion. Each group worked on the selected case by determining the green wall implementation process and defining the actors involved (Who makes the decision for the green wall in general/in the particular scenario? Who else is important in the decision-making process, for example, for giving consent/voting for the green wall?).

The selected cases included the following:

(a) Greening of vertical flat elements of urban structures (constructing side fences, retaining walls and noise barriers);
(b) Renovation of a selected elementary school, including green wall implementation;
(c) Vertical green of the Center for Reuse building.

In the workshop, it was pointed out that more emphasis is required on increasing the stakeholders' capacity, that is, the representatives of various departments of the city administration. The content of the capacity-building process would include benefits, threats, implementation type, and the financial aspects of implementation. The potential involvement of various departments in VG implementation depends on the specific characteristics of the respective project or the type of building and administrative domains. Additionally, more focus should be placed on planning documents and acts that can regulate location selection and VG implementation in the city of Ljubljana.

3.2. State-of-the-Art Vertical Green in the City of Ljubljana

The inventory of implemented green walls during the fieldwork and GIS analysis resulted in a comprehensive database of VG in Ljubljana city for densely populated urban areas (Figure 2). The database includes 710 buildings or other built structures with vertical green units, all of which are described with the following attributes: designed (true/false), density (dense/medium dense/sparse), vegetation type (evergreen/mixed/deciduous), accessible (true/false), texture (uniformed/diverse), state (maintained/neglected), material (34 options, including concrete, troughs, net, wires, wood, plastics, substrate, and net), motive (true/false), spatial representation (2D line), building type according to the European Classification of types of construction [16], offset from the structure, estimated offset from the ground, height of the green wall, surface of the green wall (calculated from the spatial representation width and estimated height; for wall fences with vegetation on both sides, both sides were included in the area calculation), and the dates of the field trip and database object created. The database consists of 380 cases of greened façades and 330 other built structures such as walls (see Table 2). According to the building cadastre, there are 37,102 buildings in the mapped area, of which VG is present on 390 buildings (1.05%). The estimated VG-covered area is 42,636 m^2; buildings account for 56%, and other structures account for 44%.

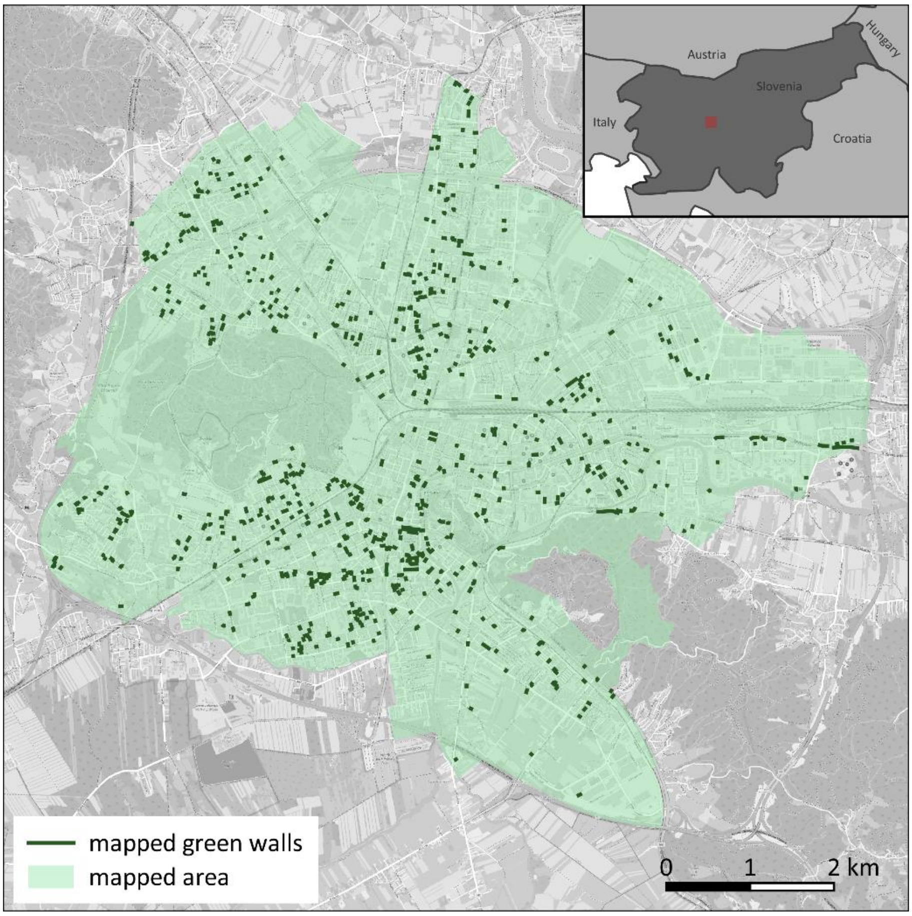

Figure 2. The inventory area for green walls during the fieldwork (author: Simon Koblar, base map [17]).

Table 2. Type of VG in the analysed area.

	All (N = 710)		On Buildings (N = 380)		On Other Built Structures (N = 330)	
Type	**Share of Cases**	**Share of Surface**	**Share of Cases**	**Share of Surface**	**Share of Cases**	**Share of Surface**
Green façade	87.5%	89.0%	78.4%	84.8%	97.9%	94.3%
Living wall	10.4%	9.5%	18.2%	12.8%	1.5%	5.3%
Combination	2.1%	1.5%	3.4%	2.4%	0.6%	0.4%

The attributes of each object in the database were used for further analysis. The area of VG for certain types of land use, for example, showed that most of the green walls can be found in residential areas (65% of all VG; 19.5 m^2/ha), traffic areas (17% of all VG; 12.8 m^2/ha), central areas (10% of all VG; 10.0 m^2/ha), green areas (3% of all VG; 1.0 m^2/ha), commercial areas (2% of all VG; 7.0 m^2/ha), and industrial areas (1% of all VG; 1.9 m^2/ha). From the architectural point of view, an analysis of the VG distribution according to the type of the building and other built structures revealed interesting results (see Figure 3), showing that over 40% of VG cover built walls and fences, 20.4% of VG are located on multi-dwelling buildings, and 16.5% of VG are on single-dwelling buildings; garage buildings, commercial buildings, farm buildings, and restaurant buildings represent up to 5% of VG each (see Figure 4).

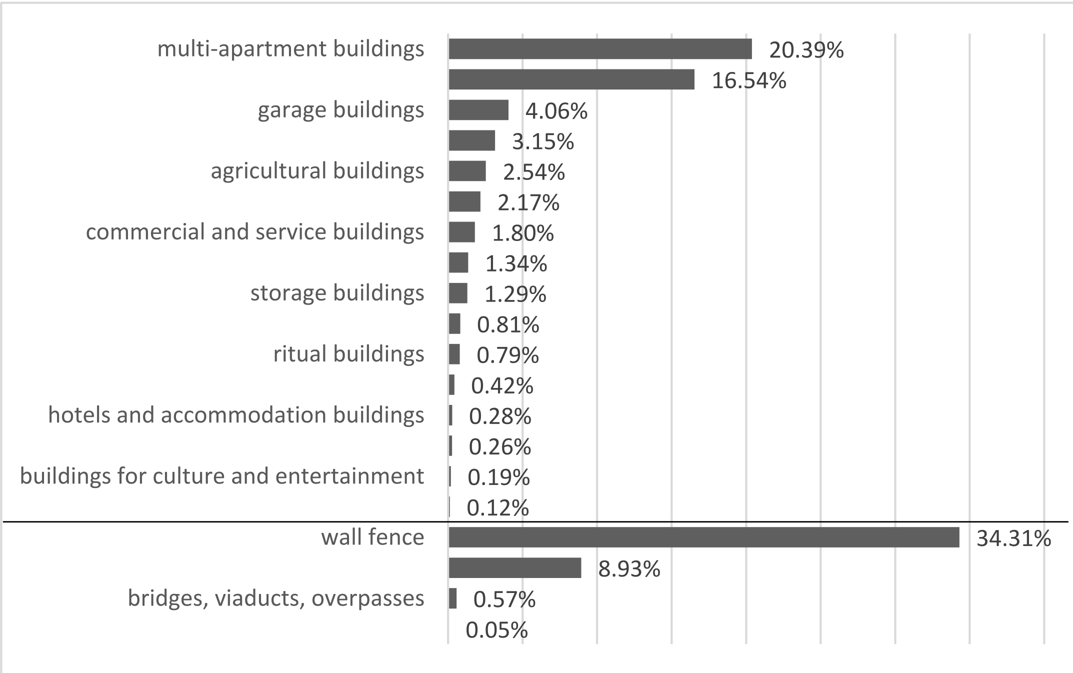

Figure 3. Share of VG surfaces with respect to their occurrence in building or structure type (author: Simon Koblar).

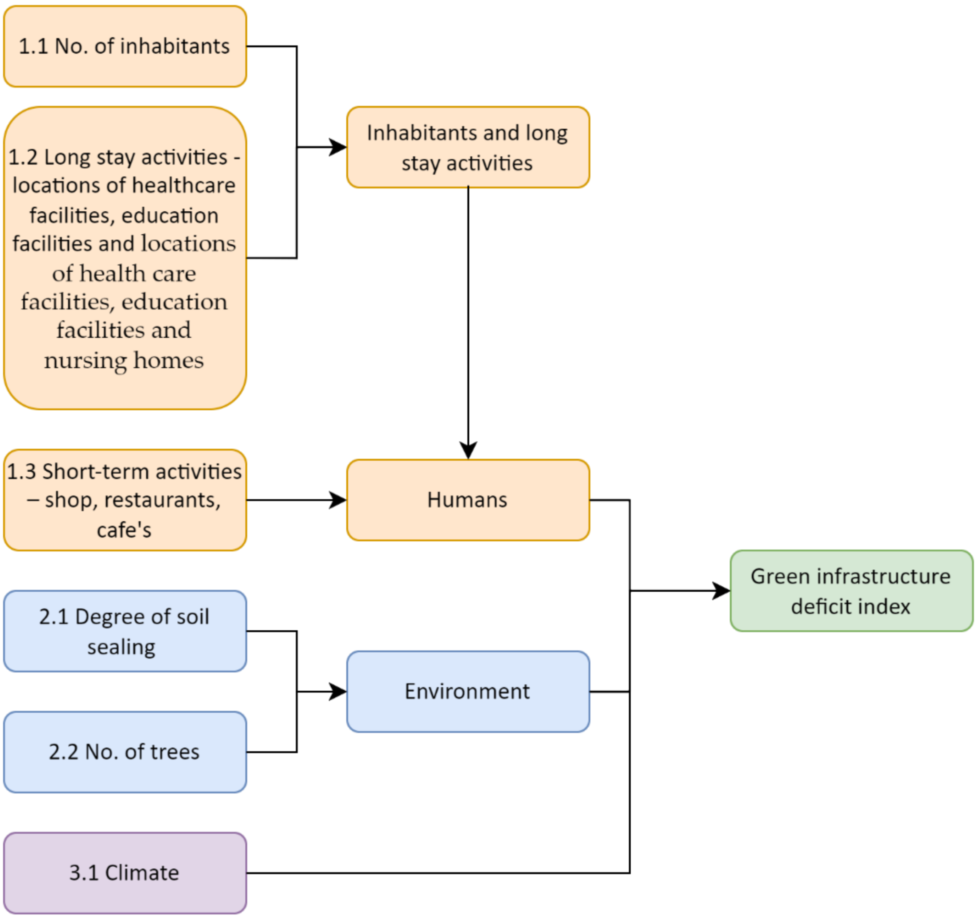

Figure 4. The GI deficit index calculation process (author: Simon Koblar).

The analysis of the type of surrounding space or area adjacent to the green façade is important for understanding the use (or purpose) of this element. Buildings with green façades are mostly oriented towards traffic areas (31.8%), gardens of buildings (26.1%), and inner courtyards (21.3%). A smaller share occurs on façades along pedestrian walkways (7.9%), car parks (7.1%), and parks and squares (5.6%). The VG on retaining walls and similar structures are predominantly oriented towards traffic areas (68.2%) and occurs to a lesser extent along car parks (9.4%) and in inner courtyards (8.2%).

3.3. Potential for New Green Infrastructure in Ljubljana—GIS Decision Support System

The potential for GI interventions in Ljubljana, which includes VG, was determined by considering the development of the GIS decision support system (DSS). It was based on the premise that certain parts of the city have a greater demand for new GI implementation because of environmental and climate factors (such as heat island area and lack of green spaces) and social factors (needs of inhabitants and visitors), and they are also more suitable for the implementation (considering the architecture and city morphology structure). These assumptions were supported by the GIS and available spatial data. The results of the model obtained show the most suitable areas of the city and can be used to prioritise future investments in GI. The type of GI to be implemented is a decision for experts and could be made in cooperation with other stakeholders (owners, tenants, managers, constructors, and the public). The results of the model, namely the priority areas for IG implementation, represent the (1) first step of the decision and should be followed by (2) identifying the constraints for increasing green areas in the actual location, i.e., through an expert evaluation, (3) identifying the potential spaces, buildings, and other structures to be greened as well as the restraints involved, and (4) selecting the priority areas or built structures in cases were VG implementation is appropriate. The limitation of this process is that, while the areas of GI deficits can be mapped to suggest the possible new areas for implementation, DSS cannot determine what kind of green infrastructure elements are appropriate in different areas; this decision requires an expert evaluation and is also conditioned by other decisions related to the development of a particular urban area.

As outlined in the Materials and Methods section, the DSS includes three contextual datasets or categories of indicators: human, ecosystem, and climate. The input data for different measurement scales were normalised with a Z score calculation (see Appendix A); the three indicators were then combined into a single indicator that shows the GI deficit index of the city of Ljubljana. Figure 5 shows the results expressed in standard deviations from the mean value for the whole city. The negative values (in blue) represent areas with low GI deficits compared to Ljubljana's average; this mainly represents greener parts of the city with lower summer temperatures, more existing green infrastructure, and lower population density. Positive values (in red) show areas with higher GI deficits. These are mainly areas with high population density, higher summer temperatures, and fewer existing green areas, i.e., the city centre, commercial and industrial areas, and high-density residential areas.

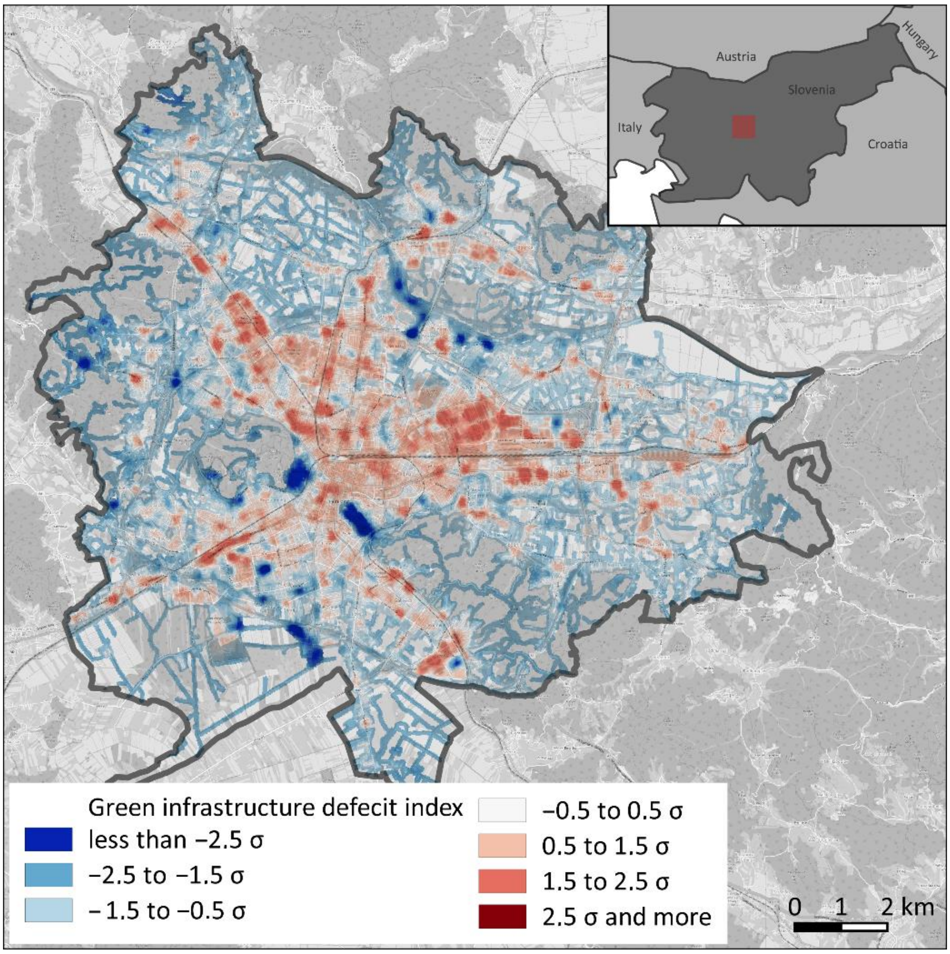

Figure 5. Map of the GI deficit index for Ljubljana (author: Simon Koblar, base map [17]).

3.4. Planning and Governance Framework for Promoting Vertical Green Structures in Principle and in Reality

Consistent with the focus of the article, this subsection presents the results for Ljubljana and Slovenia, with some no Figure examples from other cities mentioned in the discussion. In the case of Slovenia, VG is indirectly mentioned in the Development Strategy of Slovenia 2030 [18] and the Spatial Development Strategy of Slovenia 2050 (draft) [19], particularly in the content that covers green infrastructure, heat island mitigation, and green systems. The city-level strategic documents for Ljubljana mention VG implementation issues related to the objectives in the field of environmental quality that aim to reduce the impact of urbanisation on climate change as well as to adapt to climate change, protect the production potential of the soil, and promote various forms of food production for local self-sufficiency, including production on roofs and terraces [20,21]. In addition, in the strategic and executive section of the Sustainable Urban Development Strategy [22] document, Ljubljana City is committed to improving transport/mobility by developing green infrastructure and "nature-based solutions", as this is a recognised way of improving climate conditions at the regional level. Further, the strategic part of the document defines the following priority objectives: (a) the construction of new green elements (green roofs, walls, living rooms, etc.) in defined green areas by 2016—an objective that is linked to Ljubljana's Green Capital of Europe 2016 initiative; (b) the construction of new green elements (green roofs, walls, living rooms, etc.) in additional defined green areas by 2020; (c) the construction of green areas, tree-lined city avenues, green parking lots, and other elements (green roofs, walls, etc.) by 2050 to help mitigate and adapt to climate change and regulate the urban microclimate to prevent overheating.

In the field of action planning, VG is included as a type of green space in the national guideline Green Systems in Cities and Settlements: Directing the Development of Green Areas, which is part of the National Spatial Order and, as such, the official guiding document for Slovenian municipalities. Recently, the Slovenian Ministry for Environment and Spatial Planning also published recommendations for greening roofs and vertical surfaces [23].

As for the public administration support for VG in Ljubljana, there are no notable examples of projects that support green walls, but there have been some successful initiatives and projects for green roofs. However, the interviews with municipal officers from several departments in the Ljubljana City Municipality revealed that they support and encourage VG implementation if there is any kind of initiative taken by investors, and public–private partnerships are the most promising form of cooperation. Schools, retirement homes, and other public buildings are considered most appropriate for the implementation of publicly funded VG. However, no formal cooperation (calls, programmes, etc.) or funding is currently provided by the public administration. A detailed examination of the public administration support at the city level revealed the following:

- The responsibilities for VG implementation are not clearly defined.
- There are no procurement methods for VG implementation.
- VG management is not a part of regular public urban management.

4. Discussion

Vertical greenery systems alongside green roof systems are widely recognised as elements of green infrastructure (GI) that could become a "new sustainable approach towards climate change" [8] in cities. The concept of green infrastructure has been promoted alongside nature-based solutions and ecosystem services in recent years, all of which emphasise the importance of natural elements for attaining urban sustainability. Despite their recognition as emerging, innovative, and complementary approaches, all of them share a degree of ambiguity or even knowledge gaps in the closely linked diverse circles (science, policy, and planning), disciplines, and interested actors. In practice, they often overlap with other already established and regularly used approaches to green space or landscape planning in urban and non-urban environments [14,24], which pursue the same or similar goals of ensuring conditions for sustainable development, climate resilience [25,26] and quality of life and environment.

GI has been adapted and defined in European policies as a "strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" [5]. For a narrower focus of urban areas, that are considered the most anthropogenic from an ecosystem perspective [27], ecosystem services are provided within urban green spaces, such as parks, urban forests, river canals, and other water bodies, as well as green roofs and green walls, which are the elements for transforming cities into more sustainable and adaptive systems [28]. Being vertical, VG has some serious limitations for providing certain functions and benefits, especially those related to active use and accessibility. When deciding about measures, it is very important to take into consideration that VG is not a comprehensive solution that could replace other urban green spaces, especially those with prevailing social functions related to their public accessibility. Representatives of some municipal services and departments at the Ljubljana workshop also expressed the concern that the use of the VG as a measure for quality of environment could be abused by developers to gain permission to increase the density of buildings; the construction of green walls could be seen as an opportunity to reduce open green areas.

It is important to point out that the GI approach is still lacking practical and effective planning and design tools to suitably address development on a city and local level. For the comprehensive planning of urban green areas, clearly defining all types of green spaces and water bodies that are relevant in the planned area of a city is important for enabling the transfer of strategic decisions, solutions, and implementation guidelines through national and regional to municipal spatial plans. At the same time, such a typology lays the foundation for the analysis of the various roles of green areas and the determination of needs, potential, goals, and guidelines for improvement. Furthermore, the dual character of VG structures and green roofs which refers to the fact that they are both a type of green spaces and parts of the buildings or built structures opens additional challenges that need to be addressed, as these types of green spaces require different planning and governance approaches than conventional green areas do. This should be taken into consideration at all steps and stages of the development process, including initiating, decision-making, evaluating, planning, designing, financing, implementing, and managing.

The research design and its findings can assist the experts and practitioners with a comprehensive overview on the VGS thematic in a certain city, drawing attention to the missing links for reaching a well-grounded implementation based on expressed needs, adapted to architectural and urban conditions, established sets of priority sites, and the legislative and public authorities' framework and support. The presented outcomes bring initiative for further in-depth and on-site research and co-creation process leading to actual implementation.

The presented case of the city of Ljubljana is a good example that simply adopting new approaches at the declarative, strategic level, whether at the national or city level, is not enough to transfer new approaches such as VG into practice. The outcomes from surveys, as well as interviews and workshops, point out that more attention needs to be paid in the future to the transition from strategic to implementation level and to the development of evaluation tools to effectively address the city and local level problems.

The survey on the planning and governance framework indicated differences between the three capital cities Berlin, Vienna, and Ljubljana in not only the system but also in practice. From the review of the situation in all three cities, we could conclude that better VG involvement in legislation and planning is one of the important prerequisites for more effective implementation of VG at the city level. It is also necessary to consider the big differences between cities in size, character, and urban development which also affect the extent of VG implemented in each city (both of traditional green façades and contemporary living walls). The analysis of the GI deficit that was conducted for all three cities shows that each city needs additional green spaces or GI elements to improve the environmental and living quality in certain areas, regardless of the statistical data, on the average provision of green space per inhabitant in the city. Further, a more detailed analysis for other cities would be needed to define if there is a comparative typology of areas with the GI deficit. However, a quick glance at the city maps reveals that such an outcome could be expected. There are areas of densely build residential neighbourhoods, industrial or commercial zones but also street corridors and crossings that generally lack environmental and visual quality and are often exposed to heat island impacts. In such cases, VG could be an effective measure for comprehensive improvement. To support this assumption, high-density urban areas have been characterised as most appropriate for green wall implementation also by participants of the Ljubljana workshop. Furthermore, they identified publicly owned buildings as the most suitable for VG implementation due to the less complicated ownership issues and financing possibilities but also the possible multifunctionality of benefits. For example, gyms, schools, and kindergartens were identified as suitable for micro-climatic indoor and outdoor performance but also for didactic benefits.

From the point of view of comprehensive and sustainable urban development, it is necessary to identify areas where the implementation of VG is a priority measure to achieve benefits for the city and the local environment. Only in this way is it possible to effectively direct efforts, prepare appropriate guidelines and forms of support from the city administration. From the practice, we can observe that individual investors decide to implement VG mainly because of personal preferences or desire for promotion, and not for ensuring the equal quality of living and natural urban environment to all citizens. Thus, it is not realistic to expect that the implementation of the VG for the general improvement at the local or city level will take place spontaneously or from the bottom up. Therefore, the city must identify areas and/or cases where the implementation of the VG is of public interest (priority areas for the VG) and include them into all levels of spatial planning documents including guidelines and actions for supporting public and private investors.

From the point of view of spatial potential, the results of the inventory of existing green walls and the spatial decision support system presented in this article are valuable contributions to the development of priority areas for VG implementation in Ljubljana, as they represent the basis for further analysis and planning. There are clear implications that some areas of Ljubljana need more GI elements, green spaces or other interventions such as vertical greening and green roofs. Based on defined areas of GI deficit on the city level, more building type focused examination and on-site analysis can establish which type of GI provision is suitable and possible to be implemented, where the possibility to design an ordinary green space is limited and where VG is recommended particularly as the most suitable solution. The DSS model can also represent a basis for experts to monitor the green system plan or GI of the city. By combining different types of analysis at the city level and on detailed urban scales, the potential for different GI types can be further evaluated. The GIS data allow for mapping the different types of GI based on land use, but as the planning tool for analysis, it cannot determine which GI elements are the most appropriate for a particular site (e.g., parks, avenues, vertical green, green roofs). The limitations of GIS as a tool as well as its accuracy and applicability to scale must be considered. Therefore, detailed urban design aspects, such as the type of GI, must be determined with the use of more precise data at a later stage, following a local context evaluation and other expert analyses.

To implement NBS projects, specifically VG in cities, and to integrate participation processes with urban planning, it is important to understand the needs and expectations of decision-makers and key stakeholders regarding VG on a local level. It is essential to determine which benefits are perceived as most important and which perceived risks or drawbacks prevent VG implementation. Based on the results of the interviews and stakeholder workshop, the main perceived benefits are environmental benefits (air quality improvement, noise protection, urban heat island effect mitigation, and water runoff mitigation) and social benefits (improved social interactions, learning, and improved aesthetics; however, the individual interviewees had contradicting opinions). Surprisingly, economic factors seem less important as a benefit and are generally seen as a drawback due to the high costs of VG implementation and maintenance. It was not considered that the different VG systems differ greatly in terms of both cost and complexity. As mentioned above, aesthetics in winter months and the unsuitability of a certain architecture type or city area (the old town was mentioned several times) are seen as limitations to the implementation as well.

The city administration or municipal government is the most visible actor in urban governance. Their most important task is to carry out the necessary communication, inclusion, and cooperation activities with all other stakeholders, such as inhabitants, private owners, businesses, NGOs, research and planning agencies, and public actors that may have a strong influence on urban development. However, in the case of cities such as Ljubljana, which do not have a developed VG practice, it is necessary to consider when involving representatives of the city administration that they might have no professional experience with the topic and their opinion given as stakeholders may be personal only.

Governance depends not only on political, economic, and planning systems and legislation but also on government institutions' knowledge and capacity to recognise, make decisions, and support new urban development concepts. Furthermore, governance can be influenced by the personal and professional values, attitudes, and motivations of the key stakeholders. The survey included mentions VG in statutory (strategic and implementation), formal, and legally binding documents as well as planning practices at the national and local/city level. In strategic documents, VG is mostly mentioned indirectly in recognition of GI's importance. Similarly, VG implementation at the city level is part of the vision and goals of the respective development plans of all participating European cities. From the survey answers, we can conclude that VG is particularly related to climate problems. However, VG guidelines are prepared as part of city development plans (as part of the climate regulation measures) only in Vienna and Berlin. The Ljubljana strategic document [20,21] mentions the goal of constructing new green elements (green roofs, walls, living rooms, etc.) by 2020 and 2050 in defined areas. The areas, however, are not defined on any map. For the design and implementation documents Ljubljana lacs compared to Vienna and its new standard for vertical greening [29], and the Berlin recommendations and guidelines for VG design, implementation and maintenance are part of the Climate Model Berlin [30]. As for informal documents, Slovenia recently obtained recommendations for greening roofs and vertical surfaces [23]. However, public administration support programmes and funding schemes, similar to those already in use in Vienna and Berlin [31–33], and the practice of public–private partnerships at the building level for VG implementation are still missing.

Considering all the analysed levels, stakeholders, and spatial, governance, and planning frameworks, gaps were identified and opportunities recognised in accordance with our hypothesis. The knowledge obtained and the approaches considered to present the data to relevant stakeholders at the national and city levels form a promising starting point for future VG implementation in Ljubljana. Taking the neighbouring capitals as examples and implementing the city's own best practices for public buildings can set the stage for further public–private and private-only investments, thereby enhancing the city's green spaces with vertical green.

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Appendix A

Detailed information about the data used in GIS analysis and preparation for further calculations:

1 People

1.1. No. of inhabitants—global human settlement raster layer for 2015 at a resolution of 250 m [34].

1.2. Long-stay activities—locations of healthcare facilities, education facilities, and nursing homes extracted from OpenStreetMap; the extracted features were converted to point data and a heatmap generated using the QGIS 3.16 tool "Heatmap (kernel density estimation)", with a search radius of 200 m, and null values were converted to 0, thus enabling Z score calculation.

1.3. Short-term activities—shops, restaurants, cafes from OpenStreetMap; data processing was the same as for long-stay activities.

2 Environment

2.1. Degree of soil sealing was retrieved from the Imperviousness Density raster layer with 10 m resolution [35].

2.2. Street tree layer—a part of the Urban Atlas was used [36]; areas were converted to points with a density of 10 m, and this point layer was later converted to a heatmap (same as point 1.2).

3 Climate

3.1. Urban heat island raster data for July 2017 for each city were used [37]. We calculated the mean monthly temperature from the layer containing the measurements in 1 h intervals.

The steps for combining the data to calculate the green infrastructure deficit index are shown in Figure 4. Basic input data (1.1, 1.2, 1.3, 2.1., 2.2., 3.1) were first standardised as Z scores. Each connection represents the process of summing the data from the previous step and calculating the Z score of the combined layer. An exception was made for the street tree layer, where the Z score was subtracted from the degree of soil sealing. Positive values in the combined layer "environment" represent areas with more soil sealing and lower tree density. The Z score for climate (UHI value) was directly included as an equivalent part of the calculation.

Appendix B

Vertical Green 2.0, WP6 City level—planning and governance for vertical green implementation.

Analysis of status quo in the case study cities Berlin, Vienna and Ljubljana—Survey—summary for Ljubljana:

PART I PLANNING

A ON A STRATEGIC LEVEL—NATIONAL AND/OR REGIONAL How is a vertical greening aspect FORMALLY included as a topic in your national and regional planning?

- Implementation of VG is a part of the vision and goals of the national strategy.
- Implementation of VG is a part of the vision and goals of the regional strategy.

B ON A STRATEGIC LEVEL—CITY How is a vertical greening aspect FORMALLY included as a topic in your city spatial development plan? Is it part of the STATUTORY planning?

- Implementation of VG is a part of the vision and goals of the city development plan.
- It is included in different topics of the city development plan/it is not a separate topic in the city development plan.
- Areas of planned VG are not presented on a map.
- VG is not a part of the city development plan guidelines.

C ON A DESIGN AND IMPLEMENTATION LEVEL How is a vertical greening aspect FORMALLY included as a topic in your city spatial development plan? Is it part of the STATUTORY planning?

- VG standards are not set on the national, regional, or city level (for design, implementation, maintenance).
- VG recommendations and guidelines are not set on the national, regional, or city level (for design, implementation, maintenance).

D VG AS A PART OF THE NON-STATUTORY PLANNING (NGOs, civil initiatives, project calls, financial support, etc.)

- NGO and civil initiatives in Ljubljana mainly deal with open and green areas (such as parks, open green space in neighbourhoods, streets, pedestrian zones) in a sense of activating and supporting local communities to equip, maintain and use the open areas. No notable examples of projects supporting VG were noticed.

PART II GOVERNANCE

A. VG-RELATED LEGISLATION Is VG included in the legislation?

- No direct mentions; VG is not formally defined as Ecosystem service, NbS or GI, as these terms were not included in legal acts as such; but it is recognised and defined as such by experts and officials. It is expected that with the novelisation of legislation VG is going to be included in the above terms.

B. OTHER VG-RELATED ASPECTS VG is recognised and is lately becoming a more important topic, mainly as part of NBS; graduation and doctoral theses have been accomplished as well as few scientific and professional articles have been published; mainly including ecological, environmental or vegetation aspects. VG is part of the educational curriculum in several secondary schools (horticulture, agronomy) or faculties.

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