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Adapting Street Profile Design by Using Nature-Based Solutions in New Neighbourhoods and the Retrofit of Buildings †

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Abstract: The aim of this paper is to analyse ways to upgrade the existing urban and architectural features in the built environment by incorporating and enhancing the use of nature-based solutions (NbSs) in relation to the city of Bucharest, which lacks green spaces mapping and quality studies and literature. The paper draws a comparison between the design elements used in other cities, namely Lisbon, Vienna and Rome. These are also analysed and compared in relation to the integration in a mixed urban development plan for a research-to-business neighbourhood design competition in Măgurele, situated near Bucharest. A matrix of five criteria is used for the analysis: historical context, urban context, nature versus design, use and climate context. In Lisbon, examples range from new green walls, modern green Mediterranean courtyards, NbS in scaffolding and temporary walls, the placing of Miradores around the city to green-and-healthy marketing tools for restaurants. For Vienna, a street is being remodelled in an innovative way using independent green infrastructure designs in existing retrofitted parking units, hotels and residential constructions. For Bucharest, emergent pop-up, small scale, bottom-up solutions push the city's urban fabric beyond the greyish look of socialist-communist background and eclectic late 19th, early 20th century built heritage. For Măgurele, different versions of a modern neighbourhood and street profile design issues are analysed, using 3D renderings that incorporate NbS at various insertion scales. Existing example cases showcase new dimensions and toolsets of the adaptation of the urban fabric based on a more ecosystem-based approach of architectural-urban research by design, as possible instruments that facilitate a Green Transition in urban settings. Covering more cities in the future would add to the impact and contribution of this study.

Keywords: eco-systemic architecture; urban heat islands; green interfaces; green infrastructure; urban design

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1. Introduction

1.1. Issues

After the second world war, Central and Eastern European cities, in particular capital cities, were subjected to large urban interventions, either as post-war rebuilding endeavours (for the destroyed or damaged building stock, e.g., Austria, Germany, Poland, and Ukraine) or as political statements, replacing bourgeois neighbourhoods or substituting buildings affected by natural hazards (e.g., Romania). Many of these changes took place in historical centres, which displaced both heritage buildings and whole quarters (e.g., Bucharest), as well as their natural surroundings, private and public gardens and street trees, and wild vegetation.

For Bucharest, the massive replacement of the XIXth–early XXth century urban fabric with communist building blocks, corridor streets and administrative mega-palaces, such as The House of the People (now the Parliament), led to a destruction of the traditional continuous vegetation layer for large parts of the city. While new urban parks were set up and young trees lined the new socialist boulevards [1], these reached maturity long after the fall of the regime and very few to no historical trees remained in these areas; the transition period lacked protection against uncontrolled private urban developments. Most significant green areas are the output of XXIst century planting. Another effect was a disruption of the historical natural connectors linking private gardens typical of the older areas. These are in contrast to Lisbon and Rome, which still preserve these connections, or other cities in Europe (Vienna, Paris, etc.) that have urban boulevards acting as arteries still lined with centuries old canopies. Historical green solutions, where they are still in place, highlight the benefits of a more interconnected interface between the buildings and the green network.

1.2. Purpose and Relevance

Local, national governments are putting into place strategies to increase the green spaces to the built environment ratio, as is the case with Bucharest [2]. This is in line with new European policies greening cities and settlements such as the Green Deal, with national Operational Programs and local grants that have been put in place to fund environmental recovery, including the enlargement of existing green areas and the creation of new ones. This topic is also increasingly relevant to the public and as such, part of political candidates' platforms [3].

However, these strategic plans need objective data and reliable background to be efficient. Literature and studies for Bucharest regarding green spaces evolution is scarce. Mapping existing local green spaces, as well as documentation on new solutions (nature-based solutions and types of green infrastructure) and areas to introduce and integrate, connecting them with the larger and existing network, are required in order for more effective urban planning interventions to be made in the future. For Bucharest, there is a need to deliberately and thoughtfully plan and manage these green spaces [4], as the overall development of the country is speared by the growth of its capital city with many new urban areas created from empty lots that increase built density to the detriment of natural space. A census of the current situation, highlighting the opportunities and challenges, is among the first steps in formulating a diagnosis, as a requisite for reaching an appropriate development and interconnection strategy. The design of green areas in relation to existing or future built environments should be based upon solutions that have proven to be effective in similar cities elsewhere. While most case studies analyse a single place, we made a cross-country comparison for several reasons. As climate changes continue to increase, conditions at higher latitudes in Central and Eastern Europe become more comparable to the ones in Southern Europe. In addition, as more new buildings will be constructed in the future, there is an opportunity in analysing how newer parts of these cities have dealt with incorporating forms of NbSs. We also analysed connections between the history (of the architectural elements) of cities and NbSs, resulting in different solutions in historical areas such as Rome, compared to those where innovation is stronger (Lisbon, European Capital of Innovation).

Existing successful case studies, such as the Singapore model [5] in Figure 1, were not taken into consideration, as this can hardly be adapted to European types of climate, as the tropical areas in Singapore lead to a very fast and dense growing vegetation, while in Europe vegetation growth needs more resources and time. There is also an issue of incentive: most European towns are not land confined as the insular state, and green expansion is more a matter of a policy of health improvement. However, the concept of the city as a garden [6] promoted by the Asian site is suitable to all of the case studies selected from Europe.

Figure 1. Singapore, urban green, perspective view with Gardens of the Bay/Botanical Garden in the front, Crăciun, Cerasella (2017).

In this study, the use of traditional and novel NbSs in five cities is analysed and compared using a set of four criteria, as described in the methodology section. Employing NbSs for existing urban settings has been linked to the mitigation of several challenges and opportunities, such as retrofitting existing constructions; including heritage buildings; adapting existing walls, parts of streets or pedestrian walkways with new features; better balancing the nature-to-anthropic ratio and greening neighbourhoods.

1.3. Literature Review

The use of nature-based solutions (NbSs) is now a part of the planning and design of the built and landscaped environment, both at an urban scale and as smaller elements that take part in new individual buildings or retrofits of existing ones (news sites show that this is actually happening [7–9] and the scientific literature supports it [10]). These solutions are used not only for increased resilience [11–14] and sustainability reasons [15], biodiversity conservation and recovery [16,17], or climate change mitigation [18] but also for economical [19–21] and societal benefits [22] as they cover an ever-growing array of topics and policy fields [23]. As NbSs are inspired and supported by nature in its various physical layers, they favour the delivery of a number of ecosystem services [24–27], for example, cultural ecosystem services [28,29]. Supporting policies and research funding in Europe on this subject have also increased in the last two decades and that has allowed more natural features and processes to be adopted as ecosystem-optimising tools for the built environment and man-made landscapes [30]. Also, over the past two decades, many systems have been developed to support the development process of brownfield sites, but existing systems often do not fully understand the complexity of brownfield sites from a sustainable development point [31].

Pilot testing and implementation have suggested that locally adapted, resource-efficient and systemic interventions in both larger and smaller scales are recommended [32–35]. Smaller consecutive ecological interventions (private gardens and exterior green walls) may be connected to each other, to larger green areas (parks) or to vegetation corridors aligned to the streets. This increases the resilience of the local green infrastructure and also fosters growth in biodiverse habitats. These interventions have a lesser impact individually, but can add more ecological value to a built ecosystem when embedded in a bigger ecological framework [23]. In support of this, a rapid visual screening (RVS) analysis for Lindengasse Street in Vienna is exemplified in this article. In the case of Lisbon, pockets of vegetation doubling as panoramic and recreational urban hotspots known as Miradores are scattered around the historical areas within proximity of one another.

One recognized impact that NbSs, especially green infrastructures (GIs) have on cities is decreasing negative effects from urban heat islands (UHI), with their integration understood as an effective climate mitigation strategy leading to a more sustainable development of cities, better ecological ecosystems and increased human well-being [36–40]. A nationally funded research project in Bucharest, REDBHI (2013–2017), also came to similar conclusions [41]. This project aimed to achieve an urban climatic zoning of the Municipality of Bucharest, with an emphasis on the anthropogenic factors that generate the Thermal Island of the Municipality of Bucharest. Additionally, an evaluation of the thermal regime in inhabited spaces, in the absence of equipment/artificial cooling systems–dynamic simulation, on the basis of representative buildings was required. Virtual GIS platform modules were used for climate risk and energy risk forecasting; the elaboration of short, medium and long-term adaptation; the design of technical solutions for the reduction of UHIs for this city; and the elaboration of principles for an urban and architectural strategy with the aim of minimizing or cancelling the climate and energy risks (https://www.uauim.ro/cercetare/redbhi/ accessed on 18 June 2024). Through this project, an analysis of multi-criteria correlations between the UHI and architectural, urban and landscape variables was carried out, rendering buildings observed as both as vulnerable to thermal transfer and as having anthropogenic influence on the urban environment by amplifying the thermal hazards intensity [42].

NbSs emulate or integrate natural functions but they often incorporate technologies or material components that are not biological in origin. That is the case with man-made innovative materials like textile layers used in green covers, supporting vegetation stratification and brownfield recovery, such as the two types of geotextiles, of which some are biodegradable and others are non-biodegradable. The biodegradable geotextiles are good for greening hills [43] and the non-biodegradable geotextiles are good for green walls [44,45], but if nutrients and water are not enough or maintenance is not conducted appropriately, the plants die (as in the case of the Sofitel Hotel in Vienna). This was personally observed in successive visits by the authors, as it will be shown in Section 3.3.

Visual impact NbSs such as green roofs and green walls have become popular architectural design instruments and criteria for residential and governmental buildings have been developed [46]. Green roofs, in which geo-cells can be used aside geotextiles, not only contribute to decreased UHI effects, but also contribute to urban flood mitigation as a result of rainwater retention [47], and have the potential of being private inter-connectors between larger forms of urban (and public) green infrastructure [48]. This role is also taken on by the vertical layer in green walls, which can link street vegetation and biodiversity, via facade-greening strata, to the green roofs of the same or adjoining building [49], which was also exemplified in the Vienna case study and in the 3D study of a proposed development in Măgurele, a Bucharest suburban research area.

Together, biological elements such as grass and flowering plant layers and artificial materials such as the geotextiles mentioned above contribute to the overall sustainability of the urban area [50]. Green walls and other NbSs can also contribute to the increased resilience of envelopments of the buildings through thermal balance and polluting chemicals absorption [45], and can increase the protection of the built heritage in the areas where they are deployed [51], as recent studies have shown improved urban resilience in Central European cities, among them Vienna and Budapest, including their historical neighbourhoods [52,53].

2. Materials and Methods

The choice of case studies: Bucharest is the home city of the authors. In relation to green spaces, as some frame conditions are different in Bucharest and its suburbia, the peripheral town of Magurele has been considered, as it was the site for an international urban development competition, in which the first author participated as a team coordinator. One of the 3D images from the proposal submitted was chosen as a cover for publications promoting the development.

Bucharest is still deficient in regards to green spaces [4]. The Development Strategy of Bucharest 2035 [3] states that there is a need for policies regarding the management and enhancement of "diffused" green space, increasing green surfaces, the quality and diversity of the vegetation, the creation of new parks, gardens and squares, etc. However, successful examples need to be documented from elsewhere, as Bucharest lost part of its traditional diffuse or interlinked vegetation due to socialist replacement policy and the 1977 earthquake, followed by unchecked urban sprawl during 1990–2010. Three other European capital cities, which are considered among the greenest, were chosen to serve as a documentation base.

Rome and Lisbon were chosen in relationship to the older neighbourhoods in Bucharest that were destroyed by communists to be replaced with socialist blocks of flats. These areas were similar to places in the two Southern Europe capitals, spotted with monasteries and villas' interior gardens as diffused green spaces, as well as interwar architecture (Rome). Vienna is similar in climate conditions to Bucharest and is also a study case for the authors for its larger Art Nouveau architecture building stock and green spaces evolution. Vienna promotes itself as the world's greenest city [54] but Lisbon puts NbSs at the front of its urban regeneration planning as a resilience instrument [55], and the green spaces are divided into large and numerous public parks and private green courtyards, which are relevant to Bucharest.

A methodology for documenting examples in the case study cities is proposed, as a base for a decision system for city-scale green interventions. Different approaches are proposed for distinct typologies, grouped into two categories: at garden and at urban level, from micro to mezzo landscapes. These include a variety of methods as described in Figure 2. Both levels involve in-person site experimentation and later, office investigation; this results in data that are visualised and then analysed, identifying challenges and opportunities that lead to decisions for interventions so that the landscape can be experienced by the widest possible public walking through the cities.

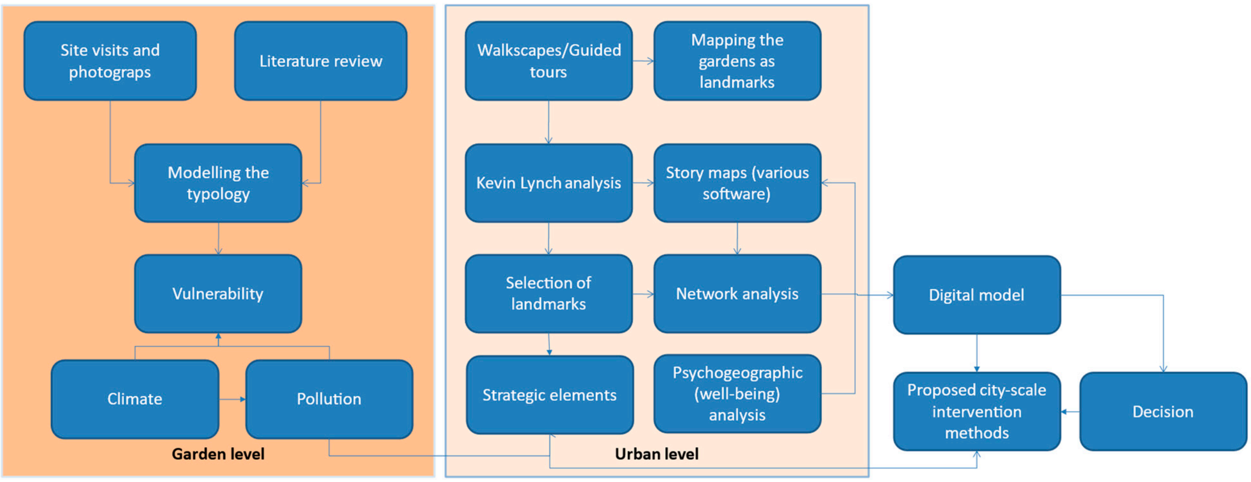


Figure 2. Proposed methodology diagram for a decision system for city-scale green interventions.

2.1. New European Bauhaus

In our project "Future on The Past" we investigate the way in which a global trend, the Interwar style, sometimes referred to as Modernism, has developed various forms known as *other modernisms*, which are local variants in which the local culture from various regions of Europe rendered different solutions and buildings in a diversity of expressions and particularities. In some cases, this local culture and local popular knowledge made them more resilient to natural hazards, for example the local seismic culture.

In the research we are carrying out, we are looking to see if the same situation could apply to resilience to floods or fires, as nowadays these forms of disasters appear more frequently due to climate change. Some answers to climate change and climate adaptation can take the form of nature-based solutions, and thus we reach contemporaneity. The name of the project builds upon the investigation of the built interwar heritage from the past, but it is also about the future, as it aims to point out resistance to ongoing disasters, and the solution proposed is in the present, responding to current, contemporary challenges such as climate change.

In 2020, the European Commission launched the New European Bauhaus (NEB) [56] as a concept within the European Research Area (ERA), on the anniversary of the historic Bauhaus—one of the Modernist/interwar movements. There are three dimensions to the buildings that should carry the NEB flag: to be inclusive, sustainable and beautiful. Accordingly, this is what we look for in the project, starting from the period (and even partially the style) of the original Bauhaus to propose solutions that align with NEB. We are investigating nature-based solutions as we consider they would be in line with the NEB concept. The solution is inclusive because we rely on local culture within a global trend, it is sustainable because it is resilient to disasters and it is aesthetic because it preserves a valuable architectural heritage.

In order to advance research regarding the NEB concept, the commission has established several initiatives and calls for funding. NEB Lab [57] is a supporting, mentoring, communication and co-creation-oriented space for community use. The platform is structured by NEB Lab Projects directed at the creation of enabling factors and instruments for the green transition to flourish (tools, frameworks, policy recommendations), mainly through commission-led initiatives that could lead to regulations, procedures, evaluation frameworks, labelling and the categorization of concrete actions. NEB Lab projects also involve triggering tangible transformation locally and regionally, mainly through NEB community-led projects, which are based on a common characteristic, such as style, region or geography.

Among those initiated by the communities, the most relevant is the NEB Lab "European Triennial of Modernism (ETOM)", essentially an architecture festival linking the historical Bauhaus from the triennial of modernism (Triennale der Moderne [58]) with the challenges of the New European Bauhaus, starting in December 2023 [59], focused on the heritage in Central and Eastern Europe, including Romania.

Two other NEB Lab initiatives, relevant to the countries analysed in this article, also have a regional character: the "NEB goes South Lab" looks at the southern Mediterranean built context in response to increased disasters, including project locations from Portugal and Italy [60] and the "New European Bauhaus on the Danube delves into the Danubian basin as a connecting/connected region" [61].

In other initiatives, "Neb Mountains" [62] focuses on a dominant geographic element, while the NEB Stewardship Lab, with academic entities including ones some from Portugal (Lisbon) and Italy, explores and enhances the role of higher education in the New European Bauhaus (NEB) initiative. Another relevant project, independent of NEB Labs, but within the NEB is the Bauhaus of the Seas Sails NEB Consortium (bauhaus-seas.eu accessed on 18 June 2024), coordinated by an entity from Lisbon.

While there is no financial support from the NEB Lab, since the NEB launch there have been a number of calls for funding to support demonstration projects for NEB principles, such as the call for lighthouse demonstrator projects "Supporting the deployment of lighthouse demonstrators for the New European Bauhaus initiative in the context of the Horizon Europe Missions" (HORIZON-MISS-2021-NEB-01, September 2021), which awarded support for five initiatives (CULTUURCAMPUS, NEB-STAR, NEBourhoods, DESIRE, and EHHUR) and a sixth one, CRAFT, as a resource for the implementation of the five above-named projects and those that will subsequently be financed through the NEB in the future [30].

More recently, the call "Demonstrating the potential of Nature-based Solutions and the New European Bauhaus to contribute to sustainable, inclusive and resilient living spaces and communities" (HORIZON-CL6-2024-BIODIV-02-2-two-stage, deadlines February 2024/September 2024) showcases a more explicit support for research in NbS use within the NEB envisioned future, as one of the objectives of the call was to "deliver visionary and integrated solutions combining nature-based innovation and social, cultural, or digital solution" [63].

2.2. The Oppla.eu Portal

The study also looked at the presence of case studies on the Oppla.eu portal, as a possible indicator of NbS adoption in the cities documented. The platform was created as a combined result of the OPERAs and OpeNESS projects, which were financed through the FP7.ENV.2012.6 competition, a call within the Environment (including Climate Change) 2012 working programme of FP7 and implemented between 2013 and 2017. Oppla was mainly directed at the "exploration of the operational potential of the concepts of ecosystem services and natural capital to systematically inform sustainable land, water and urban management". Since its inception, as a main online thematic repository of the EU, it has come to also reflect the overall state of the use and adoption of nature-based solutions and green infrastructure in the Member States and elsewhere. It harbours an extensive and informative database of case studies, knowledge, event archives, examples, resources and other tools, mostly derived from experimental and demonstrative projects funded throughout Horizon 2020, especially through the H2020-EU.3.5 Societal Challenges—Climate action, Environment, Resource Efficiency and Raw Materials calls.

Since 2015, data from this website has been previously checked by the authors for other research to the extent that it was documented that in June 2018, the keyword "*architecture*" did not return any queries, as it does in 2024. It did, however, present results for keywords such as "*landscape design, cultural ecosystem services, green infrastructure, green space management, habitat banking, heritage (cultural and natural), urban regeneration, urbanisation*" in reference to the connections between natural ecosystems and the built environment [64], and since then, these keywords have generated increased outcomes. In the same manner, location-wise, keywords for *România*, *the Danube Delta* or *the Black Sea* jumped from 0 results in June 2018 to 9 Romanian results in March 2024, out of which 3 are in Bucharest (4 in the metropolitan area). Also, in March 2024, there are 4 case studies for Lisbon (8 for the larger Lisbon Area including the Tejo Estuary), 4 examples for Rome and 1 for Vienna.

2.3. Research by Design

Following two earlier studies, a large roof garden on top of a commercial building in a landscape project implemented in Bucharest and a 3D competition proposal for a business street integrating NbSs, field work was carried out in 2022 and 2023 through site visits in Bucharest, Lisbon and Vienna, for which photography was used as an exploration method, to put in a larger European context the research by design approach. The physical walking tours [65] in these locations resulted in digital story maps.

First drafts were hand-drawn designs. The process continued with 3D models, in several stages, as it will be shown in Sections 3.1.1 and 3.1.2, and were designed in IntelliCAD. The vegetation layers were added in 2D Programs—the first versions in Adobe Photoshop and final output in Corel Draw.

Maps of seasonal flowering vegetation such as magnolias (#HartaMagnoliilor) and wisteria (Harta Glicinelor) have been created and expanded by different users on Google

Maps. A list of protected trees and bushes in Bucharest from 2009 was used to identify the locations of the magnolias and all were used to identify the flower vegetation in our map for Bucharest. The authors are aware of maps of great trees in various European and overseas locations such as the Blue Crow Media maps [66]), or the project at the French Academy in Rome mapping the trees of this city. Five criteria for the analysis and comparison of the green infrastructure observed were selected as investigative research instruments:

1. Historical context: Is the green element a historical green infrastructure (1A) or is it a new one (1B)?
2. Urban context: Is it an individual piece of greenery (2A) or is it part of a green network/a linking corridor (2B)?
3. Nature vs. Design: Is this spontaneous vegetation (3A) or planned vegetation (3B)?
4. Use: Is it already adopted in full-scale use (4A) or is it a part of new NbS demonstrative pilots (4B)?
5. Climate Context: Is the design element specific to a certain climatic zone (5A) or is it able to contribute to climate adaptation and resilience in all climatic zones analysed (5B)?

In the results section there are summarising tables for each of the analysed cities, regarding the green infrastructure status according to the four investigation criteria. In the discussion a summary table presents the overview of the analysis results.

2.4. Climatic Zones

The analysis spans several climatic zones, including oceanic (for Lisbon, which is at the intersection of climate zones), Mediterranean (Rome) and continental (Bucharest; Vienna at the intersection of climate zones) climate zones, with the choice of cities led by aiming for such a geographic spread within the cities known to the authors. This variation in climate conditions translates to variations in temperature averages and the local built environments' responses; vegetation characteristics also differ, as specific vegetation species are influenced by both the local climate, the location itself, its surrounding elements and other existing local environmental factors. For this reason, the hardiness zones for plants from the US Department of Agriculture [67] were used, as these determine how plants, which are relevant for this study on NbSs, can grow in those climate zones. An interactive map of European hardiness zones with examples of suitable plants can be found at [68].

2.4.1. Bucharest

The climate of the city of Bucharest, located in the southeast of Europe, is moderate-continental, with an average annual temperature of 10–11 °C, and the western and southern influences explain the presence of long and warm autumns, mild winter days or early spring days. This moderate-continental climate shows some differences in the air temperature, specific to big cities, caused by the additional heating of the street network, the burning of fuel, the radiation exerted by the walls of the buildings, etc. In general, winters are cold, alternating days without snow or with heavy snow. Due to its altitude and geographical position, there can be harsh winds in the city during the winter, and the temperatures during the winter can reach below 0 °C, sometimes falling below −10 °C. In summer, the average temperature for the months of July and August is 23 °C, although in recent years temperatures have exceeded 40 °C at lunchtime. The average precipitation and humidity during the summer is low, and during the summer and autumn, the temperatures vary between 18 and 22 °C, and the precipitation during this period tends to increase, with more frequent but gentle periods of rain. Against the background of the general climatic variations specific to each region, we can talk about a series of local thermal changes, generated by the structure and functionality of each city, highlighting some differences between the climate specific to the built-up territory and that of its outer areas. Lately, with the climate changes and the appearance of the heat island, there are disturbances and rapid changes in the weather, as well as thermal oscillations. Thus, from the point of view of the

USDA classification regarding the climate zone of plant resistance to cold, Bucharest falls into climate zone 6b.

2.4.2. Lisbon

Due to its geographical location, Lisbon is one of the warmest European capitals, benefiting from a Mediterranean climate with notable subtropical characteristics; due to its proximity to the Atlantic Ocean, as well as to the influences of the Tagus River, it has the warmest winters of all European capitals, with relatively stable temperatures of 15 degrees Celsius during the winter (day) and 8 degrees Celsius during the night. Frost and snow are unheard of in Lisbon, with significant amounts of precipitation during the cold season. On the other hand, summers are hot and dry, with temperatures rising above 30 degrees Celsius. Sea breezes tend to moderate the scorching heat, especially in the evening or at night, and spring and autumn remain the mildest of all seasons, with average temperatures settling around 20 degrees Celsius. Lisbon falls into climate zone 10b, from the point of view of the USDA classification regarding the climate zone of plant resistance to cold.

2.4.3. Vienna

Vienna is located in Central Europe, in a transition from oceanic climate to continental climate and in zone 7 according to the USDA, with minimal temperatures between −17 and −12 degrees Celsius during winter (night and day) regarding the climate zone of plant resistance to cold. In the summer months, Vienna is seeing increasingly long periods without rainfall, with precipitation shifting into the autumn and winter months. Climate change is having measurable consequences in Vienna: between 1961 and 1990 there were an average of 9.6 very hot days per year where maximum temperatures were in excess of 30 °C, whereas in the period from 1990 to 2010 the annual average had already risen to 17. In the period from 2010 to 2018, a maximum temperature of over 30 degrees Celsius was recorded on an average of 27 days per year. The record years in Vienna were 2015 and 2018, each with 42 very hot days.

2.4.4. Rome

Located 30 km east of the shore of the Tyrrhenian Sea, Rome does not have a Mediterranean climate, as one might think at first impression. The climate that Rome enjoys is rather continental, being characterised by all of the typical aspects: cold winters and hot summers, as well as a spring and autumn with average values. Being a highly urbanised locality, Rome has temperatures that tend to go to extremes, especially during the summer, and the Mediterranean influences hardly manage to reduce the heat during the day. The humidity is slightly high and there are strictly occasional rains, which remain unpredictable. Temperatures stabilise at an average value of 20 degrees Celsius, and snowfalls in Rome are not frequent, temperatures drop to 3 or 4 degrees Celsius. Rome falls into climate zone 9b, from the point of view of the USDA classification regarding the climate zone of plant resistance to cold.

2.5. Hazards

Hazards generated by climate change include, especially in urban areas, urban heat islands and stronger heat waves with increased frequency, higher daytime temperatures and lower night-time cooling, which in turn lead to more energy consumption for artificial ventilation [69,70] and higher air-pollution levels [71,72] and elevated greenhouse gas emissions [73] from buildings and vehicle air conditioning; this spirals into health-related dangers for citizens, including heart, circulatory, respiratory and skin conditions such as heat-related deaths and heat-related illnesses, general discomfort, respiratory difficulties, heat cramps, heat exhaustion, non-fatal heat stroke and dermatologically related inflammations. Other impacts include rises in earth temperature and aquatic systems, increased water use and impacts on flora and fauna with biodiversity chain effects leading to new cycles of secondary and tertiary impacts on local and regional life, weather and climate.

The introduction of NbSs, an increase in their use and policy-driven integration in the built environment of such solutions can contribute to the mitigation of heat waves and air pollution, and thus lower their impact on human health. Heavy rains, droughts, hurricanes, river floods and coastal floods and wildfires are also significant hazards that occur with climate change.

2.6. Air Pollution

Bucharest, as mentioned, is low in green spaces and air pollution levels are higher, affecting well-being and leading to health issues. For this reason, we studied the literature on air pollution levels in the EU [74] and in Bucharest and Măgurele [75] and put them in Table 1, in relation to the previously described temperature data, as there is a bi-directional relationship since both temperature and pollution values affect plant development, but also the presence of plants influences temperature and environmental pollution.

Table 1. Overview of temperatures and air pollution values in the case study cities.

City	Temperature °C Min Winter, Max Summer	Air Pollution—2023 Average Fine Particulate Matter (PM2.5) Concentrations in Capital Cities in Europe in *Micrograms per Cubic Meter of Air* µg/m^3 (UE Ranking)
Bucharest	Average 11 °C −10 °C min winter, +40 °C max summer	Average 15.8 µg/m^3 (56 EU)
Lisbon	Average 20 °C −8 °C min winter, +30 °C max summer	Average 17.6 µg/m^3 (98 EU)
Vienna	Average 10–11 °C −1 °C min winter, +27 °C max summer	Average 9.1 µg/m^3 (91 EU)
Rome	Average 20 °C −4 °C min winter, +40 °C max summer	Average 13.1 µg/m^3 (69 EU)
Măgurele	Average 19 °C −10 °C min winter, +40 °C max summer	Average 8 µg/m^3

3. Results

3.1. Bucharest

Investigation in Bucharest led to an overall assessment of the NbS adoption level in this city. Existing green infrastructure is both by design and spontaneous. The first type is based on parks and vegetation corridors along streets, including green pockets adjacent to these, and also along two main blue infrastructures designed in the 1970s. Vegetation lining classical corridor communist streets has doubled on some boulevards in recent years, to address traffic pollution and UHI. The spontaneous vegetation refers mainly to private gardens, climbing plants on old buildings, green fields in abandoned places and the Văcărești Nature Park Reserve, referred to locally as Văcărești Delta [76], formed in the space of a silted reservoir. New forms of greenery like green roofs and green walls (mapped in Figure 3) have been integrated into recently built constructions, both private and public ones.

Previous thematic research for a Bucharest site was carried out by experts during the ECLAS/the Le Notre Forum in 2015. The European Council of Landscape Architecture Schools (ECLAS) is an association that promotes academic development and collaboration in the field of landscape architecture teaching and research. As a spin-off of ECLAS, Le Notre Institute organizes a meeting annually—Le Notre Forum—in which invited international scholars and experts debate on various topics related to the specific site the events take place in, and try to propose solutions to a local problem. The Le Notre Forums were initially focused on four pillars: heritage and identity, sustainable tourism (strategies for landscape regeneration), rural and suburbs (urban and peri-urban landscapes).

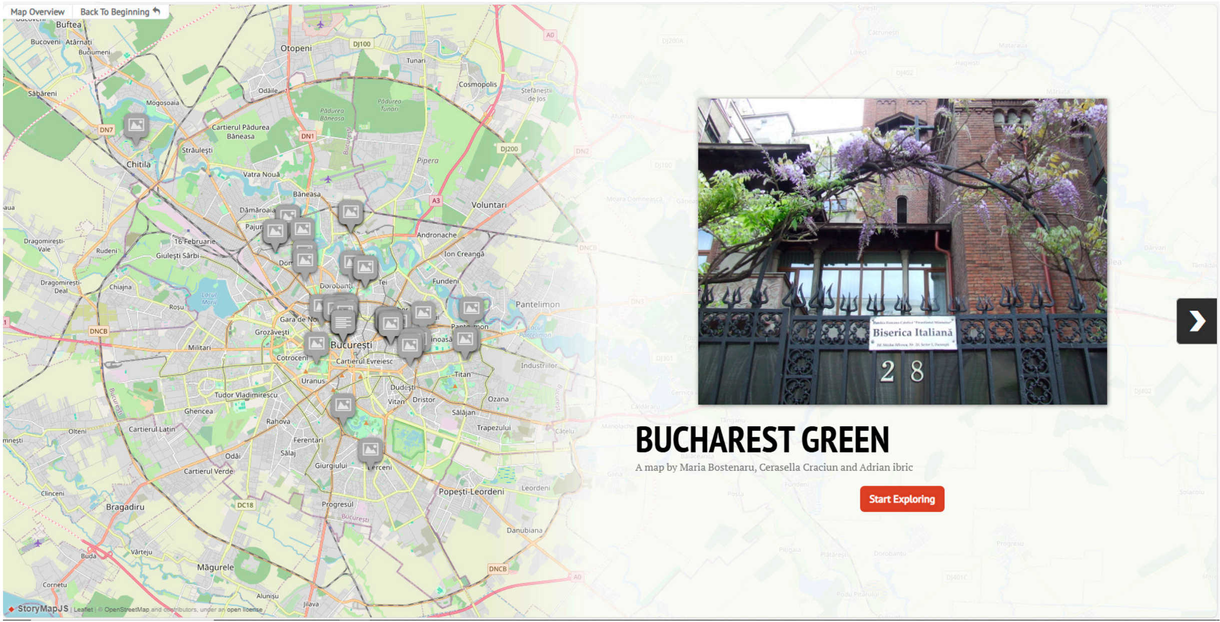


Figure 3. Bucharest. The interactive map, author M. Bostenaru, is available at https://uploads.knightlab.com/storymapjs/49284be7dd69a3ff5cff0e7d6a768b51/bucharest-green/index.html (accessed on 18 June 2024).

The 2015 Le Notre Bucharest Forum focused on the area of the Colentina lakes chain (Emerald necklace) [77]. Bucharest is crossed by two rivers, Dâmbovița and Colentina, which have suffered heavy systematisation during the communist period but are now going through partial states of the restoration of ecosystems, mostly spontaneous and due to neglect. Of the two, the Colentina river also creates a significant landscape, which, like the Văcărești Delta, is a case study available on Oppla [78], and the protection of this site is an ongoing discussion in Romania [79].

3.1.1. Design Solution in Bucharest

An example is the large-scale green roof on top of a new mall (Figure 4), a garden landscape project design by Cerasella Crăciun, a co-author of this article. The ARCHETYPAL COSMIC GARDEN—"TowerScape/LandScape"—Promenada Mall Garden Landscape Project [80] is a modern interpretation of the paradise garden. Transdisciplinary research stayed at the basis of this project. This project is located on the terrace of a mall, next to several towers including the highest tower in Romania, in the northern business part of Bucharest, and as such is highly visible from above. Because of this high visibility, a more powerful creative visual concept had to be employed. The juxtaposition of opposite layers emerged as a good option for the concept. One layer is the organic one, which uses natural materials and is plant based. The second layer is the mineral one, with natural and composite stone elements bringing a contrast to the composition of the landscape design. Being located in a dense area, it has a therapeutic function, both physical and psychological. As a paradise garden, the concept is based on the sacred garden archetype. This means both the contemplative and astronomical dimension and is translated into green waves, helped by water, sound and light shows (Figure 4a) and the choice of plants, designed specifically for the different seasons. Four sub-areas, according to the cardinal points, from mound to hill, build a specific Romanian landscape. Technically being a green roof garden, large geocells were used. The lighting system (Figure 4b) is according to a spatial calligraphy composition of Japanese inspiration, and takes on the ambient as a "rain of light" for the nocturnal lighting of tall buildings located in the immediate vicinity.

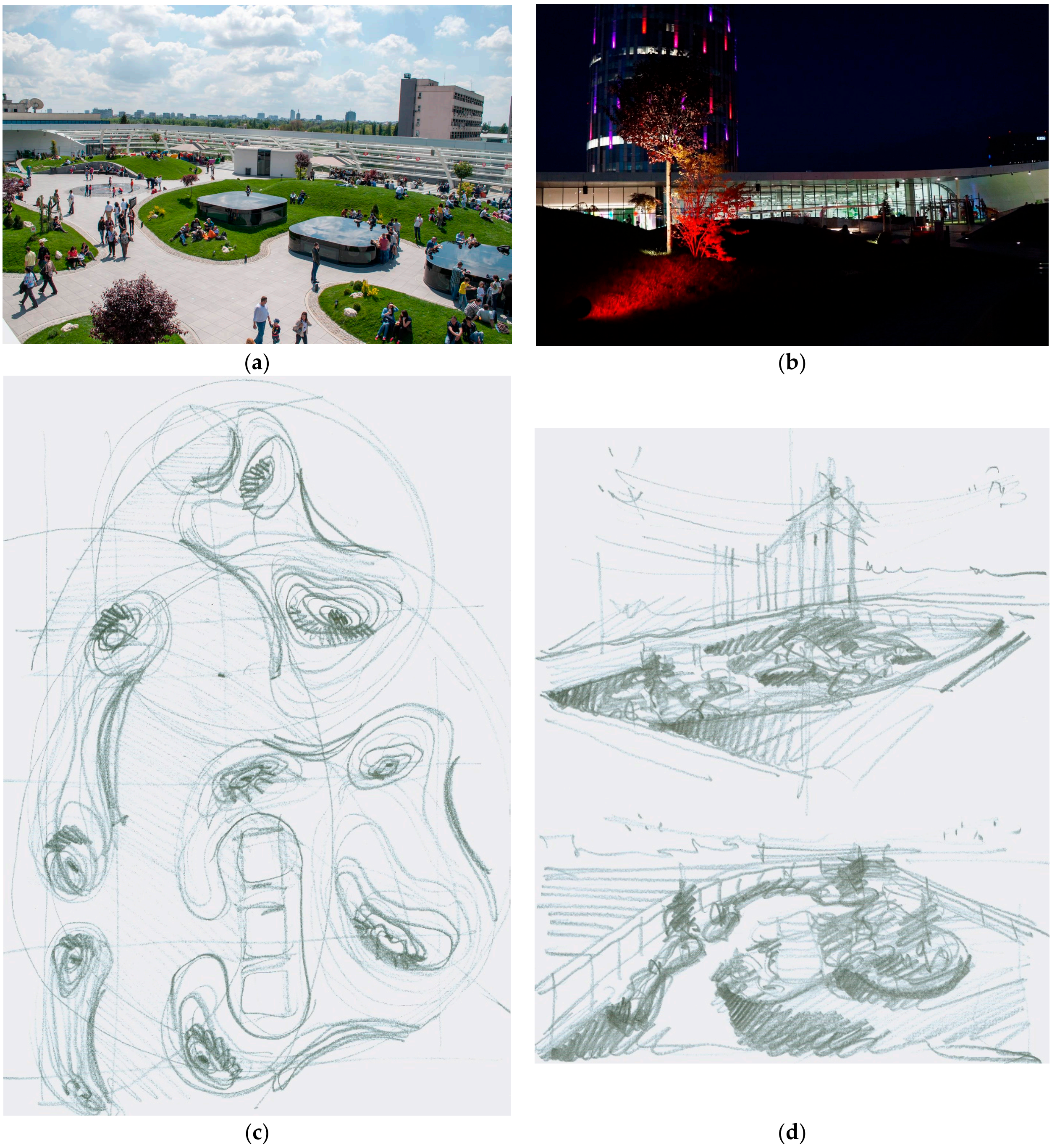


Figure 4. The ARCHETYPAL COSMIC GARDEN—"TowerScape/LandScape"—Promenada Mall Garden Landscape Project in Bucharest. Design: C. Craciun. Photos: (**a**) R. Marincoi and (**b**) A. Opris, 2014. (**c**,**d**) Hand sketches by C. Craciun.

Table 2 summarises the analysis of NbSs mapped in Bucharest.

Table 2. Bucharest overview.

NbS Analysed	Historical Context	Urban Context	Nature vs. Design	Use	Climate Context
Green walls (including demonstrations at fairs and on campus, in pots)	1B	2A	3B	4B	5B
Climbing green plants (on historic houses/interwar houses in Mediterranean style and fences)	1A	2A	3A	4A	5B
Magnolia trees	1A	2A	3A	4A	5B
Cherry trees, in one botanical garden; in the other, an Italian garden	1A	2B	3B	4A	5B
Gardens of individual houses	1A	2A	3A	4A	5B
Climbing flowers (glycine)	1A	2A	3A	4A	5B
Lotus on lakes	1A	2B	3B	4A	5B
Green roof	1B	2A	3B	4B	5B
Lichen	1B	2A	3B	4B	5B
Parks featuring fruit trees	1A	2B	3B	4A	5B
Flower tree street instead of green street	1A	2B	3B	4A	5B
Cemeteries	1A	2B	3B	4A	5B
Bucharest overview	9x1A vs. 3x1B	7x2A vs. 5x2B	4x3A vs. 8x3B	9x4A vs. 3x4B	0x5A vs. 12x5B

3.1.2. Design Solution in Măgurele

In Măgurele, an academic satellite town part of Bucharest suburbia, the international design competition "Laser Valley—Land of Lights" took place in 2016. It was organised by IMUAUP and the Ministry of Research and intended to build upon the momentum around the new European research facilities built with financial support from Horizon 2020 (ELI-NP laser infrastructures). The design scale was left to the choice of the candidates, ranging from small buildings, residential or public, to urban areas, to large territorial developments. The first author led a private architectural practice team entry that focused on two future scenarios in 2035—one for a new business area and one for a new research centre. A publication promoting the results of the contest [81] was fronted by a 3D rendering of the proposed competition entry from the first author, referring to the development of a new main business street headquartering companies involved in the local laser industry (Figure 5). This illustrates five stages of design, from a first proposal of a classical corridor street type (top left) to one with a height variation in the buildings and openings cut to address urban heat island effects (top right, middle left) to greening envelopes for buildings (middle right) to a final proposal with increased NbS usage (bottom).

NbSs and GI proposed to be integrated in the design of the new axis included five types of greenery: both classic greenery at street level, for collecting and filtering rain-water with phyto-purification systems, with low and high vegetation for shading the pedestrian/cycling paths, but also greenery for the facades, in the form of vertical living walls; high-rise green islands and gardens inserted in the subtracted empty volumes in the middle of the buildings; and roofs with grassy terraces and parks, urban agriculture rooftop gardens, and even larger tree vegetation at the upper registers, following a biophilic scenario of city amplification.

Research by design is a standard approach employed in architectural design and urban planning; newer methods like biophilia and biomimicry add to this research process the inclusion of biology and nature principles (Janine Benyus, Michael Pawlyn, Neri Oxman). The increased use of NbSs in architecture and urbanism is due to the values that nature-inspired design brings to planning (resiliency, a more efficient use of resources, circularity, ecosystems services, etc.).

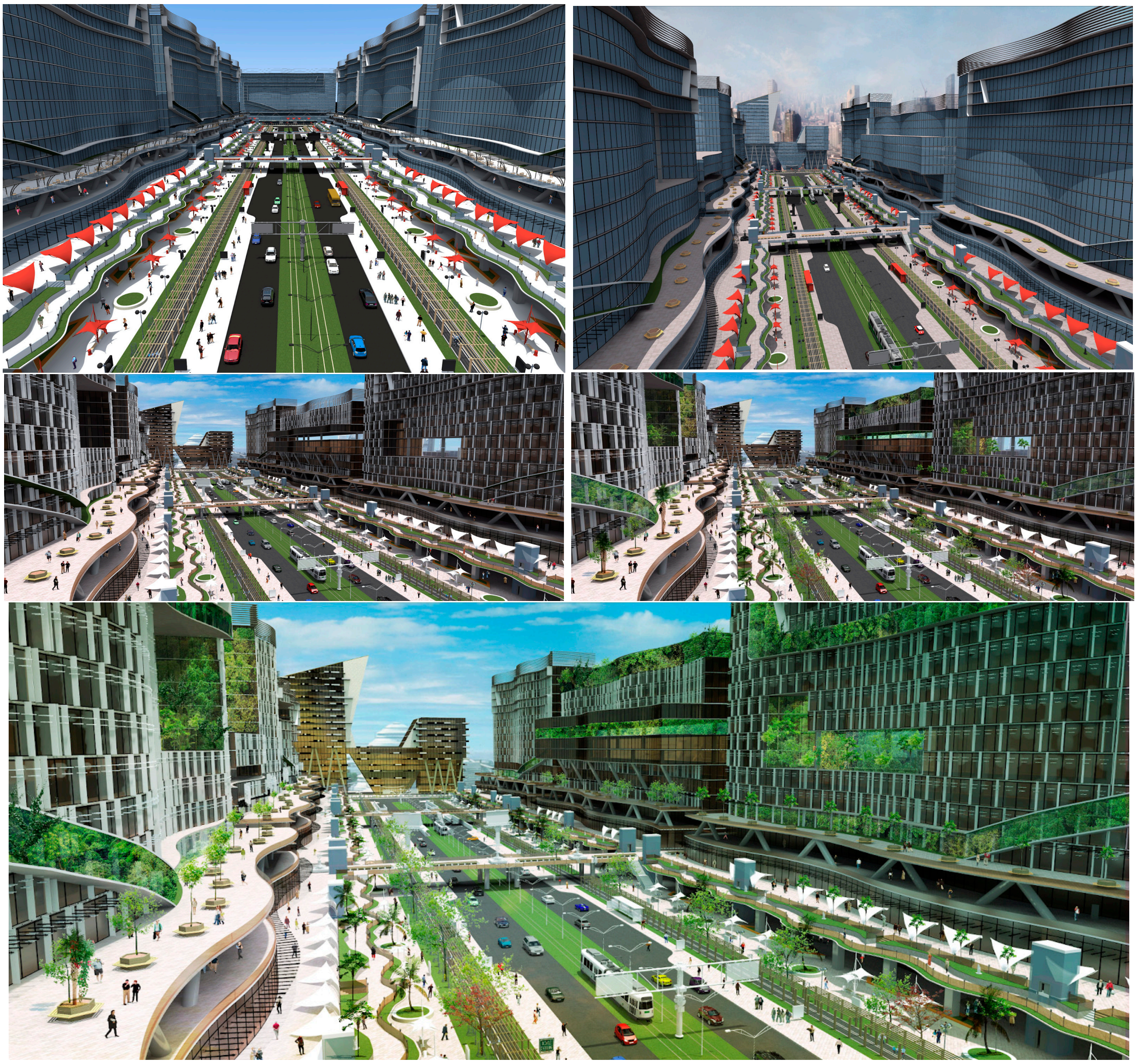


Figure 5. Măgurele Business Street, proposed development for 2035, Land of Lights Competition (2016), 3D renderings, A. Ibric.

Therefore, the proposal in Măgurele had an important component in the integration of nature in the architectural elements. We proposed five types of major green infrastructure. These include classic solutions, at street level, for collecting and filtering rainwater with phyto-purification systems, and with low and high for shading the pedestrian/cycling path. We also propose newer solutions for facades: vertical living walls, green islands and parks at height in the voids and gaps of the volumes and roofs like grassy terraces, parks and even tree vegetation at the upper registers, respectively. In an evolved scenario of public preference for biophilic growth, this should be reflected by regulations in local urban planning regulations in the future to avoid urban corridors, overcrowding, heating, air pollution and the monotony of streetscapes by extruding urban gardens at different levels of buildings, giving a sense of freedom and partying in nature, in the heart of the city, in a symbiotic relationship between green space and urban. Both empty and built spaces are expensive and should always be used to the maximum, so let us turn the empty spaces into green areas, and we can change the built spaces into interfaces with new technology.

Also, the gaps on the ground floor and in the volumes help with a better natural ventilation of the constructions, and in conjunction with the cooling of the surrounding air generated by the abundance of vegetation, "The upper floors should contain either gardens or larger terraces, withdrawn in steps to take advantage of the natural solar lighting; green roofs, urban gardens and/or parks or technological roofs (energy production) should be mandatory, regulated by local regulations, as is already the case in some European capitals" (competition memo). In the basement, we also proposed hydroponic urban agriculture for the efficient use of space, keeping the natural environment and existing ecosystems intact.

These solutions are beneficial for ventilation, energy saving, thermal regulation, microclimate and air and water remediation. The following architectural interfaces are recommended in our research by design proposal—these are multifunctional, green envelopes with digital control, centralized, urban, administrative or individualized, per building/owner, acting as a type of double skin for primary or secondary circulation, or public spaces with vegetation. Table 3 summarises the analysis of NbSs proposed in Măgurele.

Some of the NbSs proposed for Măgurele are already showcased in the five case study cities previously documented. These include solutions already fully adopted, like public parks and urban connectors aligned to boulevards, but also the vertical green walls and green roofs emerging in these cities. Other solutions, such as clear ground floors with partial vegetation, as well as intermediate upper-level gardens, are not represented in any of the documented cities, perhaps due to the heritage fabric of these urban centres. As the proposal deals with an entirely new planned street, Rome is least suited for comparison, although its warm climate might induce clear ground floors for air ventilation. Bucharest and Vienna are more likely to integrate such proposals, as although they are at a higher altitude, and have colder climate conditions, the current linear building stocks favours the formation of urban heat islands, and as such, intermediate upper-level gardens and clear ground floors with vegetation could prove beneficial. Lisbon is most likely to accommodate novel NbSs both for climate and built environment reasons.

3.2. Lisbon

For the Lisbon Case Study (Figure 6), aside from three botanical gardens, smaller green spaces are scattered around the city in pockets of natural local vegetation, either private museum and palace gardens or large Mediterranean pine trees grouped in small numbers that also provide shelter for public spaces. They are multifunctional as they are tourist hot spots—panoramic and recreational places known as Miradores. They surround the historical areas, situated on different levels on the upper sides of the hills of Lisbon, within proximity of one another. At street level there are old landscaped corridors of large local London planetrees, but the Miradores themselves are not yet interlinked due to the lack of horizontal space. Thus, vertical green space could be a solution for connecting the various green spaces in this city.

Table 3. Măgurele overview.

		Historical Context	Urban Context	Nature vs. Design	Use	Climate Context
Proposed NbS or NbS connected to the Magurele project	ROLE IN PROPOSAL	Is the green element a historical green infrastructure (1A) or is it a new one (1B)?	Is it an individual piece of greenery (2A) or is it part of a green network/a linking corridor (2B)?	Is it spontaneous vegetation (3A) or planned vegetation (3B)?	Is it already adopted in full-scale use (4A) or is it a part of new NbS demonstrative pilot (4B)?	Is the design element specific to a certain climatic zone (5A) or is it able to contribute to climate adaptation and resilience in all climatic zones analysed (5B)?
Clear open-air ground level, including partial vegetation along circulation	- Tools for reducing the urban heat island effect with implications for energy savings in operation and comfort in the outdoor space: with better air circulation, better natural ventilation occurs and the street receives even more direct sunlight. Using the same principle, we also propose raising the ground floors, below which a naturally ventilated walking level ventilates bicycle-parking or bicycle exchange services and access to the upper parts of the buildings.	1B	2A/2B	3B	4B	5B
Intermediate upper-level gardens, inside the buildings, both open-air and enclosed gardens, both vertical and horizontal	- For interaction between building users, as a mini vertical park; - For the insertion of sensors for measuring climate indicators; - For phytoremediation for grey water.	1B	2A/2B	3B	4B	5B
Vertical walls including vertical gardens, flowering gardens and urban farming	- For vertical gardens and urban agriculture (vertical farms) as an efficient use of land and for urban beekeeping; - Rainwater collection through facade elements; - The insertion of sensors for measuring climate indicators; - Cascades from the facade to the ground floor with hidden cleaning systems (decanters, filters, sensors).	1B	2A/2B	3B	4B	5B

Table 3. *Cont.*

		Historical Context	Urban Context	Nature vs. Design	Use	Climate Context
Rooftop gardens, green roofs, rooftop farming	- Green roofs and terraces intertwined with solar heating and photovoltaic panels; - The insertion of sensors for measuring climate indicators and vegetation health.	1B	2A/2B	3B	4B	5B
Urban public connectors and parks	- Ground shading; - Decreasing UHI effects; - Rain water retention; - Visual aesthetics; - Mental and physical health.	1A	2A	3B	4A	5B
Măgurele NbSs proposal overview		1x1A vs. 4x1B	1x2A vs. 4x2A/2B	0x3A vs. 5x3B	1x4A vs. 4x4B	0x5A vs. 5x5B

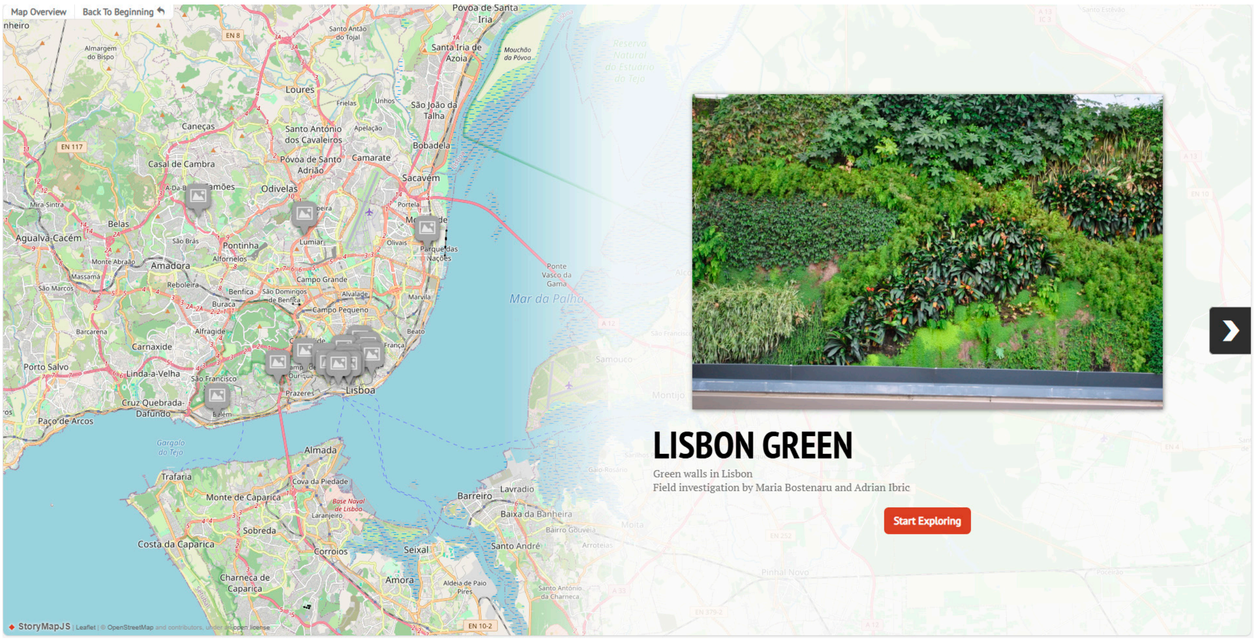


Figure 6. Lisbon. The interactive map, author M. Bostenaru, is available at https://uploads.knightlab.com/storymapjs/49284be7dd69a3ff5cff0e7d6a768b51/lisbon-green/index.html (accessed on 29 March 2024).

The local seismic culture can be an example of how the local culture can result in the resilience of the built environment to disasters, and in this context in 2004 the Istanbul Masterplan was developed featuring a component of resilience to earthquakes [82] and specific risk management outlines in relation to this hazard [83].

Twenty years later, the master plans of Lisbon propose nature-based solutions as methods for flood protection [84]. In this case, sustainable drainage approaches differ from traditional design approaches to manage flooding risks, where runoff is regarded as a nuisance; instead, it would be more appropriate to consider surface water as a valuable resource that should be managed and harvested. The example is also included on the Oppla.eu portal as one of the case studies for this location [55].

Other Oppla.eu case studies for Lisbon refer to the connectivity of green and blue infrastructures in the city [85], its strategy for urban biodiversity [86] and a project on re-naturing urban spaces [87].

Some examples of new green walls are offered by local public buildings, such as the Centro Cultural de Belem, one of the locations for the Lisbon Architecture Triennale. The Belem Center (Figure 7) and the Triennale were visited by the first author in 2022 and by the second author in 2023, as field research for the Future on the Past project, a nationally funded project at IMUAUP, Romania, led by the second author. This site was the subject of Open House Lisboa, operated by the Lisbon Architecture Triennale, “Open House” being a worldwide movement to show the backstage of some buildings that are not usually open to the public. The Triennale, smaller but similar in format and layout to the Venice Biennale, also chose the Centro Cultural de Belem as the theatre for its Cycles exhibition, about the need for circularity in architecture nowadays. The exhibition was on the ground floor, but also accessible from the green roof overlooking the Tejo River that flows into the Atlantic; through the inner courtyard, a lively public space contains two high green walls with flowering plants that regulate the humidity and temperature in the court and provide shelter for local fauna, increasing biodiversity. The Belem area of Lisbon has been enriched with the earthquake museum, one of the few of its kind in the world, but also includes the historical tower of Belem, one of the witnesses of the 1755 earthquake that has been preserved, which is situated in a newly landscaped green area dedicated to the use of the larger crowds visiting. However, the most recent green feature of this neighbourhood is the large-scale green roof and public park on top of the new building of the museum of architecture MAAT, also on the banks of the Tagus River. The vegetation on this pedestrian roof includes high grasses adapted for climate change, resilient to faster winds and high temperature. The infrastructure is automated as the vegetation layer benefits from a controlled watering support system.

Figure 7. Vittorio Gregotti, 1988–1992, The Cultural Center, Belem, Lisbon, Portugal, photos M. Boștenaru, 2023.

Table 4 summarises the analysis of NbSs mapped in Lisbon.

Table 4. Lisbon overview.

NbS Analysed	Historical Context	Urban Context	Nature vs. Design	Use	Climate Context
Green street	1B	2B	3B	4B	5B
Genuine green wall (on geotextile) interior/exterior	1B	2A	3B	4B	5B
Elevated roof garden as half-closed courtyard (on historic building/interwar building)	1B	2A	3B	4B	5B
Green interiors at Honest greens chain	1B	2A	3B	4B	5B
Green fences (pots)	1B	2A	3B	4B	5B
Miradouro	1A	2A	3B	4A	5B
Palace gardens in surrounding localities(Sintra, Mafra, Queluz)	1A	2B	3B	4A	5B
Botanical gardens (>4)	1A	2B	3B	4A	5B
Cemeteries	1A	2B	3B	4A	5B
Lisbon overview	4x1A vs. 5x1B	4x2A vs. 5x2B	0x3A vs. 9x3B	4x4A vs. 5x4B	0x5A vs. 9x5B

3.3. Vienna

In Vienna, climate conditions parallel those in Bucharest (Figure 8). However, NbSs and GI are much more integrated in the planning and redesign of urban areas. The rapid visual screening (RVS) investigation method was used for the analysis of new green infrastructure in Vienna (2022). A route was selected, linking several architectural and street design examples, selected intentionally outside Vienna classical tourist hotspot areas. This route connects at one end the Commercial Center part of Westbahnhof Wien (Figure 9a), in which architects simply placed independent pots with trees at a larger than human scale on each level of the building; these potted trees are low maintenance and flexible in use, reuse, recycle and replacement. At the other end of the walkscape is the Gilbert Hotel (Figure 9b), a new building incorporating a green facade that takes into consideration limiting the propagation of fire hazards from the vegetation layer, which has been recognized as a vulnerability of this kind of infrastructure.

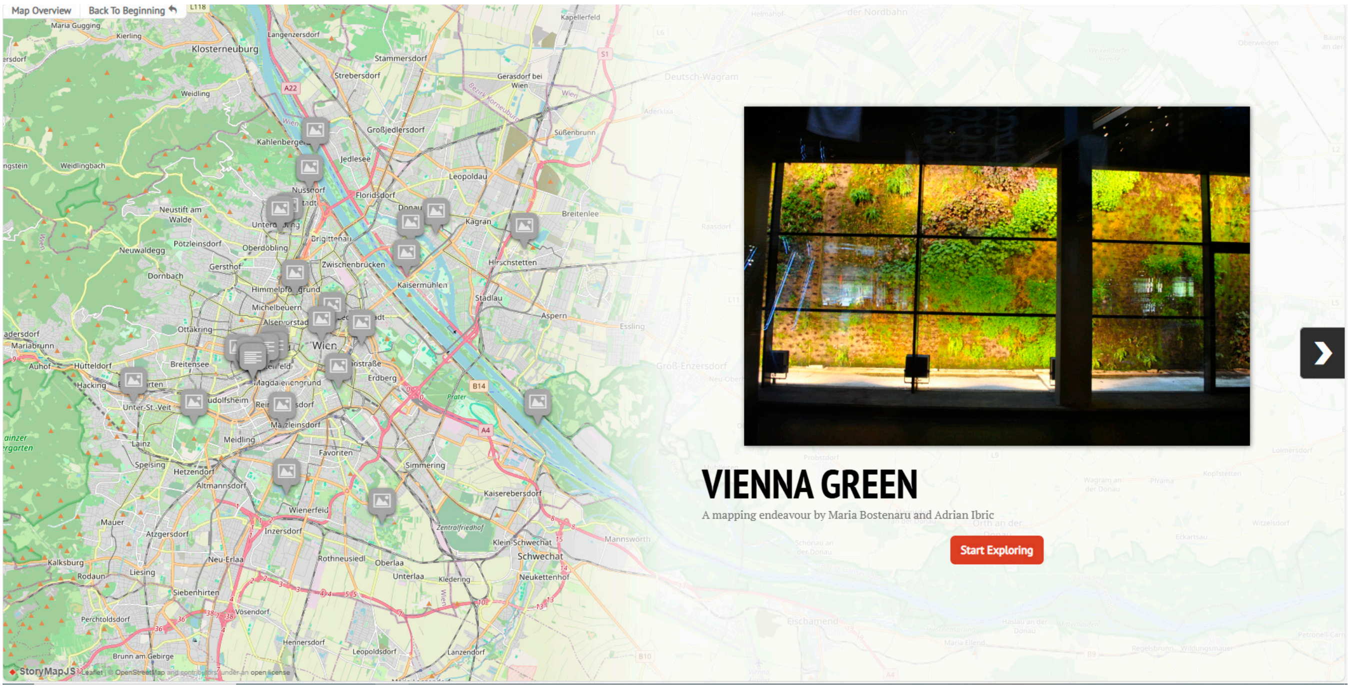


Figure 8. Vienna. The interactive map, authors M. Bostenaru and A. Ibric, is available at https://uploads.knightlab.com/storymapjs/49284be7dd69a3ff5cff0e7d6a768b51/vienna-green/index.html (accessed on 30 March 2024).

A prominent element on this route is Lindengasse, an older street in Vienna whose built environment is being refurbished with new architectural interfaces and features or replaced with new buildings into which green infrastructure is integrated, pre-designed. Such novel built examples on Lindengasse (Figure 9d–f) integrate by design vegetation and green infrastructure, either on the top retracted floor as rooftop gardens (Lindengasse 15) or by using nets and cables put in place for climbing plants, that link vegetation at street level with vertical green layers up to rooftop greenery (Figure 9d). The street sidewalk flowering vegetation garden spot (Figure 9f) adds another value to the green stratification, as a biodiversity support with an experimental urban green flowering infrastructure—a perennial vegetation layer possibly supporting local insects and birds—while the luxuriant foliage-rich green facade for the parking at Lindengasse 17–19 acts like a filtering and absorbing interface for gas emissions from cars, whether from the parking itself or the street traffic. A new local participatory initiative in Vienna refers to adopting a tree, in which Viennese citizens can foster the maintenance and protection of trees by providing support for putting fences in place, similar to Figure 9f. The route also includes the nearby Marianne Fritz Park/Zieglergasse 21–23, a type of mixed urban green infrastructure for residential and public space.

Vertical green walls face a number of challenges. Among these, maintenance is difficult and costly, especially for larger vertical areas, for which there is the need to employ specialised high-rise utility climbers, trained landscapers or gardeners for this particular type of green infrastructure. For especially high walls, when the green layer is not maintained, the visual perception of the underneath strata can lead to a loss of visual comfort and ambience that can further impact the mental health of the users of the spaces affected, even more for returning users—see the then and now in Figure 10 showing the Sofitel Hotel green wall in 2012 vs. 2022.

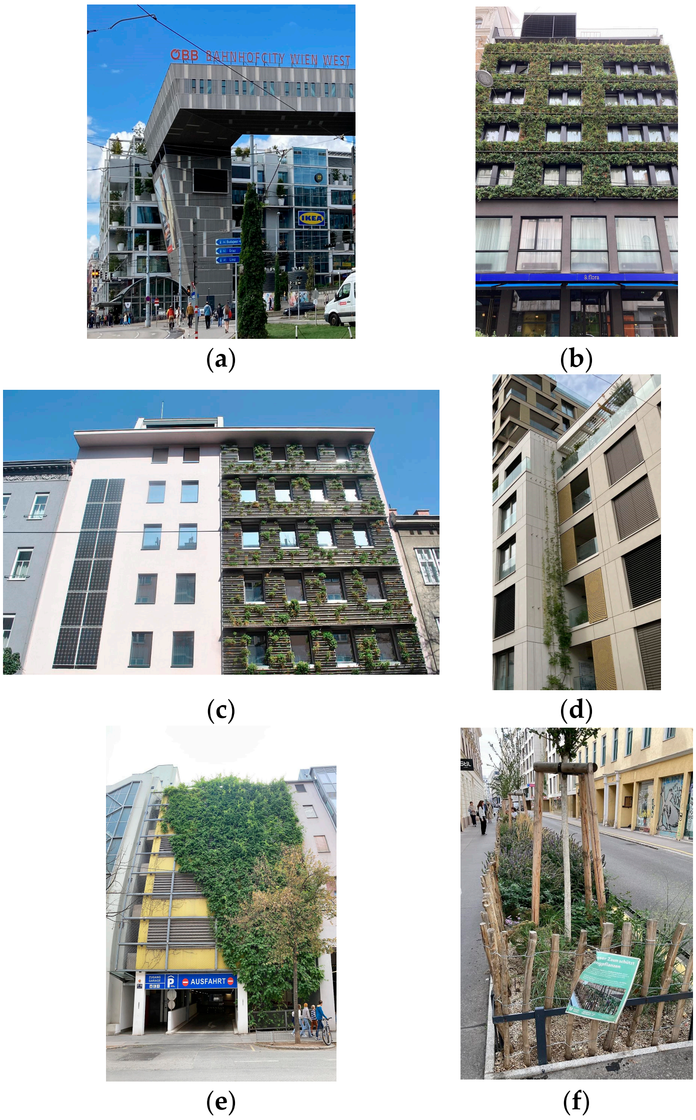
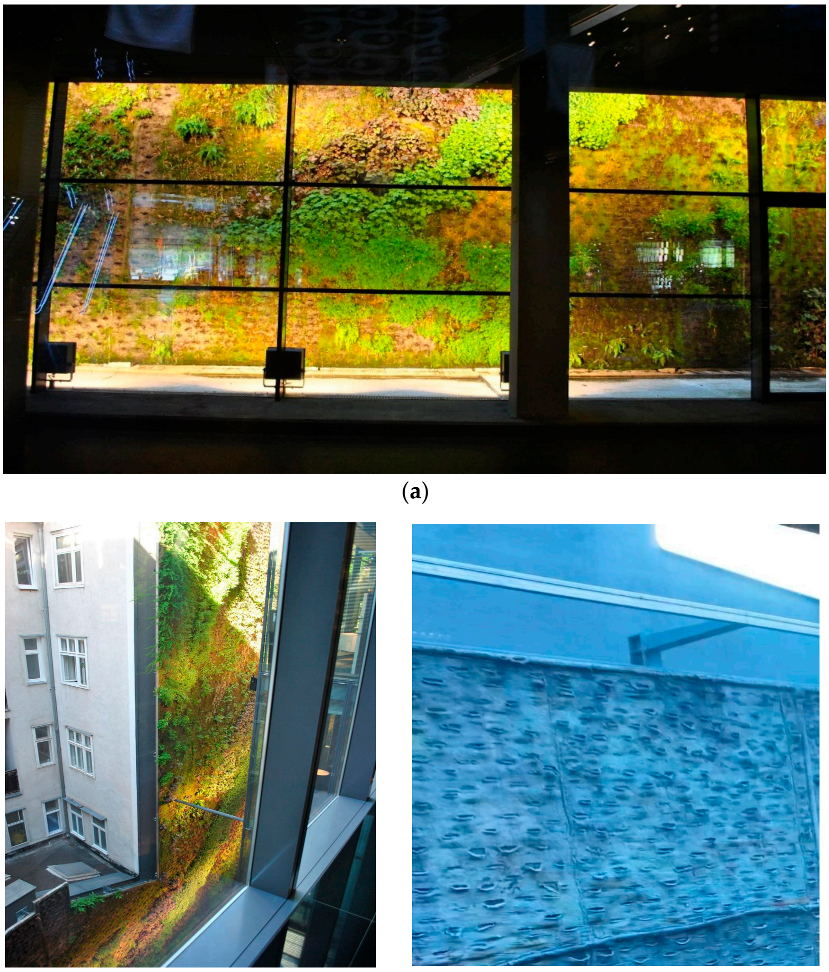


Figure 9. Vienna, green walkscape linking OBB Bahnhofcity Wien West Commercial Center (**a**), Hotel Gilbert green facade, Breite Gasse 9 (**b**), boutique Hotel Stadthalle, exterior green wall facade (**c**), Lindengasse 54 vertical climbing plants and upper-level green vegetation (**d**), Lindengasse 17–19 green wall parking (**e**), and Lindengasse 55, Street Biodiversity Sidewalk Garden (**f**). Photos: (**a**,**b**,**d**–**f**) A. Ibric, 2022 and c., M. Bostenaru, 2012.

Unexpectedly, there was only one instance of a Vienna case study on Oppla.eu out of 542 case studies worldwide (as of March 2024). This could be in relation to the fact that the portal groups large interventions on landscapes and ecosystems, and overlooks smaller NbSs. However, the Viennese example looks upon the regeneration of a formerly industrial site covered by factory buildings, which is being converted into a dense, green residential area following the guiding principles of an urban biotope [88].

Table 5 summarises the analysis of NbSs mapped in Vienna.



(a) (b) (c)

Figure 10. Vienna, Austria, Hotel Sofitel vertical green wall, a then and now showcase of a higher vertical green infrastructure that has not been maintained. Photos: (**a**,**b**)—M. Bostenaru, 2012 (April); (**c**)—A. Ibric, 2022 (September). The site was revisited in April 2024 and it was in the same state as in 2022.

Table 5. Vienna overview.

NbS Analysed	Historical Context	Urban Context	Nature vs. Design	Use	Climate Context
Green street	1B	2B	3B	4B	5B
Cherry trees	1A	2B	3B	4A	5B
Green belt	1A	2B	3A	4A	5B
Green walls on geotextile	1B	2A	3B	4B	5B
Elevated garden (Hundertwasser)	1B	2A	3B	4B	5B
Climbing plants on historic building (interwar)	1A	2A	3A	4A	5B
Green walls (in pots)	1B	2A	3B	4B	5B
Adopt a tree	1B	2A	3B	4A	5B
ECOLOPES Project [16]	1B	2A	3B	4B	5B
Island on the river	1A	2B	3A	4A	5B
Parks resulting from garden expo	1A	2B	3B	4B	5B
Gardens of interwar buildings and respective archive	1A	2A	3B	4A	5B
Palace gardens	1A	2A	3B	4A	5B
Cemeteries	1A	2B	3B	4A	5B
Heuriger (Wine production in the urban green belt)	1A	2B	3A	4A	5B
Vienna overview	9x1A vs. 6x1B	8x2A vs. 7x2B	4x3A vs. 11x3B	9x4A vs.6x4B	0x5A vs. 15x5B

3.4. Rome

Rome, a well-known subject of Grand Tour architecture and architectural history travels, is another case study in the project and the third Latin country capital analysed. It is also the place where one of the methods employed was initially developed, the psycho-geography and literature that deals with psycho-geographic approaches for Rome already exists. Some other innovative mapping methods aside from psycho-geography were developed in Rome, such as the Nolli map in the 18th century (when Illuminism brought the advent of modern seismology after the Lisbon earthquake) or the approaches building on it of Muratori and Caniggia, some of the innovative approaches of the 1960s. More recently, and in line with the Grand Tour, fellows at the Romanian and French academy, respectively, mapped the green space and the pavement, with a focus on material, as the topic of the year in Art Nouveau in 2023. One of the authors (Bostenaru) has been a fellow in Rome as a postdoc and exploring the city and its different layers from Piranesi to the present has been an ongoing investigation of several topics of research. Part of the current research was a 2023 field documentation to the local MAXXI museum, which offers an important architecture component. The targeted exhibitions were, on one side, the archival holdings themselves—at that time featuring an exhibition on engineer Sergio Musmeci, author of the mediated bridge in Potenza, which collapsed. The visit also provided access to the Technoscape exhibition, offering insight into the cooperation between architects and engineers, a topic previously explored for Bucharest. This interdisciplinary collaboration is most relevant in the case of disasters, as both fields deal with the built environment.

The Rome edition of the Le Notre Forum took place in 2013. It had the same sections as the event in Bucharest, but for each of the sections an area was chosen, as follows:

1. The EUR 42 (Esposizione Universale di Roma 1942) district. This is already mapped above in Figure 8, it is a modernist site of a more monumentalist manner, but enveloped in large green spaces.
2. Appia Antica Regional Park. Appia Antica is the area of a famous ancient Roman archaeological site road, encompassing larger neighbourhoods, for example, wider fields of poppies.
3. Acilia and the Dragona Loop, close to Ostia Antica, the antique port of Rome.
4. The Landscape Context of Ostia Antica. This is the former port of ancient Rome and now an archaeological site; the landscape of archaeological sites was the subject of subsequent Le Notre Forums, for example, in Paphos.

Other notable elements of the landscape of Rome are covered in the bibliography, and include the following: the archaeological part is seen as identity landscape, “the ecologic network [green corridors] underlying the landscape”, the historical vegetation of the garden of the villas (which are typical of Italian landscapes), like the ones in Valle Giulia (Villa Medici, Villa Borghese etc.), and parks (of the city walls, along the river, new parks in some of the suburbs and farming areas), as well as protected natural areas [89].

The Roman landscape has, as a first layer, the landscape of ancient ruins (not only Appia and Ostia Antica), followed by that of the Roman villas, some of which have been preserved until the XXI century. Even post-war neighbourhoods suggest the typology of garden cities, with large courtyards of medium-rise buildings. Special attention was paid to the interwar garden designs of Raffaelle de Vico [90].

The typical Roman landscape can be seen in the attached map and photographs (Figures 11 and 12). An overview of the highlights is given by seeing green spaces with a focus on the temporal simultaneity to the Japanese blossoming of cherry trees. Such were seen in two places: the EUR, which was a notable interwar development, and the Valle Giulia of the foreign academies, from 1911, both former exhibition sites. The visit to the latter encompassed visits to green places of interest such as the Japanese Institute’s garden and a tour of the Faculty of Architecture from the Sapienza University in Rome, which has its premises in Valle Giulia, as well as the outdoor installations of the National Gallery of Modern Art. Valle Giulia is located at Villa Borghese, and because the foreign academies and institutions such as the French Academy (the villa Medici) and the Swiss Institute, as well as the Bibliotheca Hertziana, are on the other side of the Borghese garden, the entire area is an example of classic green infrastructure overlapping a culturally significant site, enriching the experience of both citizens and visitors in this city. The Technoscape exhibition at MAXXI featured earthquake engineering in Pavia and showcased the fragility of the local (Italian) built environment facing this particular type of hazard of interest for the authors who are involved in a larger research project regarding the early 20th century heritage, hazards affecting it and the mapping of different solutions to mitigate the impacts. Nature-based solutions for disaster resilience related to flood and fire are also to be considered. Future visits should also include the Museum Luigi Pigorini at the EUR. Other sites visited, such as the Art Nouveau Museum of Rome, the museum Ludovisi Buoncompagni and the Maltese order, featuring developments in both the architecture and landscape of Piranesi, a contemporary of Nolli, who drew the mentioned seminal plan of Rome, are also significant for a *greening* experience walking tour.

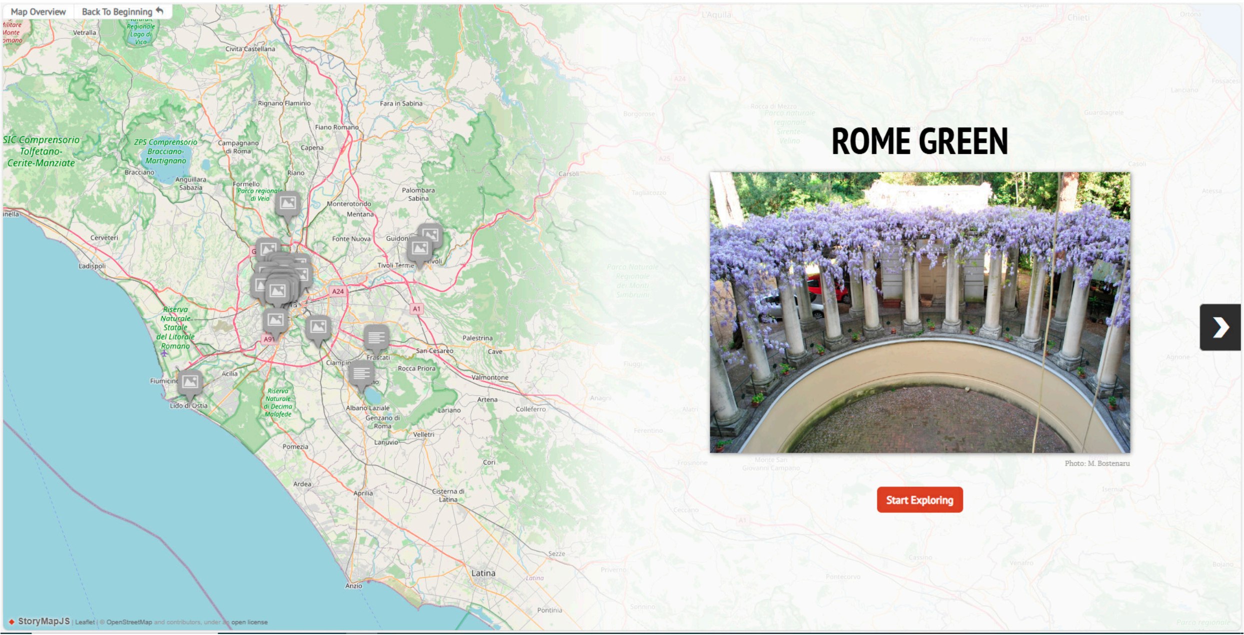
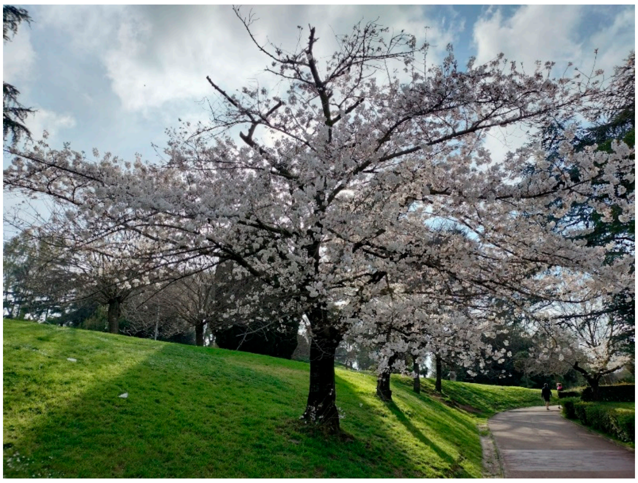


Figure 11. Rome. The interactive map, author M. Bostenaru, is available at https://uploads.knightlab.com/storymapjs/49284be7dd69a3ff5cff0e7d6a768b51/rome-green/index.html. (accessed on 18 June 2024).

(**a**)

(**b**)

Figure 12. *Cont*.



(c)

(d)

Figure 12. Rome (**a**,**b**) Villa Medici. (**c**) EUR Park. (**d**) Accademia di Romania Garden. Photos: M. Bostenaru, 2016, 2023.

Table 6 summarises the analysis of NbSs mapped in Rome.

Table 6. Rome overview.

NbS Analysed	Historical Context	Urban Context	Nature vs. Design	Use	Climate Context
Climbing flowers (glycine and bougainvillaea—typical for the Mediterranean)	1A	2A	3A	4A	5A
Cherry trees in interwar neighbourhood park	1A	2B	3B	4A	5B
Mediterranean trees	1A	2B	3B	4A	5A
Antique sites	1A	2A	3A	4A	5B
Italian gardens of (interwar) villas	1A	2A	3B	4A	5B
Gardens of diplomacy villas	1A	2A	3B	4A	5B
Gardens of ministates (Cavalieri di Malta, Vatican)	1A	2A	3B	4A	5B
Flower market	1A	2A	3A	4A	5B
Cemeteries	1A	2B	3B	4A	5B
Island on the river	1A	2B	3A	4A	5B
Poppies on Via Appia	1A	2B	3A	4A	5B
Rome overview	11x1A vs. 0x1B	6x2A vs. 5x2B	5x3A vs. 6x3B	11x4A vs. 0x4B	2x5A vs. 9x5B

4. Discussion

The research contributes to a wider comparison between NbSs in both similar settings (climate and architecture history) or different conditions useful in the context of climate changes. There is a need for future research regarding the expansion of criteria employed in the analysis and updates of case studies. Valuable data could be gathered from a uniform database of green infrastructure typologies based on existing classifications (Maes Report, Urban Ecosystems). Other data can be based on further observations between the same types of NbSs applied to historical settings in different climate conditions or information on NbSs in relation to buildings belonging to different periods in the same climatic settings. Table 7 summarises the analysis of the mapped NbSs across the five cities.

Table 7. Comparison of cities.

City	Historical Context	Urban Context	Nature vs. Design	Use	Urban Context
	Is the green element a historical green infrastructure (1A) or is it a new one (1B)?	Is it an individual piece of greenery (2A) or is it part of a green network/a linking corridor (2B)?	Is this spontaneous vegetation (3A) or planned vegetation (3B)?	Is it already adopted in full-scale use (4A) or is it a part of new NbS demonstrative pilots (4B)?	Is the design element specific to a certain climatic zone (5A) or is it able to contribute to climate adaptation and resilience in all climatic zones analysed (5B)?
Bucharest	9x1A vs. 3x1B increased historical green elements, possible indicator of low novel NbS adoption	7x2A vs. 5x2B an equal distribution of each kind	4x3A vs. 8x3B mostly planned vegetation, which, when connected to the historical point, hints to historical planned corridors	9x4A vs. 3x4B low degree of new demonstrative pilots	0x5A vs. 12x5B all NbSs present in the city that were analysed can be used in all climatic zones studied
Lisbon	4x1A vs. 5x1B new green elements add to the existing infrastructure	4x2A vs. 5x2B mostly interconnected	0x3A vs. 9x3B almost no spontaneous vegetation that suggests the green infrastructure is a clear part of the urban planning process	4x4A vs. 5x4B new experimental NbSs are showcased throughout the city	0x5A vs. 9x5B all NbSs present in the city that were analysed can be used in all climatic zones studied
Vienna	9x1A vs. 6x1B still more historical elements but there are already a number of new green insertions	8x2A vs. 7x2B an almost equal distribution of each kind	4x3A vs. 11x3B mostly planned vegetation, which, when connected to the historical point, hints to historical planned corridors	9x4A vs.6x4B medium degree of new demonstrative pilots, but overtaken by the existing full-scale green solutions.	0x5A vs. 15x5B all NbSs present in the city that were analysed can be used in all climatic zones studied
Rome	11x1A vs. 0x1B all historical green elements, perhaps due to the immense built heritage layers	6x2A vs. 5x2B an equal distribution of each kind	5x3A vs. 6x3B planned vegetation are showcased better than spontaneous spots	11x4A vs. 0x4B no new experimental NbSs, also perhaps due to the immense built heritage layers	2x5A vs. 9x5B almost all NbSs present in the city that were analysed can be used in all climatic zones studied. Those that are specific may have flora counterparts in the other zones (e.g., climbing plants)

The five criteria employed in the analysis of the use of NbSs led to different overviews for the five case study cities, regardless of the similarities in climatic or historical settings. From the five cities analysed, Vienna appears to be the greenest city, in both interconnectedness and the advancement of novel NbS use in urban redevelopment, even outside of public tourist areas. The city employs a wide array of solutions, adapted to the scale of the buildings and streets, including vertical vegetation layers that protect the urban air from pollution emanated from parking buildings. In contradiction with this observation, on the Oppla platform, there are four examples of European projects for Lisbon, including master plans, while for Vienna there is only one project. Lisbon is also a city case study of nature-based solutions [91]. For Bucharest there are also four examples, including the Văcărești Delta and Colentina river and lakes system (the Le Notre Forum chosen site in 2015). There are also several instances of Rome on the portal. It is the authors' opinion that Oppla could benefit from an update on NbS case studies to better reflect the most recent developments and include a smaller scale for NbSs which are of architectural or street level. Currently, the lowest scale on Oppla.eu is "local".

The use of nature-based solutions (NbSs), on both a small and large scale, is indeed a part of the new planning and design of the built and landscaped environment, both for existing retrofits and new projects. This was our second criteria for our analysis (2A vs. 2B), which asked about an equilibrium between individual pieces of greenery and parts of green networks/linking corridors, in all cities, as summarised in Table 7.

Criterion 4 regards whether the example is already adopted in full-scale use (4A) or is part of new NbS demonstrative pilots (4B). Pilot testing and implementation has suggested that locally adapted, resource-efficient and systemic interventions in both larger and smaller scales are possible in these cities, as shown in Criterion 2. Smaller consecutive ecological interventions (private gardens and exterior green walls) may be connected to each other, to larger green areas (parks) or to vegetation corridors aligned to the streets.

This increases the resilience of the local green infrastructure and also fosters growth in biodiversity habitat. These interventions have indeed a lesser impact individually, and they add more ecological value to the built ecosystem when embedded in a bigger ecological framework.

Criterion 3 regarding spontaneous vegetation relates best to studies in literature regarding biodiversity. Non-spontaneous vegetation relates to supporting policies and research funding in Europe (in conjunction with the New European Bauhaus) that have increased in the last two decades, which has allowed for more natural features and processes to be adopted as ecosystem-optimising tools for the built environment and man-made landscapes, as exemplified by the Oppla aggregator.

These solutions led to increased resilience to climate change and climate change mitigation overall as the last criterion (5A vs. 5B) suggests. Very few design elements are specific to a certain climatic zone, while most analysed are able to contribute to climate adaptation and resilience in all climatic zones in discussion. Our results support the impact that NbSs, especially green infrastructures (GIs), have on cities in decreasing negative effects from urban heat islands (UHI).

Regarding Criterion 1, all cities with the exception of Lisbon have a prevalence of historical green infrastructure (1A). Wherever present (all but Rome), new ones (1B) do emulate or integrate natural functions and they incorporate technologies or material components that are not biological in origin, but not all are success stories (e.g., geotextile—Sofitel Vienna). In Lisbon (new MAAT, the commercial and cultural centres) and Bucharest (Promenada Commercial Center), large green roofs and walls are used as public and connecting places due to their visual and well-being impact—they have become popular architectural design instruments.

As a field documentation-based study within a national funded project, the analysis was shortened by travel costs and limited time and research resources to cover all existing variations of NbSs for each city. As a team of three authors, we were able to put together and compare data and knowledge from different periods and from connected approaches, from historical ones to landscape design principles to theoretical design proposals.

Nature-based solutions in these locations contribute to decreasing negative effects from urban heat islands but also fire hazards, climate change and even flood hazards.

5. Conclusions

In this article we have mapped a series of NbSs in relation to the historical context and climatic zoning, but also in relation to the degree of the use of different green infrastructures. A dense built environment, but in different climatic zones, such as the historical ones of Rome or Vienna, does not offer the same response to using NbSs. In innovative environments such as Lisbon, the historical factor has an important impact on the adoption of different NbSs. In areas with similar climate and history, Rome and Lisbon benefit from different uses. Although in climatic zones at a close latitude, Bucharest and Vienna are different mainly in terms of planning decisions.

Bucharest, Lisbon, Vienna and Rome face different solutions for towerscapes, including green walls and green roofs. This can be compared to notable solutions such as Bosco Verticale in Milan, which features some of the other solutions used here. Green walls and roofs are mainly advanced in new public buildings (museums) and large commercial constructions such as shopping centres, office spaces, hotels and restaurants.

The climate conditions in Bucharest and Vienna are similar, but in Lisbon they are different (Mediterranean/Oceanic), which is reflected in the choice of plants and of greening solutions, mitigating climate change affecting local settings.

Rome is notable for an exceptional outdoor green setting which is carefully and intentionally overlapped with the rich cultural layers and its green infrastructure has a cultural side in itself.

For the fifth criterion, climate context, almost all NbSs present in the cities that were analysed could be used in all climatic zones studied or could have climatic equivalents (e.g., for specific climbing flora). However, the climatic zones that were taken into consideration for this study have many similarities in terms of overall conditions. The data driven by this criterion may vary for climatic zones with more distinct properties.

Additional work should be carried out in the future in order to narrow this comparative research to Tier 2 cities similar in size and part of the temperate climate zone such as Lyon, Milan, Budapest, Belgrade, Berlin, Prague and Warsaw, at least in Europe. Oppla recommends NbSs for urban regeneration for Milan, Budapest and Oradea, among others. These cities are also relevant for the related 20th century built heritage, as are the chosen case studies. Budapest is also a capital, Milan is of similar size to a capital and both are in the same climate zone as Bucharest. Oradea is a smaller city, but is in Romania as well. Budapest is also a former socialist city, as Bucharest is, thus with differences, for example, in public participation because of a former authoritative regime, which makes the creation of pocket parks in the community to be an exception. Thus, the intention is to see the interaction between Bauhaus heritage and New European Bauhaus challenges including the European Green Deal, as stated at the beginning. Comparisons to other continents (for instance Montreal in North America or Singapore in Asia), will be included in further publications.

There is also an opportunity for criteria expansion to include air pollution, brownfield recovery, nature-based economy and societal benefits, in relation to ecosystem services, in particular cultural ecosystem services. While the presence of green spaces in the city improves the external ambient temperature, the presence of plants in the green roofs and walls also improves the temperature of the interior spaces—and this can be further studied in relation to UHI effects and overall NbS benefits.

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