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Design for urban biodiversity: flourishing the vertical plane

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Abstract. Nature-based solutions (NBS) emphasize the importance of linking biodiversity conservation with climate-resilient and sustainable development plans. In the built environment, artificial ecosystems, such as vertical gardens (VG), cannot be considered NBS if factors such as biodiversity and sustainability are disregarded. This project demonstrates the workflow of incorporating the suitable plant composition in the process of designing a conceptual VG, in a case study in Athens, Greece, while additionally explores the vegetation influence in buildings' microclimate. Initially, the process relies on digitizing data pertaining to suitable native plant species along with their growth and maintenance parameters; this further enables the establishment of criteria for selecting plants for VG within the architectural proposal. In the second part, a conceptual design experiment of a VG is conducted, where the selected plant species are evaluated in terms of site-specific characteristics, before reflecting on the prospects of the process, in the third part. As a result, this work demonstrates a design approach that is extended to harness local plant capital for the benefit of urban biodiversity. In doing so, it promotes transdisciplinarity by merging different concepts into a coherent, valuable research set that is replicable and accessible to all.

1 Introduction

Nature-based Solutions (NBS) refer to different types of green infrastructure (GI) which efficiently use local resources - such as flora, to address various environmental, societal, and climate challenges, as opposed to the prevailing unsustainable interventions [1]. They emphasize the importance of linking biodiversity preservation with climate-resilient and sustainable development plans. A key feature of NBS practice is the use of natural elements in the design process so that these align with the socio-ecological context in which they are implemented [2]. For example, the construction of NBS-type 3 (such as vertical gardens - VG), are not considered as NBS, if factors like biodiversity and sustainability are disregarded in their design and implementation [3]. In this case, native and local species should be favored when designing the VG, while the overall project should take into account - among other things, the environmental impact, the maintenance requirements, and the climate conditions. Furthermore, the use of high diversity of plants helps VGs to be resistant to pathogens, responsive to the site and to the environment in general, an asset capable of fostering resiliency [4 – 5].

VGs, as multifunctional artificial ecosystems, are employed to accomplish specific architectural, engineering and functional requirements of contemporary buildings. Thus, they improve microclimate of the building's surroundings [6-7], air quality, while they have health and well-being benefits for people [8], among others. A common oversight is ignoring the requirement for biodiversity of VGs in the design process, thereby compromising and weakening their long-term sustainability advantages. In this regard, expert guides, policy reports and the relevant international literature recommend the green building sector to adopt an impact-oriented approach; they emphasize on the importance of ecological monitoring and evaluation in VG initiatives, to assess their benefits and ensure their contribution to biodiversity aligns with their role as effective and comprehensive architectural solutions. Moreover, their evaluation within a narrow, fragmentary scope, the fact that their adoption is primarily driven by city-level priorities rather than national-level legislative actions, as well as, the considerable costs associated with their installation hinder their popularity and make them a rather challenging option, as alternative solutions [9].

Nevertheless, it seems that there is no existing method or prior example in the global literature to aid architectural practice in making well-informed choices, concerning plant selection based on considerations of biodiversity and the specific attributes of plants that interact with buildings in the local context. As a response to this gap, the current project aims to fill this void by establishing the necessary connections to encourage interdisciplinary collaboration.

2 Research Project

The authors' general research question is: How can biodiversity and sustainability be incorporated into the design and implementation of a VG within an architectural project? Additionally, a more specific

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inquiry relating to the case study is: how do local climatic conditions influence the success of such an installation and what impact does it have on the local microclimate? The primary objective of studying the utilization of a VG in an architectural project is to assess the environmental challenges and implications associated with its implementation. The methods used involve a detailed analysis of the hypothetical installation of a VG in the South (S) – (fig. 3) side of a building under renovation in Athens. The architectural design process is conducted by Parthenios architects + associates [10] (fig. 2 - 4) and concerns the conversion of a former five-storey residential building into a modern office building. Throughout the design process, the aim was to determine the integration of the VG, select suitable plants for the project, explore the use of digital tools to account for factors related to plant growth and biodiversity, and approach an assessment of their impact on the local microclimate. Consequently, the paper explores how the results from this specific case study could be applied to different contexts and lead to interdisciplinary collaboration, i.e., ignite convergence across various frameworks for future research endeavors.

Figure 1. Project Location: Piraeus, Athens, Greece.

Figure 2. Building's façade, 3D rendering.

Figure 3. View of South (S) side, 3D rendering.

Figure 4. View of South-Southeast (SSE) side, 3D rendering.

The geographic coordinates of the building's location are (37.952011, 23.637676) (fig. 1), and it is situated at an altitude of 8 meters above sea level. It falls under the (Csa) Köppen climate classification, which stands for characteristic Mediterranean climate with hot summers.

3 Methodology

The research approach is developed in two parts. The first part is about documenting which species grow in the specific geographical area. For this task, the authors have created a new database to collect information from the most complete, detailed and up-to-date plant databases in Greece [11-12] and elsewhere [13,14,15,16]. In this database, the species and their planting information criteria relevant to VG projects – according to international literature [17-18], are documented. Furthermore, this section addresses the necessity for quantifiable measurement and assessment of the ecological outcomes resulting from the intervention, by making available the compiled list of the chosen plants.

Based on this database, the second step revolves around the evaluation and selection of the plant species for the case study in question. As an evaluation requirement, the authors examine the classification criteria for the flora (table 2), in parallel with the annual direct sun-hours analysis for the building's south wall (fig. 3 - 4). As an extension of this second part, an evaluation of how vegetation influences the (ground level) microclimate of the southern side of the building, is conducted. Additionally, intriguing aspects of the interplay between the engaged technical and biological systems are explored, thereby featuring their potential future dynamics.

3.1 Plants Database

The process is based on the digitalization - from the existing PDF format into an Excel file with comma-separated values (CSV), of the data from the checklist of Dimopoulos et al. [11-12], which summarizes the entire floristic inventory of the Greek region.

The checklist is an essential inventory of the plant history of Greece and serves as a basis for a wide range of interdisciplinary research, including efforts to protect and sustainably use plant diversity; according to Dimopoulos et al. the total number of entries in the checklist is 7739, including 185 families, 1073 genera, 5758 species and 1970 subspecies, for a total of 6620 registered taxa [12]. For the present study, the floristic region *Sterea Ellas (StE),* which includes Athens, was selected to distinguish it from the main checklist. *StE*, includes 160 families, 860 genera, 3116 species, 977 subspecies and 3318 recorded taxa [12]. Consequently, the list referring to the floristic region *StE* includes the parameters of the plant selection criteria in VG projects, for each registered taxon (table 1).

The checklist includes the following qualities: botanical nomenclature, regional distribution (in the 13 Greek floristic regions), status of taxa (native, alien and range-restricted), as well as chorological categorization (the current disperse range), life form categorization (falling under six groups of the life form system of Raunkiaer, 1934) and habitat categorization (eight groups of habitat types). Further explanations of the categories *Stat*, *Ch*, *Lf* and *Hab* can be found in [11-12]. For the specific case, the objective was to design for minimal irrigation and maintenance requirements. Furthermore, the emphasis was on establishing the best plant location in relation to the orientation of the building. Based on [13 – 16], these additional data were added to the inventory.

Table 1.

Nomenclature	Stat	Information derived from [11-12]
	Ch	
	Lf	
	Hab	
	Height	Information derived from [13 - 16]
	Width	
	Direction of development	
	Irrigation needs	
	Maintenance requirements	
	Plant heat zone	
	Plant hardiness zone	
	Ground pH	
	Position	
	Aspect	
	Planting distance	
	Plant type	
	Rate of growth	
	Pathogens/Pests	
	Bloom time	
	Bloom color	
	Wildlife attraction	

Table 2.

Stat	-
Ch	-
Lf	All, excluding T and A
Hab	All, excluding H
Height	Up to (<=) 100 cm
Width	-
Direction of development	Upwards
Irrigation needs	Low
Maintenance requirement	Low
Plant heat zone	-
Plant hardiness zone	-
Ground pH	-
Position	Sun – semi-shade (Fig.4)
Aspect	South, All
Planting distance	-
Plant type	All, excluding annuals and biennials
Rate of growth	Slow, moderate
Pathogens/Pests	-
Bloom time	-
Bloom color	-
Wildlife attraction	-

The created database, which contains a number of interrelated categorization criteria, allows for a parametric approach to data processing. Therefore, taking into account various factors, the classification criteria for the flora were finally established (table 2). A sample of the created list can be accessed here https://docs.google.com/spreadsheets/d/1dvXTtKTEpV1vmuKIhdnKOLLPmCQQURU4wkuev2OGZfk/edit#gid=0

3.2 Digital Tools

For this analysis, in the south façade of the office building under-construction in Athens, Greece, the computer applications of Rhinoceros 3D, Grasshopper 3D, and the Ladybug and Honeybee components from the Ladybug Tools suite (version 1.6.0), are used [19]. The surface of the south wall studied is 4.5 meters wide and 16.5 meters high.

The first step of the procedure is to model the block and create the Ladybug Tools simulation workflow, which is done by combining and modifying the existing scripts. As the study concerns the integration of vegetation in the main wall of the south side of the building (fig. 2), the first step is to perform an annual direct sun-hours analysis for this area of the building. The simulation takes into account the orientation of the area, as well as, the existing building stock to determine the total hours of sunlight on the surface in question. This simulation can be used to determine the solar requirements of the plants (sun, partial-shade, shade). In this given situation, it is clear that for the majority of plants, ample (sun – semi-shade) sunlight is the prerequisite (fig. 4).

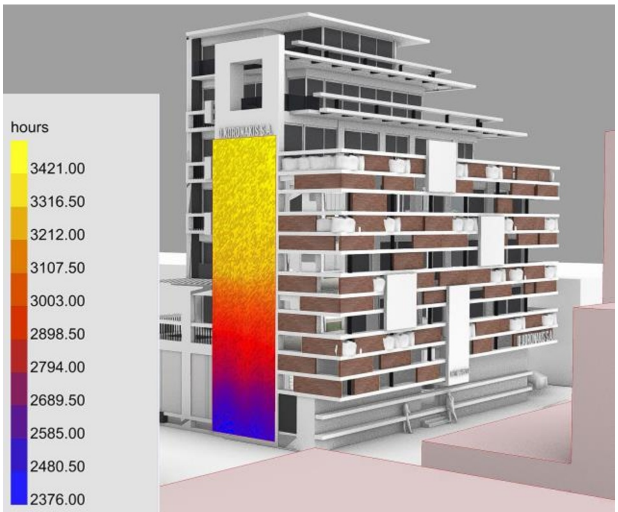

Figure 4. Annual Sun-Hours Analysis.

The second element selected for examination is the potential impact of vegetation on the microclimate of the surrounding area. Therefore, an outdoor thermal comfort assessment is carried out, taking into account certain simplifications in the contextual factors. These relate to the integration of the variety of building volumes and materials into one element - *HB (Room solid – Concrete pavement)*. The second material is a paved surface - which includes the *HB (SensorGrid – Concrete Pavement* - for the thermal map analysis), while the third element represents the vegetation, via the component *HB (VegetationMat)*. The values of the component *HB (VegetationMat)* represent both plants and soil; for the variety of underlying material models, the default values are used, except for a) the height of the plants, which is set to the average value of the plants used, and b) the leaf area index (LAI) which is set to 3, as the average value for bushes and shrubs according to [20]. The LAI, is a dimensional measure of vegetation that may be precisely detected using an optical device; additionally, the amount of cooling, heat flow and reduction in ambient temperatures given by a green façade is directly connected to the amount of leaf area, therefore, LAI is a vital input in conducting VG simulation studies [21]. The simulation period is from the 1st to the 10th of August. For technical reasons (i.e., overly lengthy simulation times), the surrounding buildings were not taken into consideration into the simulation, but rather were considered for their type (size, scale, orientation). Nonetheless, the presence of flora is seen to influence temperature, particularly close to the VG structure (fig. 5), which is consistent with corresponding research on the effect of vegetation on local microclimate [22-23]. Thus, this study on outdoor comfort does not aim to precision, but rather to serve as a foundational point for future, more comprehensive research endeavors.

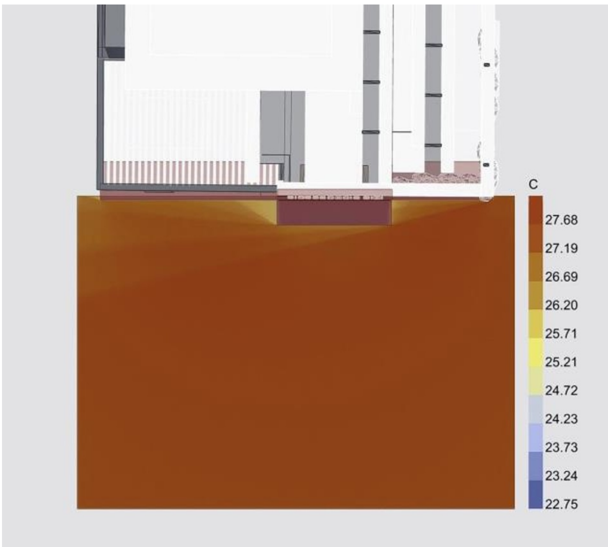

Figure 5. Outdoor Thermal Comfort Analysis.

A notable aspect of the process is about the emerging synergism between technical and biological systems within the utilized digital ecosystem (Rhinoceros 3D, Grasshopper, and Ladybug Tools); the seamless integration of various elements grants easy access to a diverse range of interconnected factors relating to space, building, plants, and the environment. As a result, a harmonious relationship between the technical and biological aspects of the involved systems is cultivated.

The modular system of a UK-based VG initiative (fig.6) [24] was used to portray this (fig. 7). The dimensions of each module are 500x250x100mm, with eight modules occupying a m^2. Using this modular framework, the vegetated surface (4.5m x 16.5m) is composed of 594 modules. The integration of plants' list - together with their attributes - as well as their processing into the 3D visual interface, is performed using Grasshoppers' components i.e., *File path* (Path) and *Read from Excel* (XL In). Figure 7 depicts the modules on the surface which provide information about the sunlight requirements of the selected plants (yellow indicates plants with full-sun requirements, red – full-sun to semi-shade and blue, semi-shade to shade, sun requirements). Accordingly, the procedure allows the utilization of a multitude of plant parameters (Table 2), in relation to circumstance, design approach or requirement, thus facilitating interdisciplinary input and collaboration.

Figure 6. *ANS Global*, module dimensions: 500x250x100mm.

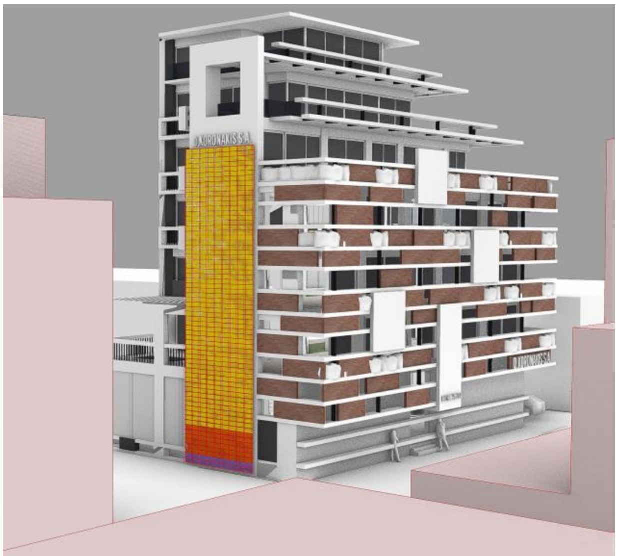

Figure 7.

4 Discussion

The research study reflects on the practice of VG, a subtype of NBS that has yet to gain traction, particularly in Greece. Thus, participating in a broader discussion about dense urban environments with insufficient green space, such as Athens, the project uncovers and introduces aspects of a climate-smart and biodiversity-driven strategy, while concurrently reflects on the critical role of hyper-local, green interventions in urban space regeneration; in this context, certain observations are recorded pointing out towards possible future directions.

Initially, regarding the phenomenon that refers to the rise of temperature within a city - Urban Heat Island (UHI), when compared to the surrounding rural areas, caused among others, due to the lack of vegetation. While it may be complex to implement city-wide changes for modifying the local climate, the local microclimate can be more easily influenced to mitigate UHI and create comfortable outdoor spaces [25]. In this direction, it is underlined that even small NBS – like green roofs or VGs can have a notable local impact on individual buildings, but only by incorporating a network of NBS and other GI into the urban fabric can a major city-wide effect be realized [26]. Similarly, considering the possibility of enhanced design support tools and procedures in the future, there is a viable chance that the analysis, showcasing the implementation of aground NBS, could potentially decrease peak warming by 0.1ºC in the scenario aligning with a 1.5ºC temperature increase by 2055 [27].

The project is an operative scheme that merges the concepts of smart growth, GI and NBS, to achieve urban resilience by integrating greening solutions from the projects' initial design stages. This approach allows for informed and purposeful enhancement of biodiversity by considering it from the start of the project development. Additionally, inquiries regarding the spatial organization of the vegetation and its characteristics, as well as their multifunctionality or desirable ecosystem services (ESS), are enabled [28-29]. In this context, another important element that emerges is that of measurability and the possible extensions it incorporates upon biodiversity objectives and ecologically-relevant actions. This may involve developing measurable ecological criteria to support sustainability-oriented principles and policies, or offering directions for effective resource management, among various other possibilities [30]. In addition, the integration of this extensive plant information into the digital design environment serves the following purposes: firstly, it establishes the necessary communication channels among the involved stakeholders (architects, landscape consultants, ecologists, etc.), secondly, it enables the design process that relies on informed decision-making, and thirdly, it incorporates the feasibility of assessment as well as measurability in the overall process.

Building upon the current research, two possible future steps come to light. The first step could involve the development of a tool (plugin) that will integrate the plant information used in this research (refer to table 2), within the utilized digital ecosystem. This integration would facilitate the incorporation and widespread adoption of similar workflows within architectural practice. The second step involves cross-validating the obtained results (of the microclimate analysis) with other relevant contemporary digital platforms, such as ENVI-met. Nevertheless, the authors' current priority, based on the presented case study, lies in further investigating and improving the development of the considered tool.

5 Conclusions

An ever-growing research body indicates the critical importance of nature for cities' future livability and sustainability. In line with this research, the project leverages local vegetation for the design of a VG, a strategy which could also be used in a variety of nature-based practices. The significance of the approach is manifold: first, as an initial approximation of an ecological spatial strategy; second, as an attempt at convergence between interdisciplinary fields; third, as an incentive to encourage the use of both VG and NBS in general, thereby promoting well-informed and biodiversity-driven, urban green interventions. Some critical components of planning were discussed in the context of architectural practice. One crucial aspect of the research paper involves the enlargement of the plants database. Finally, this work promotes convergence by facilitating transdisciplinarity through fusing various concepts into a coherent, valuable research set that is comprehensible, replicable and accessible to all.

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