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Towards Biodiverse Urban Public Spaces: A Morphological Study in Milan

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ABSTRACT

This study explores the role of architectural composition and urban design in enhancing urban biodiversity, which is crucial for improving ecosystem services and overall urban sustainability. It addresses a gap in the literature by providing empirical evidence on how specific morphological characteristics in urban regeneration projects can support biodiversity, emphasizing the overlooked potential of architectural morphologies in urban greening strategies. Focusing on five recent urban regeneration projects in Milan, the study conducts a detailed analysis of built volumes and green areas. Quantitative measurements, such as green area compactness, perimeter edge continuity, and building front permeability, were combined with qualitative assessments to identify correlations between urban morphology and biodiversity potential. The analysis revealed three distinct urban morphologies—"Central Park," "Fluid Park," and "Garden Between Houses"—each offering unique conditions for accessibility and biodiversity development. These morphologies demonstrate varying capacities for conserving, promoting, and implementing urban biodiversity, depending on their interaction with the surrounding urban fabric. By establishing a clear correlation between urban morphology and biodiversity potential, this research highlights the critical role that architects and urban designers play in addressing the emerging challenge of enhancing urban biodiversity. It provides valuable insights for future urban regeneration projects aimed at fostering sustainable and biodiverse urban environments.

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Highlights:	Contribution to the field statement:
- Architectural composition in urban design can significantly enhance biodiversity in public spaces by optimizing morphological characteristics. - Distinct urban morphologies, such as "Central Park," "Fluid Park," and "Garden Between Houses," influence biodiversity potential through their interaction with surrounding urban fabric. - Urban regeneration projects with increased green area compactness and perimeter edge continuity foster higher biodiversity and ecological connectivity. - Milan's urban regeneration efforts demonstrate that specific settlement forms can successfully integrate biodiversity with accessible, visible public spaces.	By identifying the correlation between urban morphology and biodiversity potential, this research contributes to the field of urban studies and architectural studies by shedding light on the role that architectural composition and urban design – and therefore architects and urban designers - can play in the emerging challenge of designing urban spaces aimed at conserving and enhancing urban biodiversity, facilitating ecosystem services provision and creating accessible, safe and inclusive public spaces.

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1. Introduction

1.1 Background and Context

The preservation and promotion of urban biodiversity are crucial for achieving the objectives outlined in the European Union's Biodiversity Strategy for 2030: ecosystem restoration, ecological balance, human well-being, and overall urban sustainability (European Commission, Directorate-General for Environment, 2021). With a population share of about 50% in 2020, projected to increase to 58% over the next 50 years, the responsibility for the majority of the world's carbon emissions (Moran, et al., 2018) and ongoing threatening dynamics as urban sprawl, irreversible land-use changes, resource and energy-intensive consumption patterns, urban areas are a critical field of study to understand how to conserve and improve biodiversity globally (Luederitz, et al., 2015) and, at the same time, learn how to intervene in the built environment to provide cities with ecosystems services: a range of benefits granted by natural ecosystems (Millennium Ecosystem Assessment, 2005) (Danley & Widmark, 2016), involving in cities the improvements in air quality and microclimate regulation, recreational opportunities for nature experience and sports activities, water regulation and stormwater runoff control (Ronchi & Salata, 2022). The enhancement of green infrastructure is also connected with multiple health benefits (Dipeolu, Akpa, & Fadamiro, 2020) and can also promote crucial investment and business opportunities to foster Europe's economic recovery following the COVID-19 crisis (European Commission, Directorate-General for Environment, 2021).

This research is situated within the scientific activity of the National Biodiversity Future Center (NBFC), one of the five centres supported by the Italian post-pandemic National Recovery and Resilience Plan, focusing on frontier research aligned with European research priorities. The NBFC's goal is to generate knowledge for conserving, restoring, monitoring, and enhancing Italian and Mediterranean biodiversity. NBFC's Spoke 5 focuses on the generation of knowledge regarding the conservation and improvement of urban biodiversity. Urban public spaces in Italy still exhibit a considerable lack of biodiversity. Nevertheless, documents such as Law No. 10 of January 14, 2013, "Regulations for the Development of Urban Green Spaces", the National Strategy for Public Green Areas[1] issued in 2018, and the integration of the EU's Biodiversity Strategy for 2030 into a national strategy[2], reveal a regulatory and cultural context where the role of urban biodiversity is acknowledged as crucial for creating sustainable and resilient urban environments. Therefore, the city of Milan serves as a significant context for the investigation presented in this paper: it boasts a high-quality, consolidated urban environment that has experienced rapid growth and densification over the last two decades, particularly in regeneration areas within and around the city centre. This growth has highlighted the prominent role of architecture in embodying the city's economic and cultural development. Simultaneously, both the municipality and the metropolitan city are committed to improving the quality of public spaces through forestation policies and naturalization programs.

1.2 Problem Statement and Research Gap

Several frameworks and disciplinary approaches have been developed globally in recent years to design greener and more biodiverse cities while ensuring their functionality and livability (Beatley & Newman, 2013; Garrard, et al., 2018; Kirk, et al., 2021; Dizdaroğlu, 2022). In such models, the architectural composition is often relegated to a peripheral role in favour of larger-scale, ecology-related tools and systemic approaches, which are believed to be more effective in addressing complex, multifaceted, and extensive issues related to the integration of nature in the built environment in a comprehensive manner. However, architectural composition can provide substantial contributions to the challenge of envisioning urban public spaces that conserve and implement biodiversity and, at the same time, are also beautiful, safe and accessible for citizens.

The paper explores the disciplinary contribution that architectural composition and urban design can provide to the conservation and enhancement of urban biodiversity. It investigates the possibility of

[1] See Ministero dell'Ambiente e della Tutela del Territorio e del Mare - Comitato per lo Sviluppo del Verde (2018). Strategia nazionale del verde urbano [Narional Strategy for Urban Green Areas].

[2] See Ministero dell'Ambiente e della Sicurezza Energetica (2023). Strategia Nazionale Biodiversità 2030 [National Biodiversity Strategy 2030].

morphological definition of open spaces and spatial conditions that are potentially conducive to the development of organic components, the increase of biodiversity, and the provision of ecosystem services while, at the same time, outlining highly accessible and visible public green spaces. Combining the tradition of morphological and typological studies (Muratori, 1963; Caniggia, 1979) with the more recent research on urban biodiversity is an interdisciplinary approach that remains underdeveloped yet holds great potential. In recent years, a relatively limited number of studies have attempted this combination. Among these, Ståhle (2005) and Marcus (2008) have explored the connections between urban form and its influence on environmental ecology. Marcus and Colding (2011) discuss how to shape urban development towards more sustainable directions. Benelli and Pellegrini (2013) propose a methodology to relate settlement forms to different climatic and environmental performances. Andersson and Colding (2014) delve into how built urban forms influence biodiversity by comparing different suburban residential patterns in relation to their surroundings. More recently, Palazzo (2022) reflected on the potential to bridge urban morphology and urban ecology, starting from conceptualising cities as urban landscapes (Andersson, 2006; Forman, 2008; Forman, 2014) to identify patterns that better support urban resilience within the historic city framework. Much like the present study, these studies share a common trait: the development of geometric descriptions of urban forms pertinent to ecosystem services and environmental issues. They all advocate for a more interdisciplinary approach, where each discipline must acknowledge its potential role and express its limits to foster collaboration. This investigation aims to further contribute to the relationship between urban form and biodiversity potential, particularly by closely examining newly constructed contexts in medium-to-high-density urban areas resulting from regeneration projects.

1.3 Objectives and Contribution to the Field

This research has multiple objectives: 1) define a new methodology for the morphological analysis of urban open spaces aimed at recognizing biodiverse potentials in urban morphologies; 2) identify urban and architectural morphologies that are more conducive to supporting the conservation and development of urban biodiversity, as well as the provision of ecosystem services, and to generating more favourable conditions for citizens' interaction with nature; 3) generate useful knowledge to enhance biodiversity in new constructions and interventions in the existing built environment as a basis for the future definition of design guidelines; 4) considering the multidisciplinary of this issue, raise questions that can be addressed collaboratively with other disciplines to proceed in the direction of defining design guidelines.
The research focuses on five case studies selected from the Atlas of Urban Regeneration of the Municipality of Milan[3], on which quantitative analysis was performed at the urban and architectural scale, combined with qualitative remarks.
This study's expected contribution to the field of architecture, and more broadly, to the challenge of designing more biodiverse urban public spaces, revolves around the generation of new knowledge on the role that architectural composition and urban design can play in conserving and enhancing urban biodiversity and in the facilitation of ecosystem services provision. Additionally, the present research aims to provide guidance for integrated design approaches beneficial to designers and public administrations dedicated to enhancing urban biodiversity and ecosystem services in their cities (especially aimed at contexts similar to Milan).

1.4 Significance and Structure of the Paper

This research paper is organized into six parts. Following an introduction, the second part emphasizes the marginal role that architectural composition still plays in initiatives to enhance biodiversity in urban spaces. The third part introduces the analysis methodology, covering also the choice of the case study of Milan, highlighting its importance as a highly significant research context due to the rapid expansion of

[3] The Atlas is a periodically updated digital map developed by Comune di Milano - the Municipality of Milan - providing an overview of the ongoing urban regeneration projects (above 5000 sqm) and the most relevant public and private interventions.

buildings over the last two decades and the attention given to environmental performances of open spaces. The analysis methodology is based on a quantitative approach, combined with qualitative remarks, applied to five case studies within the city of Milan. Parts four and five present the findings and their discussion. Finally, the sixth part outlines conclusions regarding the main contribution of this paper to the field, presenting the limitations of the current study and the main perspectives for development towards a comprehensive and more robust research methodology.

2. Architectural Composition for Urban Biodiversity: An Overlooked Potential

In recent years, several frameworks and disciplinary approaches have been developed globally to design greener cities. Landscape Urbanism (Mostafavi & Najle, 2003) (Waldheim, 2006) proposes planning cities through the design of the landscape rather than buildings and infrastructure, imagining new relationships and possibilities among the elements involved, reasoning with horizontal alignments rather than vertical development and introducing an understanding of the dimension of time and the changing nature of environments into the planning process (Corner, 2006). Ecological Urbanism (Mostafavi & Doherty, 2010), stemming from Landscape Urbanism, bends the focus towards envisioning and planning cities not only as cultural constructs but also as artificial ecosystems, to be designed and organized based on their demand and supply of resources (Hagan, 2014).

Within these approaches, the architectural scale is often overlooked among the levels of intervention at which it is possible to make substantial contributions to envisioning biodiverse urban public spaces. Architecture is a critical field in the challenge to make cities more sustainable and biodiverse: the construction sector is responsible directly and indirectly for more than one-third of global energy and process-related CO2 emissions (Aste, Del Pero, & Leonforte, 2022), and buildings play a crucial role in the formation of urban heat islands; furthermore, architectural design holds the potential to shape the built environment and therefore drive or support greening strategies and integrated and sustainable models for urban biodiversity. Several recent innovations in the practice show through prototype buildings the feasibility of integrating trees and greening in architecture, especially in the framework of NBS at the building scale (World Bank, 2021), entailing the construction of new green roofs and green façades on new buildings or existing buildings. Biophilic design, on the other hand, poses humans' innate connection to nature as the foundation of an approach aiming to incorporate natural elements and references into the built environment to improve physical and mental well-being, enhance productivity, and promote a sense of harmony (Kellert, Heerwagen, & Mador, 2008). However, as far as efficient systems, in most cases, these strategies are not involved in the compositive conceptualization of the building: they represent "applied" solutions that are integrated into the design process at a later stage than other fundamental disciplinary tools of architectural design. A similar issue exists with the framework known as Animal-Aided Design (Hauck & Weisser, 2019) which, despite looking at the urban environment as an integration of scales and dimensions, including architecture, this approach is more oriented towards applied strategies *on* and *around* buildings, rather than investigating the effect of their outlining, composition and massing towards biodiversity.

Apart from these innovations, there is a general lack of attention to integrating urban biodiversity targets among the main challenges in the field of architecture. Furthermore, urban greening plans or strategies rarely involve the architectural scale: research developed within Activity 3.1 of NBFC Spoke 5 reveals that urban Green Plans[4] (Pastore & Lazzarini, 2024) in Italy have a scarce commitment to implementation (Lazzarini, Mahmoud, & Pastore, 2024), highlighting, among the rest, a weak ability of planning instruments to engage with the architectural and urban design scale and domain. Given the multidimensional nature of urban challenges, it is crucial to increase knowledge on the possible role of

[4] In Italy, the Green Plan is a voluntary tool supplementary to general urban planning. It defines the city's profile in terms of fundamental natural ecosystems and collects strategies, guidelines and actions for developing and enhancing urban and peri-urban green spaces. The Green Plan serves as a strategic instrument directing local urban transformation policies and municipal decisions regarding public green spaces, establishing principles and criteria for their development, shaping the city's green landscape. See Pastore, M. C. & Lazzarini, L. (2024). Piani e strategie del verde per la biodiversità urbana. In *Urbanistica Informazioni*, 313, pp. 67-72.

architecture in better integrating design solutions at different scales for more sustainable and biodiverse urban environments. Architectural composition can make a key contribution to the challenge of designing biodiverse urban public spaces by employing disciplinary fundamentals such as morphological study and typological methods: it can integrate ecological and qualitative requirements of urban public spaces, creating the conditions for biodiversity to thrive while ensuring that these spaces are safe, allergy-free, easy to maintain, welcoming, and accessible, suitable for developing high-quality uses and fostering meaningful relationships.

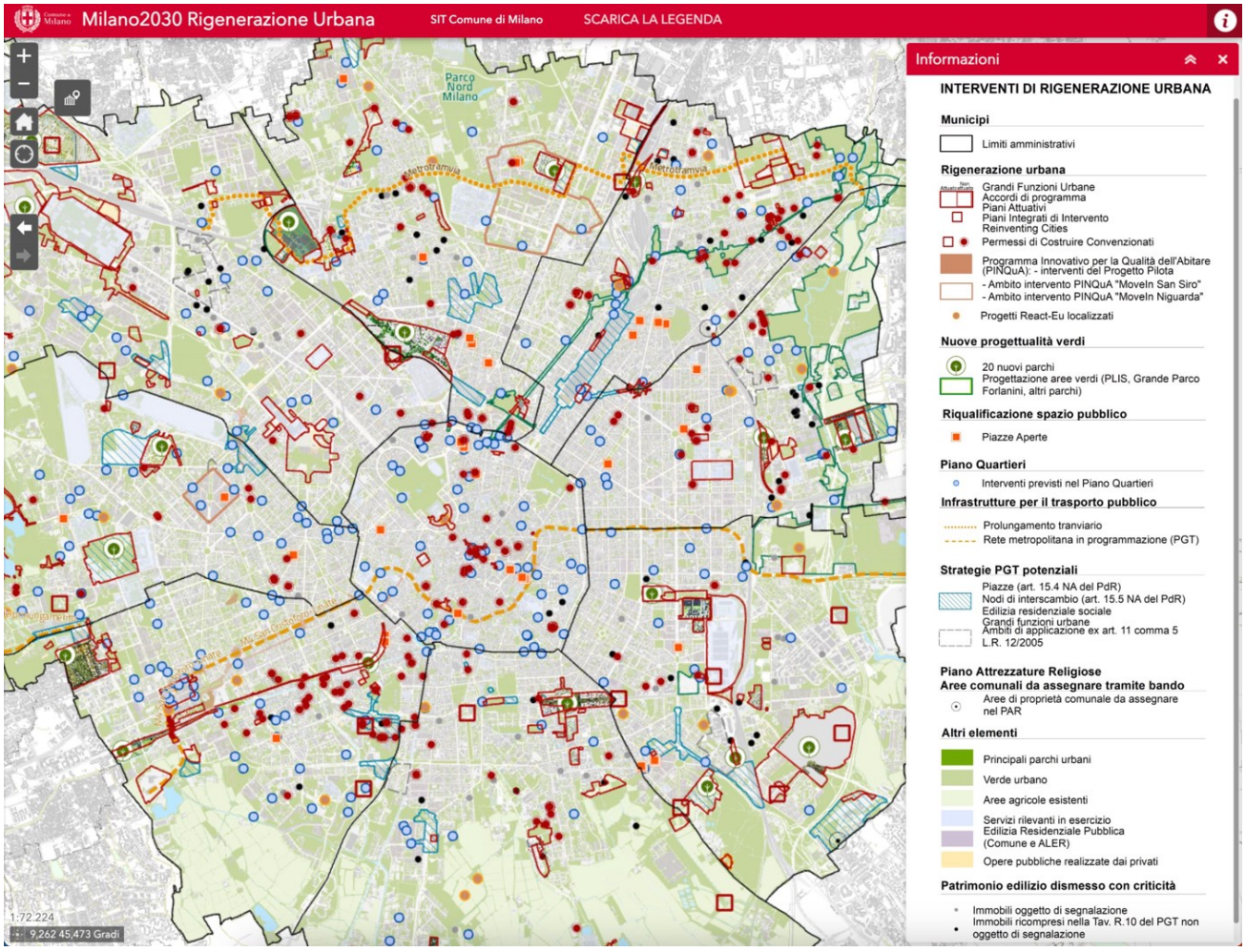

Figure 1. Extract from the Atlas of Urban Regeneration of the Municipality of Milan. The online Atlas map provides an overall and periodically updated view (Credits: Municipality of Milan).

3. Materials and Methods

3.1 Study Design and Setting

The methodology's first step involves choosing a context of study. The NBFC Spoke 5 research units are based in Milan (Politecnico di Milano, Università degli Studi di Milano-Bicocca), Florence (Università degli Studi di Firenze), Rome (Sapienza Università di Roma) Campobasso (Università degli Studi del Molise), and the different locations where Consiglio Nazionale delle Ricerche – CNR is based. Milan is the spatial context where the majority of Spoke 5 researchers are based, and the city has been chosen as the context of this study due to the potential usefulness of the results to further Milan-based research within Spoke 5. Furthermore, the city of Milan was chosen as it offers a compelling example for studying the role of urban open spaces in medium and large-scale developments, focusing on the existing relationships between biodiversity and different urban morphologies, for a large amount of land developed

or re-developed over the past 30 years, which amounts around 10 square kilometres[5]. Milan has undergone multiple large and medium-scale transformations, continuously following one another: a rare occurrence at the Italian national level and a prominent case also at the European level.

At the same time, the city of Milan is characterized by local regulations, such as the Piani di Governo del Territorio (territorial government plans) along with actions resulting from public-private negotiations (PRU - Urban Redevelopment Program, Programma di Riqualificazione Urbana - and PII – Integrated Intervention Program, Programma Integrato di Intervento), which have consistently considered the need to improve public green spaces and parks; initiatives such as "Nine Parks for Milan"[6] (Comune di Milano, Laboratorio di progettazione urbana, 1995) (Marinoni, 2007) and, more recently, "20 Parks for Milan"[7], the strategic policy document "Future Landscapes - Milan: open spaces in a metropolitan vision"[8], the "Public Green Regulations of the Municipality of Milan"[9], "Forestami"[10] project, the "Guidelines for the design of the public space"[11] and many other initiatives demonstrate, together with a vibrant public debate, how urban planning and implementation tools for urban development have strengthened environmental parameters and, at the same time, have oriented public interest towards recognizing the benefits of urban nature and advocating for a more widespread presence of green spaces in the city of Milan. The rapid pace of building activity in Milan has transformed the city's landscape within a few years. This speed also allows us to observe how, over a short period, the evolution of public discourse about the benefits of urban nature – both in Milan and at the European and global levels – has influenced, or failed to influence, architectural morphologies and settlement layouts.

With the aim of uncovering which urban morphologies are most conducive to creating space and conditions for biodiversity to thrive, as well as providing ecosystem services while ensuring high accessibility and visibility, the research focuses on five case studies of architectural and urban development in Milan conducted in the last three decades, chosen among a broader selection, to investigate how their building morphology influences their interactions between open and built spaces. A quantitative-qualitative analysis is conducted at the urban scale, involving tracing the perimeter of open space in each case study, examining their shape, compactness articulation, and continuity conditions that the perimeter edges can establish with the elements of the adjacent urban fabric. The quantitative investigation includes: 1) the connectivity established within each case with existing or potential ecological corridors and/or green infrastructures at the municipality level; 2) the connectivity established within each case with green areas at the neighbourhood level; 3) the extension of building fronts (intended also as windowed fronts, which allow for overlooking outside) generated by each case within the masterplan; 4) the extension of building fronts from the existing urban fabric with which each case establish connectivity; 5) the "compactness" of each open space. Qualitative remarks are then expressed to supplement the quantitative findings.

[5] See Scenari Immobiliari (2023), Primo Rapporto Nazionale sulla Rigenerazione urbana [First National Report on Urban Regeneration].

[6] The strategic project elaborated in 1995 on behalf of the City of Milan by the Urban Design Laboratory, with a concept by Pierluigi Nicolin, Cecchi & Lima and Pippo Traversi, envisages the definition of a broad strategy of restructuring the form of the city starting with the configuration of nine urban parks in peripheral areas, where buildings are structured around new central urban parks. See Comune di Milano, Laboratorio di progettazione urbana (1995*). Nove parchi per Milano* [Nine Parks for Milan]. Milano: Electa and Marinoni, G. (2007). Milan. An Evolving City. The changes in strategies of transformation from 1984 to 2007. In *Lotus navigator*, 131, pp. 132-141

[7] "20 parks for Milan" is among the initiatives of the territorial government plan in force "Milan 2030" for a green, livable and resilient city.

[8] See Bisconti, C. & Balducci, A. (2016). PAESAGGI FUTURI. Milano: spazi aperti in una visione metropolitana [Future Landscapes - Milan: open spaces in a metropolitan vision]. Comune di Milano.

[9] See Comune di Milano (2017). Regolamento d'uso e tutela del verde pubblico e privato [Regulations for the use and protection of public and private green space].

[10] "Forestami" is the project promoted by the Metropolitan City of Milan, Milan City Council, Regione Lombardia, Parco Nord Milano, Parco Agricolo Sud Milano, ERSAF e Fondazione di Comunità Milano, which plans to plant 3 million trees by 2030 to grow natural capital, clean the air, improve life in greater Milan and counter the effects of climate change. Born from research by Politecnico di Milano thanks to the support of Fondazione Falck and FS Sistemi Urbani.

[11]See Comune di Milano & AMAT Agenzia Mobilità Ambiente e Territorio (2021). Spazio pubblico. Linee guida di progettazione [Public space. Design guidelines].

Figure 2. Planimetric extract of the 15 urban-scale interventions detailed for this study. The park area is highlighted in red on the aerial photo. The projects, listed vertically from top left, are: Merezzate, Figino Borgo Sostenibile, Ex Macello, Ex Trotto, City Life, Cascina Merlata, Ex Scalo Porta Romana, Ex Scalo Farini, Porta Nuova, Ex OM, Adriano, Palizzi, Santa Giulia, Ex Calchi Taeggi, Ex Piazza d'Armi. (Aerial photos: Google Earth; edited by the authors with Michele Porcelluzzi).

3.2 Materials

Five case studies carried out in the last three decades were selected from the Atlas of Urban Regeneration of the Municipality of Milan (Figure 1). Among the regeneration areas listed in the Atlas, the selection criteria excluded transformation areas under 10.000 sqm, those under construction, those that did not involve an increase in the volume of residential use, those that did not provide substantial associated open spaces, and those presenting non-recurring morphologies deemed irrelevant for building a thesis due to their infrequency. The results of this initial selection identified 15 regeneration areas (Figure 2), from which 10 were excluded due to their unique characteristics (such as the presence of heavy infrastructure, the presence of a water body, the recreation of historical layouts), making them less comparable to the others. Consequently, five case studies were selected as they presented comparable spatial conditions. The five selected case studies are the districts named PII Santa Giulia, PII Cascina Merlata, PII CityLife, PII Garibaldi-Repubblica, PII Calchi Taeggi e Bisceglie. With the exception of Cascina Merlata, which was built on former agricultural land, the cases studied have in common that they are developed on land previously occupied by other functions, often called brownfields. These include former industrial areas released by relocations, as seen in the cases of Santa Giulia and Calchi Taeggi; former urban macro-functions, as in the case of City Life, which replaces the old pavilions of the Milan Trade Fair; and urban voids created by the transformation of the railway system, as in the case of Garibaldi-Repubblica. This means that, in most cases, the start of the transformation is preceded by land reclamation from polluting sources. In examining their location in relation to the more consolidated parts of the city, the selection includes areas located in densely built-up central areas, immediately adjacent to the consolidated city, and more rarefied peripheral contexts, as seen in the other three cases.

3.3 Procedures and Data Analysis

The cases were examined using publicly available project documents, orthophotos, and direct observations during visits. The perimeter of the open space in each area was traced using AutoCAD software (Figure 5). The Municipal Ecological Network map[12] of Comune di Milano (Figure 3) was superimposed onto each area to evaluate the compliance with existing or potential ecological corridors and the openings' width (Figure 6). Connectivity towards four elements (existing or potential ecological corridors and/or green infrastructures at the municipality level, green areas at the neighbourhood level, building fronts within the masterplan, and building fronts from the existing urban fabric) was visually represented in schemes using different lines and symbols, to aid in visualizing the conditions of each perimeter (Figure 7).

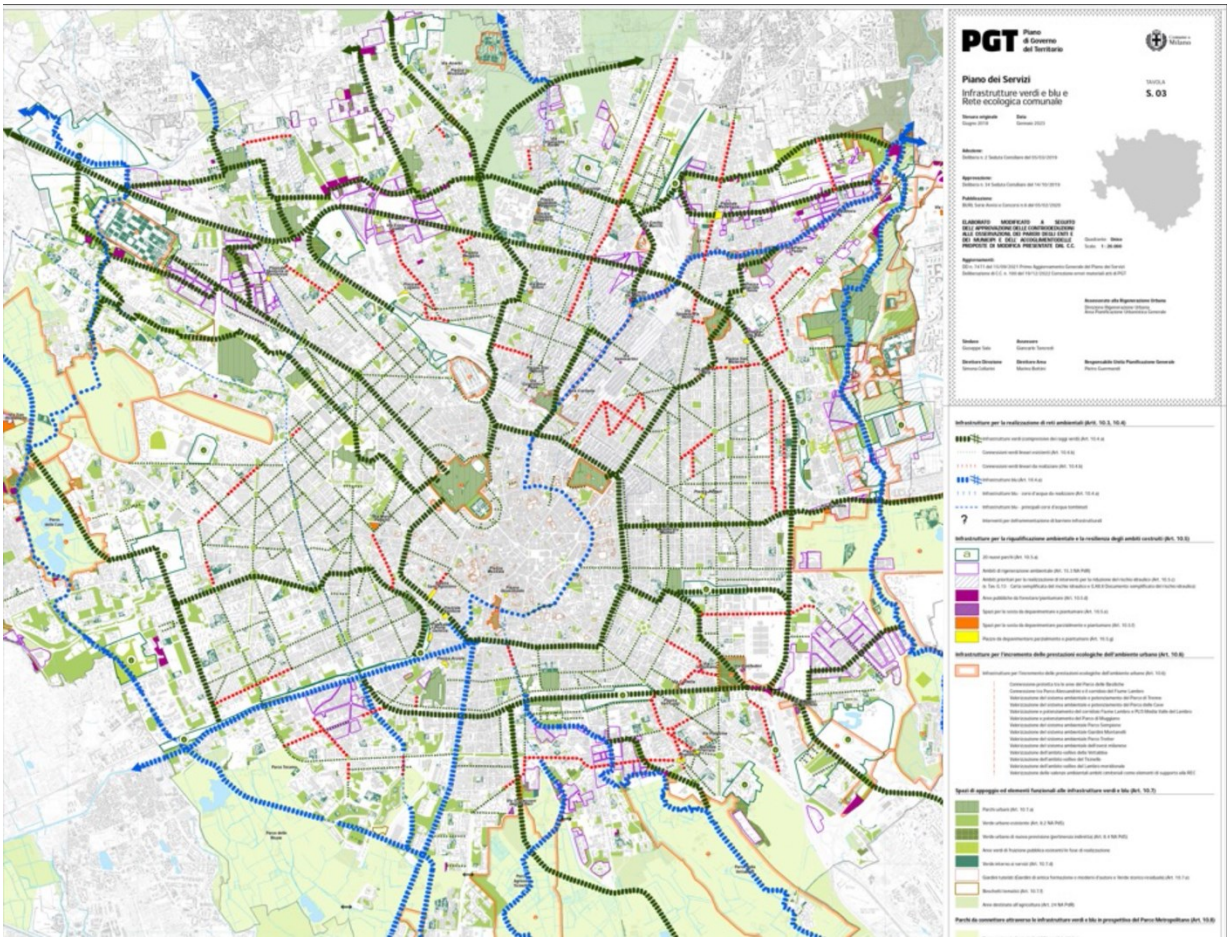

Figure 3. Extract of the 'Municipal Ecological Network and Urban Green and Open Space System' map. Territorial Governance Plan of Milan. (Map: Comune di Milano).

A "compactness" index was calculated by relating the perimeter and area to understand the relationship between the compactness of the open space outlines and their ability to provide a higher ratio of ecological connectivity and citizens' accessibility as well as views from the architectural objects part of the same masterplan and those part of the existing urban fabric.

Perimeters and their connectivity conditions were compared visually to assess which case offered better conditions for the conservation and implementation of urban biodiversity. The results of this comparison were then coupled with the qualitative characteristics of such spaces and the potential biodiversity

[12] The Plan of Services – Piano dei Servizi (PdS) of the Territorial Management Plan of the city of Milan includes elaborates describing at the different territorial scales, regional, provincial and municipal, the ecological network of the city of Milan: its green endowment, ecological corridors and the system of green connecting rural and built-up territory, as well as between road works and urbanized areas and their rational distribution over the municipal territory to support settlement and planned functions.

conditions they may create, providing an opportunity to reflect on the possible interconnection between ecological connectivity and citizens' accessibility and views. The diagrams (Figure 7) enable the interpretation of contexts, and their abstract nature makes them suitable for transferring the methodology and the emerging topic to other case studies. The study does not explicitly consider variables such as management, choice of plant species, or maintenance, nor does it measure actual biodiversity. The considerations primarily focus on spatial configuration.

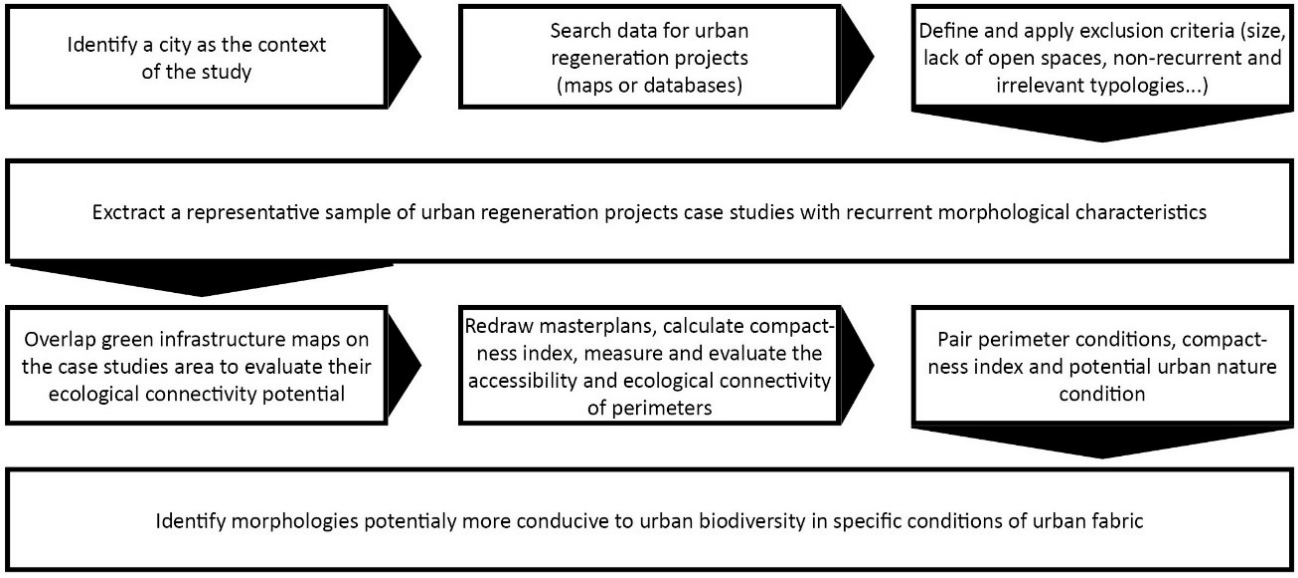

Figure 4. Methodology of the Research.

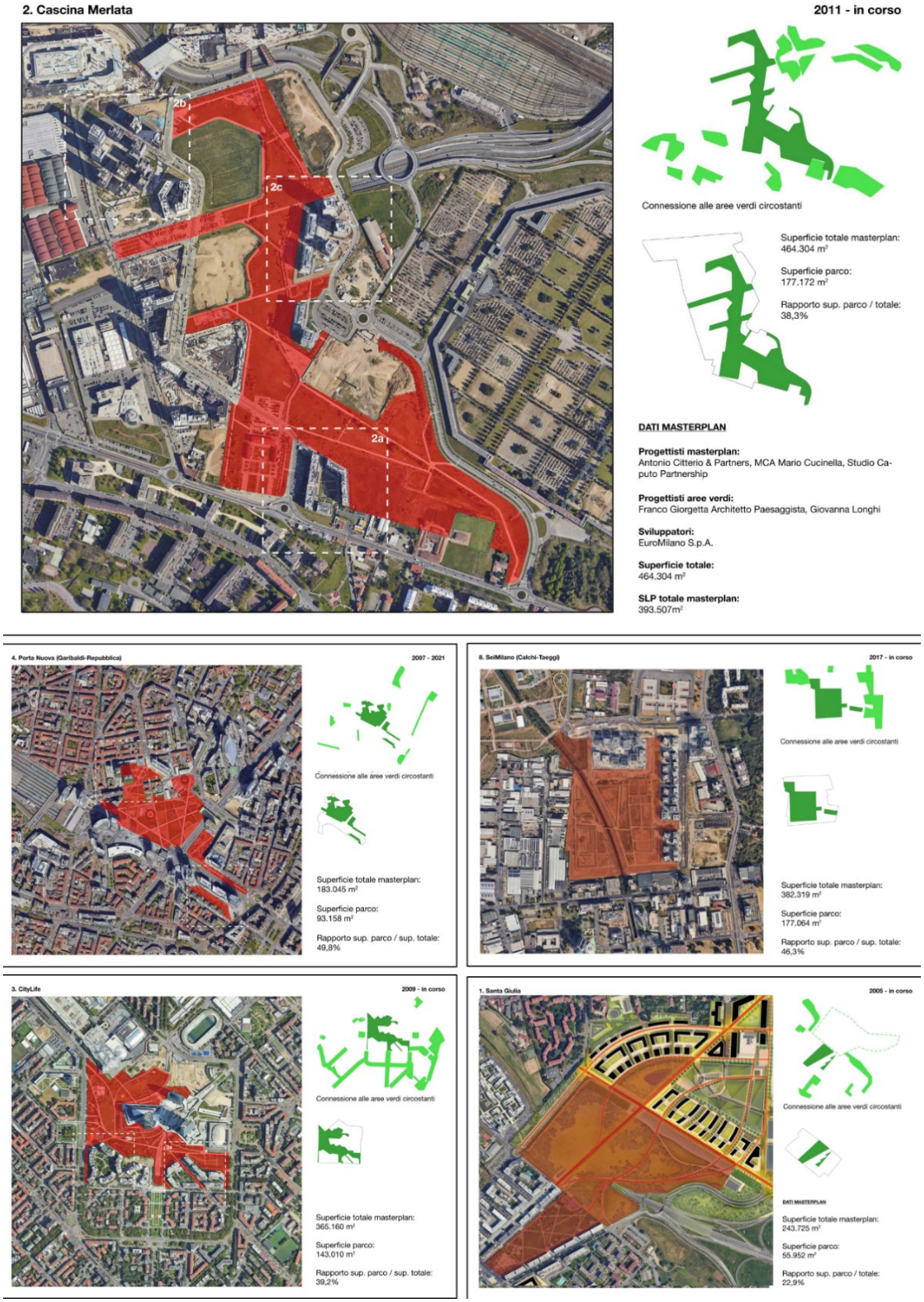

Figure 5. Extract from the analysis files of the five sample projects selected as representative of the most common morphologies. Drawings by the authors with Michele Porcelluzzi. (Map: Comune di Milano. Aerial photographs: Google Earth).

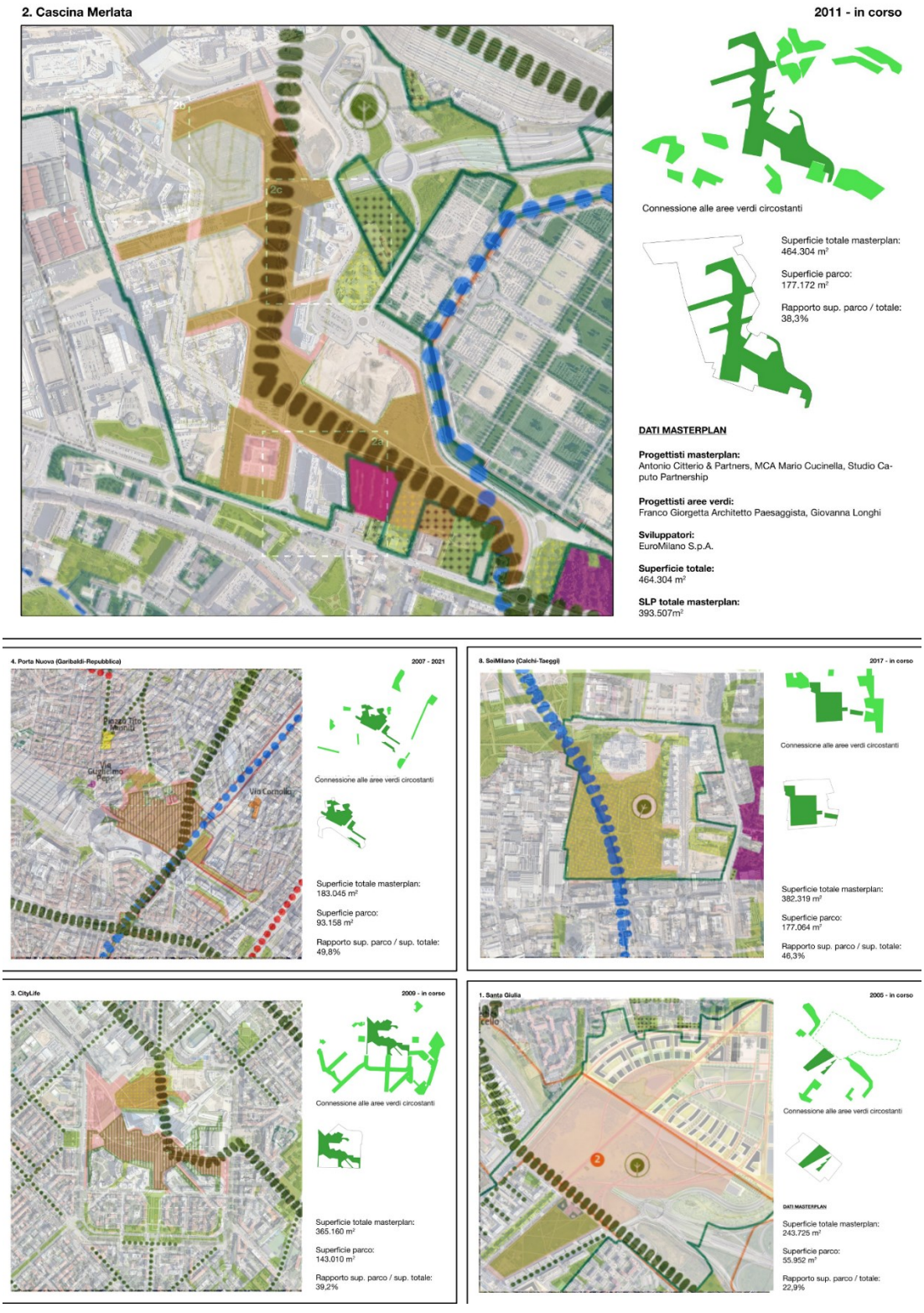

Figure 6. Extract from the analysis files of the five in-depth case studies, superimposed on the map 'Municipal Ecological Network and Urban Green and Open Space System' of the Municipality of Milan, to assess consistency with existing or potential green infrastructure. (Aerial photos: Google Earth; map: Comune di Milano; edited by the authors).

4. Results

4.1 Presentation of Key Findings

The results of this investigation allow us to answer the initial research question preliminarily: it is possible to outline some correlations between urban morphology, potential biodiversity, and the level of accessibility and visibility of green spaces. These correlations concern, at the urban scale, some characteristics that may be crucial in defining the biodiverse potential of a given settlement form: (1) the variation in the compactness[13] of the green surface and/or its articulation, and (2) the continuity conditions that the perimeter edges can establish with the elements of the adjacent urban fabric. During the study, important considerations emerged at the scale of the built plot: (3) the degree of permeability of the building front adjacent to the perimeter and, consequently, the possibility of ecological exchanges to and from the areas pertaining to the plots. The analysis of these characteristics with respect to the cases under study led to the identification of three recurring morphologies, which present different characteristics capable of generating different conditions for the potential development of urban biodiversity in terms of accessibility and visibility: the "Central Park", the "Fluid Park", and the "Garden Between Houses". The study was limited to the Milanese context and a time range identified within the last 30 years.

5. Discussion

5.1 Interpretation of Key Findings

The results obtained from this study have enabled the development of an interpretative framework aimed at substantiating the initial hypothesis, namely the existence of a relationship between urban form and biodiversity. This framework also preliminarily defines an analysis method to evaluate a given settlement's biodiversity potential. The following paragraphs, therefore, present a series of considerations with potential implications for design practice, exploring the geometric reasons that make some settlement forms more predisposed to foster the development of organic components, enhance biodiversity, provide ecosystem services, and define highly accessible and visible urban public spaces. The main distinguishing aspects will be highlighted, initially at the urban scale and subsequently at the scale of each single plot. The analysis method developed has been applied to the urban transformations of the Milanese territory, although it is believed that it can be generalized. This has allowed the identification of some recurring morphological settings that respond to different quantitative and qualitative relationships between green spaces and built parts. The ability to recognize these different geometric settings has enabled us to reflect on the diverse potential that each morphology possesses in favouring (or hindering) the construction of a biodiverse urban environment and equitable access to the latter – inspired by parameters such as the 3-30-300 rule[14] (Konijnendijk, 2021). Considering that this represents the inaugural step in a newly initiated and developing research line, some limitations and directions for future development are outlined.

5.1.1 Compactness / Articulation: Three Morphological Categories

Starting the morphological analysis at the urban scale, the first discriminator that allows categorisation is related to the degree of compactness (or articulation) assumed by the open green areas in relation to the built environment. A compactness index, resulting from the geometric ratio between the perimeter of the green area and the area itself, can give indication of the biodiversity potential of a given urban form, e.g. it quantifies the amount of green front per unit area. The increasing value of this ratio describes the transition from a more compact geometry to a more articulated one, approximating the ability of a given shape to generate areas of exchange with the peripheral built spaces, whether existing or planned. This first phase of the study, limited to the Milanese context and to a specific time period, identified three main categories that, although arising from the specific context of the study, exhibit a certain degree of

[13] A compactness index can be defined by the ratio of green area perimeter to green area.

[14] Applying the 3-30-300 rule can help improve urban forestation in many cities, promoting health, wellbeing, and resilience. The rule suggests that every citizen should be able to see at least three trees (of a decent size) from their home; that in every neighborhood a minimum percentage of 30% of tree canopy cover can ensures that residents benefit in terms of health and wellbeing; a maximum distance of 300 metres to the nearest green space can encourage the recreational use of green space with positive impacts for both physical and mental health. See Konijnendijk, C. (2021). The 3-30-300 Rule for Urban Forestry and Greener Cities. In *Biophilic Cities Journal*, 4(2).

generalisation: the "Central Park", the "Fluid Park", and the "Garden Between Houses". These three morphological categories present different compactness and connectivity levels to different elements and urban environments, potentially creating the spatial conditions for the development of urban biodiversity.

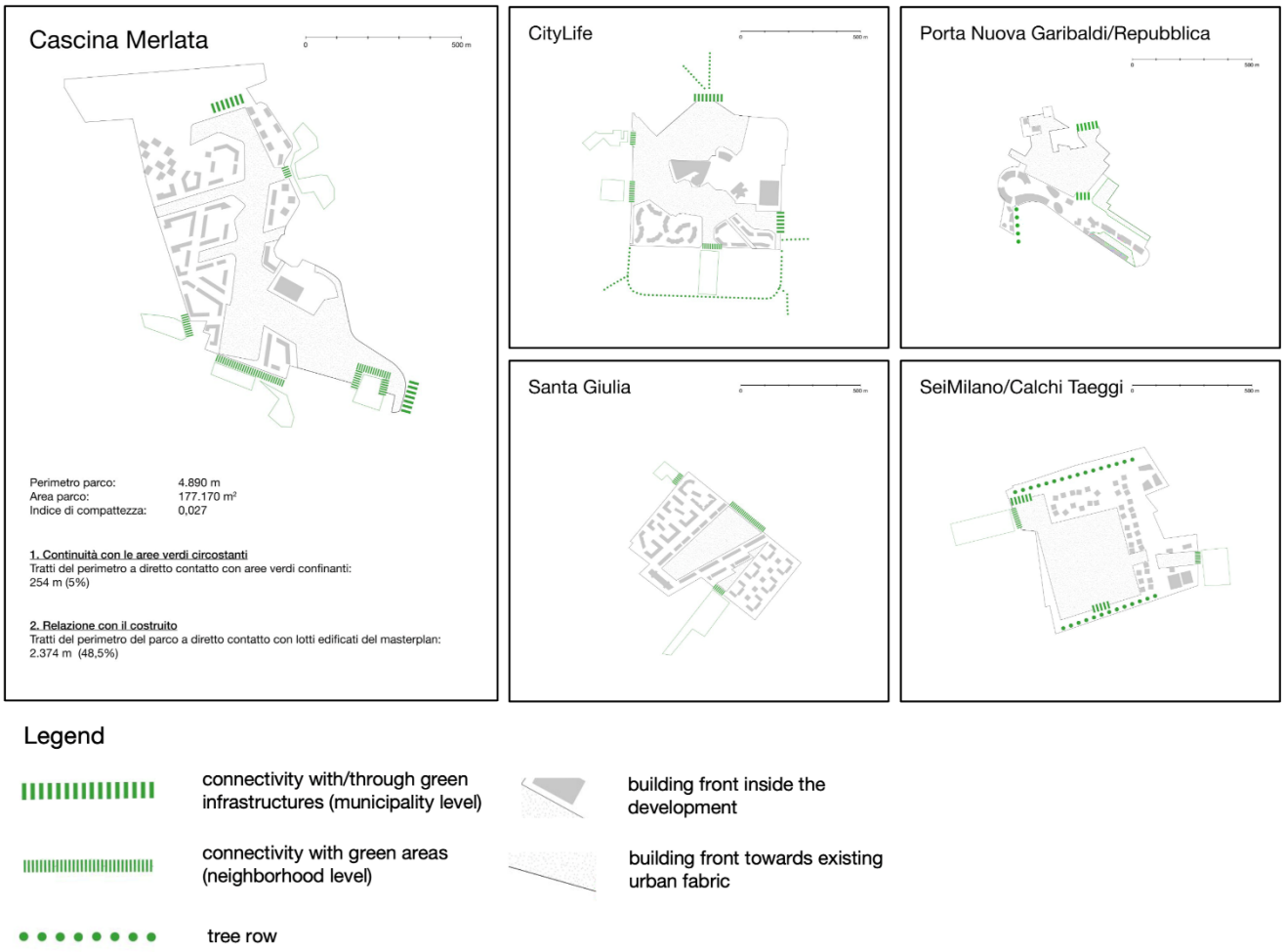

Figure 7. Example of graphical results of the proposed analysis method. The perimeter of the open space is drawn with different graphic symbols to highlight the connectivity with the different elements and the tangency with the different urban environments. (Drawings by the authors with Michele Porcelluzzi).

The "Central Park" features settlement forms that clearly distinguish between the areas allocated to the public park and built lots (mainly residential). In this case, the large green space presents a compact geometry characterized by a low perimeter-to-area ratio. In the most representative cases, the use of a regular form prevails, aspiring to define a recognisable and identity-bearing geometry. Among the characteristics of this settlement form, the reduced perimeter relative to the green surface tends to concentrate and limit contact points with the built environment (newly constructed or belonging to the existing urban fabric) and territorial systems. Additionally, greater geometric compactness correlates with an increased average depth separating from the edge to the park's centre, creating conditions favourable to biodiversity – for example, reducing light or noise pollution in the park's core. For this same reason, however, green areas farther from inhabited zones are less frequented at night, which can lead to safety concerns. Examples in this category include the completed interventions of Garibaldi-Repubblica and Calchi Taeggi and the park planned by the Santa Giulia district masterplan, partially realised today.

Like the previous category, the "Fluid Park" refers to settlement forms that define a clear distinction between the areas allocated to the public park and built lots. Unlike the previous case, the "Fluid Park" presents a complex, articulated geometry, resulting in a long perimeter in relation to the enclosed area. In the most representative cases, the perimeter presents a complex and branched geometry that tends to maximize contact points with the surrounding built environment and territorial systems, facilitating the reconnection of natural elements. Compared to the "Central Park" model, this condition can offer more benefits for ecological connectivity at both the neighbourhood and metropolitan scales and greater accessibility and visibility between the park and the built volumes. Examples of this category include the City Life and Cascina Merlata interventions.

A third category emerged from the initial selection of case studies. Even if it was not analysed in detail in the five case studies, it emerged as relevant and will require future investigation. Unlike the previous categories, the "Garden Between Houses" refers to settlement forms that do not clearly distinguish between areas allocated to the park and the built lots. This approach does not introduce a large, autonomous park separate from the built lots, but promotes a more homogeneous and integrated distribution between green spaces and built volumes. In contrast to the previous cases, where there was a concentration of overall volumes in densely built lots with limited spaces for nature, this third category involves a more horizontal distribution of building density and green spaces. With equal overall volumes, the built environment can be developed on a smaller scale, with open spaces more closely resembling a neighbourhood garden: an articulated network of houses and gardens for local use rather than an urban park. This morphological category allows for small-scale green development, which does not necessarily enhance ecological connectivity on a metropolitan scale but can generate local or neighbourhood-scale biodiversity or the possibility to experience biodiversity in domestic outdoor spaces (Uwajeh & Ezennia, 2018), supported by various private frontages (Beumer & Martens, 2015). Integrating green spaces with inhabited areas results in high accessibility, visibility, and safety — both real and perceived – and can benefit from informal surveillance by residents. Examples include the interventions in Figino, Merezzate, and Crescenzago.

5.1.2 Continuity Conditions along the Edge

The proposed analysis method includes a qualitative examination of how the edges along the perimeter of green surfaces are designed. Characterising these edges allows for the description, through quantitative data (percentage of perimeter length) and qualitative planimetric diagrams, of the capacity generated by a given settlement form to interact with (1) primary elements of ecosystem continuity, such as existing ecological corridors and/or green infrastructures at the municipality level, environmental networks, and biodiversity nodes; (2) secondary elements, such as roadside trees or arboreal areas covering parking spaces and green areas at the neighbourhood level; (3) building fronts belonging to the same settlement system or referring to the surrounding urban fabric. The greater a settlement form's ability to introduce continuity conditions along green surface edges, generate or strengthen ecosystem networks, and interact with the built environment, the greater its biodiversity potential.

5.1.3 Permeability of Built Fronts

A second complementary analysis must be introduced to complete these initial considerations, focusing on the internal morphology of individual built lots. This internal morphology can vary independently of the overall settlement scheme and the geometry assigned to the green surface, impacting ecosystem continuity along the edge. The settlement forms adopted within the lots are clearly influenced by the quality of frontages and the potential relationships the built environment can establish with the surrounding context. Different morphological choices can thus exploit these opportunities to varying degrees, either limiting or multiplying them. The distribution of volumes can propose either closed geometries, defining discontinuous and introverted courtyards, or permeable geometries, where the heart of the lots is in continuity with the surrounding open space system. In these cases, the biodiversity potential

varies depending on a series of interrelated geometric factors impacting the quality of open space between buildings. Designing a permeable building front, for example, involves repositioning volumes to free up the plot's edge. In purely geometric terms, these volumes can find new placement by increasing in height or occupying internal open spaces within the plot. These choices impact aspects such as the presence of trees or shrubs (whether in open ground, planters, or pots) within the lot's depth, as well as the shading and usability conditions of the open spaces themselves. The analysis at this scale was implemented using a taxonomic approach, extracting from the selected urban transformations a number of samples able to represent the most recurring typical conditions.

5.2 Limitations and Implications and Future Directions

As stated, the study does not explicitly consider variables such as management, choice of plant species, or maintenance, nor does it measure biodiversity in any of the cases. The considerations primarily focus on spatial configuration. In this initial study phase, some possible additional morphological categories were excluded, such as modernist open-plan estates. Over the past 30 years, the international trend in Milan, as well as much of the continent, has followed settlement schemes proposing the idea of the *îlot ouvert* (Lucan, 2012), based on a clear identification of buildable lots, generally for private use, interspersed with networks of roadways and public spaces. Open-plan systems, characterised by single buildings distributed over entirely public, often predominantly green, land crossed by pedestrian and vehicular paths, refer to an earlier era of development recurring in Milan within Public Residential Housing contexts. Expanding the initial sample, both geographically and temporally, could, therefore, subsequently reveal additional categories. Future developments of this study, therefore, involve applying to the methodology to other architectural and urban typologies to assess their conduciveness to urban biodiversity.

6. Conclusion

In conclusion, based on the case study analysis and the results that emerged, this research suggests that within the context of large urban transformations involving changes in settlement layouts and new developments adjacent to established urban fabrics, there are no single morphologies definitely more suitable than others for conserving, promoting and implementing urban biodiversity while maintaining accessibility and visibility for citizens. Instead, different morphologies create different conditions that are potentially more favourable to specific objectives. This answers the research question and confirms the initial hypothesis about the possibility of identifying a morphological definition of urban open spaces that can foster the development of organic components, enhance biodiversity, provide ecosystem services, and define highly accessible and visible urban public spaces.

The study unveils how certain morphologies, with specific conditions, can be more suitable for conserving, promoting, and implementing urban biodiversity in specific spatial conditions within the surrounding urban fabric. Although it requires further study, this result is significant on several levels: it provides a possible decision-making tool for architects and urban designers for planning urban spaces to support green infrastructure networks. It also allows the examination of different design options to understand which can increase urban biodiversity, both in support of green infrastructure and as a qualitative factor in building development. This can have implications for quality of life by considering the accessibility and visibility of green spaces in new buildings or in urban and environmental regeneration actions.

Due to the complexity and diversity of variables in the analysed case study, the research scope was limited to analysing open space morphology at the urban scale, deferring an in-depth study at the building plot level to future studies. Another aspect not investigated concerns those factors interacting with morphology in determining the effective conservation, promotion and implementation of urban biodiversity, such as the choice of plant species, the positioning of species, maintenance, and user behaviour in the open spaces, among others. Furthermore, within this study, biodiversity is not measured but rather considered in the spatial characteristics that affect its development.

Another perspective of this research involves identifying issues related to the green transition of urban public spaces from an interdisciplinary perspective. This aims to identify interaction points among different areas of expertise. Future perspectives include transferring and verifying this method to other architectural and urban typologies to assess their conduciveness to urban biodiversity and in contexts other than Milan. This will help examine potential variables related to changes in the scale of the investigation context and/or different planning layouts. It will also verify the method in built environments characterized by settlement schemes from different historical periods, opening up further studies on the possibilities of intervention in the built environment by introducing or intensifying green landscapes. These perspectives contribute to refining and solidifying the methodology, making it not only an analytical tool but also a predictive one.

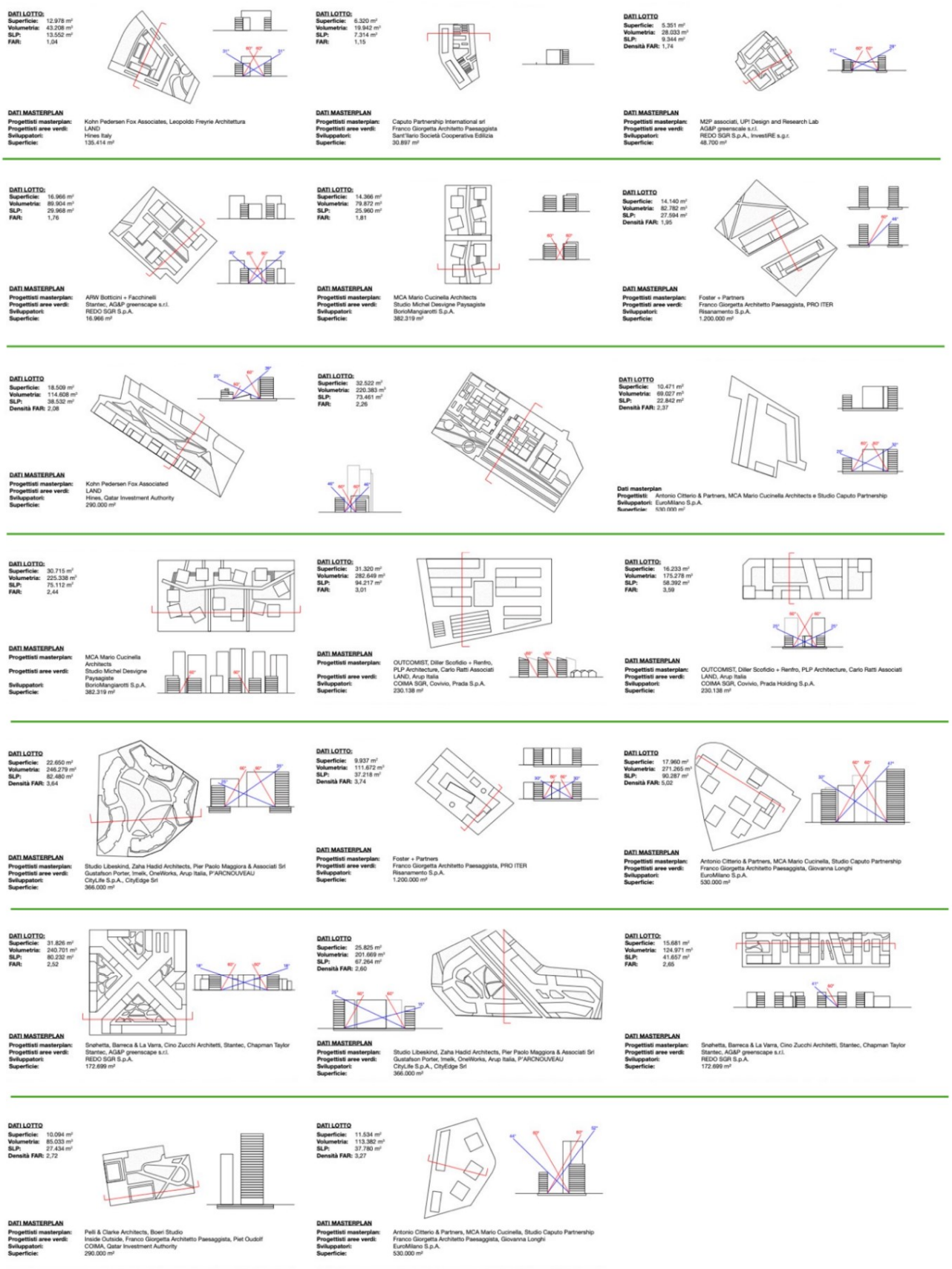

Figure 8. Morphological analyses of a sample of representative built plots extracted from the case studies to interpret the permeability of the built fronts. (Drawings by the authors with Michele Porcelluzzi).

Implications of the Findings

This study and its potential developments highlight the largely unexplored yet crucial role that architectural and urban composition, particularly morphological definition, can play in conserving, promoting, and implementing urban biodiversity while ensuring accessible public spaces. By identifying the correlation between urban morphology and biodiversity potential, this research contributes to the field of architectural and urban design and urban studies by shedding light on the role that architectural composition and urban design – and, therefore, architects and urban designers - can play in the emerging challenge of designing urban spaces aimed at conserving and enhancing urban biodiversity and facilitating ecosystem services provision.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data availability statement

The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding author.

Institutional Review Board Statement

Not applicable.

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F.L. and F.Z. share first authorship rights; the order is purely alphabetical. Conceptualization and methodology: F.L. and F.Z. Writing: Part 1, 6: F.L. and F.Z. Part 2, 3: F.Z. Part 4, 5: F.L. The figures, unless otherwise indicated, are elaborated by the authors. Both authors have read and agreed to the published version of the manuscript.

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