Hungarian University of Agriculture and Life Sciences

Institute of Landscape Architecture, Urban Planning and Garden Art

Fostering Resilient Cities through Urban Green Infrastructure: A Complex Evaluation Method for Urban Green Morphology on a Budapest Case Study Site

Theses of the Ph.D. dissertation

by

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Budapest,

Hungary 2024

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1.RESEARCH BACKGROUND

As a contextual background, in this study, 'urban resilience' is interpreted as the capacity of urban environments to withstand and adapt to adversities while maintaining their fundamental functions and identity (Meerow, Newell & Stults, 2016). The concept of urban resilience has become a key theme in urban planning, supporting development that balances growth with long-term liveability standards. The current ecological and socio-economic climate calls for a more attentive approach to the development—or revitalization—of existing urban centers. Thoughtful reconstruction has emerged as a viable alternative to large-scale demolitions or massive projects in distant locations.

Local residents' "appropriation of space" (Hory, 2023), where they reshape their environment, plays a vital role in enhancing urban adaptability. In Ferencváros, Budapest, the transformation of former industrial zones into dynamic mixed-use areas exemplifies this adaptive resilience, aligning with broader themes of socio-spatial dynamics explored in this dissertation. Urban growth presents sustainability challenges, as cities consume 70-75% of natural resources. Resilient cities mitigate these pressures by promoting compact, walkable neighborhoods, green spaces, and efficient public transit (Zucaro & Maselli, 2022).

Framing urban resilience within sustainable development involves addressing immediate climate and disaster risks while promoting long-term sustainability through integrated urban policies and stakeholder collaboration. Policy and governance are essential in this process, as resilient cities require multi-stakeholder frameworks to manage resources adaptively and inclusively (UN-Habitat, 2020; Vale, Shamsuddin, & Gray, 2019).

Urban Green Infrastructure (UGI) is recognized as an

effective resilience strategy, integrating natural systems into urban landscapes to address climate, urbanization, and socio-economic disparities. UGI provides cost-effective solutions for stormwater management, supports biodiversity, and mitigates the urban heat island effect, thereby strengthening ecological resilience (Ranjha, 2016; Staddon et al., 2018). Socially, UGI enhances public health, promotes equity by ensuring accessible green spaces, and fosters social cohesion. Economically, it reduces infrastructure costs while delivering ecosystem services. Successful UGI implementation, however, requires careful planning, interdisciplinary collaboration, and continuous assessment (Staddon et al., 2018; Connop et al., 2016).

This study examines São Paulo and Budapest to understand regenerative urban strategies in varied contexts. Ferencváros, Budapest's IX District, serves as the primary case study due to its advanced urban intervention and implementation of green infrastructure, which incorporates critical morphological elements supporting resilience. Ferencváros's selection was further supported by data availability and field investigation feasibility. The "Budapest 2030 Long-Term Urban Development Concept" underpins this study's objectives, prioritizing sustainability, resilience, and livability through resource management, UGI development, and social equality. This strategic framework also emphasizes compact urban growth, public transit, and the revitalization of brownfield zones, aligning with efficient land use and green preservation.

The research trajectory, illustrated in Figure 1, follows a structured process moving from the literature review through applied methods to a synthesis of findings organized in two phases: "results" and "expanded results," with the latter building upon the former.

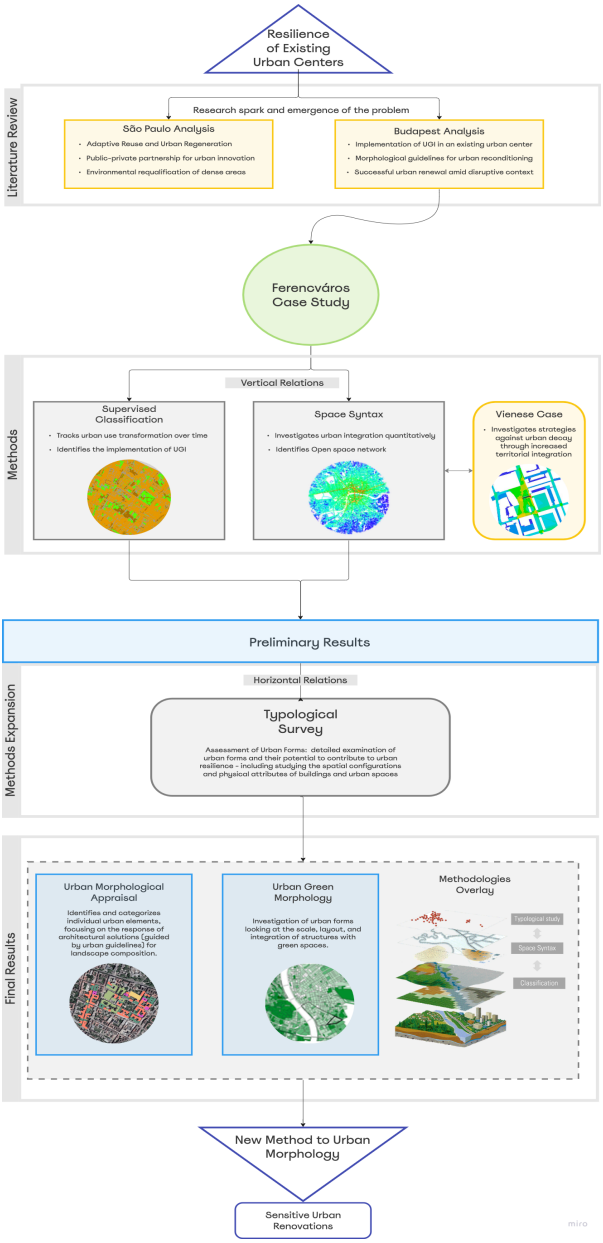

Figure 2: Research Structure Diagram

2. RESEARCH OBJECTIVES AND QUESTIONS

This research, centered on Budapest's IX District, systematically examines urban growth, transformation, and the role of green infrastructure in enhancing resilience. It investigates the evolution of urban densification and the interplay between built structures and natural elements. A critical analysis of urban renewal processes follows Budapest's shift from a centralized to a market-oriented system, exploring changes in the urban fabric, social dynamics, citizen well-being, and public-private housing strategies shaped by this transition. This analysis highlights how historical shifts continue to influence contemporary urban development, social equity, and spatial organization (Taraba et al., 2022).

A significant focus is placed on resilient urban structures and their impact on livability, specifically through the integration of sustainable design and green spaces. These resilient forms are shown to enhance both the aesthetic and environmental quality of urban areas, contributing positively to the city's social and ecological fabric (Yamagata et al., 2016).

Additionally, the study assesses the role of green infrastructure in promoting sustainable and circular urban development, examining how its design and placement foster more sustainable ecosystems within existing urban environments (Wang et al., 2018).

The research questions posed in this study are grounded in an exploration of the elaborate interplay between urban design, resilience, and sustainability. This investigation seeks to unravel how Urban Green Infrastructure (UGI), as both an ecological asset and an integral component of urban architecture, can catalyze

renewal and balance the increasing population density within existing urban fabric. The following questions are proposed to analyze various aspects of this interplay:

- **Exploring the Impact of Urban Green Infrastructure on Urban Performance**:
How does the integration of UGI enhance the functional performance and liveability of urban areas?
- **The Role of Typological Appraisal in Urban Resilience:**
What role does a detailed typological appraisal play in identifying resilient urban elements?
- **Reimagining Private Spaces for Public Benefit:**
How does the conversion of private to semi-public green spaces influence urban cohesion and community interaction?
- **Benefits of Territorial Connectivity in Dense Urban Environments:**
To what extent does establishing territorial connectivity in dense urban environments support urban resilience and circular economy principles?
- **Urban Green Infrastructure as a Strategy Against Urban Decay:**
Can a comprehensive approach to UGI serve as a strategy against urban decay, and how could it be adapted for various urban contexts?

By addressing these questions, the research offers a practical tool for urban morphology investigation applicable to urban development, particularly in areas experiencing social, political, and economic challenges. It provides a clear mechanism for renovating urban fabrics undergoing population densification and their evolution in response to contemporary challenges.

3.MATERIALS AND METHODS

This study adopts a multi-phase methodological framework designed to analyze the complex interplay between green infrastructure, urban morphology, and social cohesion within post-socialist cities, focusing on Budapest's Ferencváros district. Drawing from established urban development models—specifically the principles of the Barcelona Urban Ecology Agency and the LEED Reference Guide for Neighborhood Development—the framework synthesizes ecological urban planning with morphological analysis to address the challenges and potentials of urban renewal. Key methodologies include Supervised Classification, Space Syntax Analysis, and a Typological Survey (see figure 02).

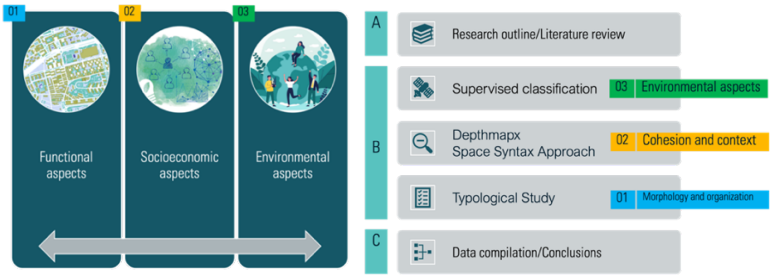

Figure 2. The study's methodological construction (Source: Author)

Phase A: Contextual Foundation

This initial phase establishes the study's context through an extensive literature review on urban development in Ferencváros, examining forty years of planning decisions and socio-political shifts. This historical overview highlights the impact of political changes on urban green spaces and resilience-building measures. Ferencváros is selected due to its complex urban structure, which varies from low-density

former industrial zones to high-density residential areas, making it an ideal site for exploring diverse urban forms and their adaptability. The district's recent transformations provide a convenient opportunity to analyze contemporary renewal trends, with abundant data supporting a detailed morphological analysis and categorization system.

Phase B: Empirical and Spatial Analysis

In this phase, three key analytical tools—Supervised Classification, Space Syntax Analysis, and Typological Survey—are applied to assess physical cohesion and morphological aspects within urban spaces.

- **Supervised Classification**: This method utilizes satellite imagery to track changes in green infrastructure over three key years: 2000, 2011, and 2021. By applying GIS-based land-use and land-cover mapping, the analysis identifies shifts in vegetation and impermeable surfaces, marking demolitions, new constructions, and green space evolution. This Environmental Baseline sets a data-driven foundation, offering insights into the district's spatial dynamics and transformations over time.
- **Space Syntax Analysis**: Space Syntax provides a quantitative assessment of urban connectivity, revealing how spatial configurations impact social interaction, movement, and accessibility. Using DepthmapX software, the study conducts Full Angular Segment Analysis on road networks to evaluate pedestrian and vehicular flows across varying radii. This analysis highlights areas of high and low integration, emphasizing how spatial layout influences urban cohesion. For comparative insights, integration patterns from Ferencváros are contrasted with Vienna’s Landstrasse district, given their shared history yet divergent political influences.

Phase C: Integrative Analysis - the Typological Survey

Building on findings from Supervised Classification and Space Syntax, the Typological Survey explores the morphological characteristics of green infrastructure within Ferencváros. The survey is divided into two stages: the first examines architectural elements, assessing the role of courtyards, building forms, and their impact on urban structure. The second stage evaluates green elements, focusing on size, form, and functionality within open spaces. This survey examines ownership, management, and physical features to understand the socio-spatial dynamics of green infrastructure, providing a qualitative layer to the previously quantified data.

The final phase synthesizes results from each method to assess urban resilience and renewal potential. This integrative approach examines how environmental, spatial, and architectural factors collectively support or inhibit urban adaptability. The findings from the typological survey, grounded in morphological analysis, emphasize how mixed-use ownership and semi-private open spaces promote social interaction and enhance green infrastructure accessibility, fostering resilience in urban contexts.

Together, these methods offer a comprehensive assessment of Ferencváros, addressing environmental, spatial, and architectural aspects of urban green infrastructure. Supervised Classification and Space Syntax reveal an environmental baseline and spatial configuration aspects, while the Typological Survey examines physical attributes that support cohesive urban patterns.

4. RESULTS AND DISCUSSION

The study emphasizes the role of green infrastructure, connectivity, and cohesive urban morphology in enhancing resilience within Budapest's Ferencváros district. Using Supervised Classification (SIC), Space Syntax Analysis, and Typological Surveys, the research provides insights into green space integration, historical continuity, and public accessibility in a post-socialist urban context.

4.1 Urban Morphology and Connectivity

Ferencváros maintains strong morphological continuity, with 89.81% of 206 assessed buildings being historic, and only 10.19% newly constructed. Courtyards are central elements, accessible through shared gates (56 units), symbolizing the resilience of historical urban layouts and the prevalence of the semi-public configuration in renovated areas. The comparative analysis with Vienna's III District indicates that both cities leverage green infrastructure to address urban decay and reconnect fragmented urban spaces, particularly in areas previously marked by industrial voids and low-density development. While the urban layout prioritizing the use of courtyards is similar, distinct cultural and administrative approaches lead to different public space experiences, with Ferencváros showing slightly restricted accessibility due to maintenance practices.

The typological survey further shows that Ferencváros maintains a balanced mix of residential and mixed-use buildings, with most structures ranging between 1 and 3 floors or 6 to 10 floors. This creates a varied cityscape but, at some points, threatens the previously established landscape character. Most buildings have 2 access points (126 units), primarily through public streets (157 units), highlighting

good connectivity within the area. The presence of multiple access points likely improves circulation and accessibility, facilitating movement within and around the district.

4.2 Green Infrastructure and Typological Patterns

The SIC analysis reveals a 16.56% increase in vegetated areas over two decades, reflecting deliberate efforts to reduce urban voids and strengthen green connectivity. The typological survey corroborates this, identifying a well-balanced presence of green elements, with "Group of Trees" representing 30% of the green space elements of the analyzed site. The district displays a transparent block structure, with 35% of buildings organized around shared courtyards that enhance both visual and physical permeability. Most open spaces are compact (65%) and small (60%), bordered by tall facades that nonetheless allow ample sunlight, improving usability. Public transport access and this layout foster an“intense-protracted” usage pattern, observed in 40% of spaces, indicating high urban integration.

4.3 Ownership, Accessibility, and Functional Diversity

The survey shows that 65% of green spaces are under mixed-use ownership, with 80% primarily serving residential functions, giving these areas a semi-private character. However, the dominance of residential use limits functional diversity, which may compromise long-term resilience. Although many spaces are visually accessible, practical accessibility and maintenance are lacking in some cases, underscoring the need for strategies to diversify functionality and improve upkeep.

4.4 Challenges and Adaptability

Despite the positive impacts of green infrastructure on connectivity, the renewal process raises challenges in heritage preservation, as some historic structures were partially or entirely modified. Adopting Kropf's (2017) concept of"configuration," the partial reconfiguration of courtyards, though challenging heritage preservation, reinforces spatial cohesion by revitalizing urban patterns. The methodology, especially SIC and typological surveys, proved effective for assessing green infrastructure and urban morphology, though limitations like low-resolution imagery led to classification difficulties between exposed soil and building materials, suggesting that future studies could benefit from higher-resolution data.

4.5 Implications for Urban Resilience and Sustainable Development

Findings underscore that integrating green infrastructure within historical urban fabrics significantly enhances resilience, promoting connectivity, social cohesion, and environmental sustainability. Typological surveys effectively identify underutilized spaces and can guide renewal efforts, ensuring that green infrastructure meets both ecological needs and morphological parameters. For sustained resilience, future Ferencváros renewal projects should prioritize functional diversity and enhanced maintenance. Comparative insights from Vienna's III District underscore the importance of culturally informed policies and adaptive approaches in creating sustainable, livable urban environments that respect historical context.

5. CONCLUSIONS AND RECOMMENDATIONS

This dissertation examines the relationship between urban morphology and green infrastructure in Budapest's IX District through a methodological framework that combines spatial analysis with typological surveys. The study explores how green infrastructure supports urban resilience, focusing on cities undergoing significant transformations, with Budapest's IX District serving as a primary case study to explore urban, ecological, and morphological adaptation.

While Budapest remains the central focus, the study also draws comparative insights from São Paulo and Vienna to broaden its perspective on urban renewal and green infrastructure integration. São Paulo, characterized by socio-economic disparities and a substantial housing deficit, illustrates the challenges and innovations involved in adapting traditional urban layouts to meet contemporary sustainability needs. Projects like Parque Novo Santo Amaro highlight how green spaces can address social vulnerability and environmental issues, blending public housing with ecological resilience.

Vienna, in contrast, represents a cohesive approach to sustainable development, incorporating green infrastructure within its historic urban fabric. The renewal of the Landstrasse district demonstrates how green spaces can enhance connectivity while preserving historical identity. Together, São Paulo and Vienna provide contrasting models of urban resilience—São Paulo adapting to rapid growth, and Vienna applying strategic, integrated planning—offering adaptable frameworks for ecological and social sustainability in urban regeneration.

The findings emphasize the value of a multidisciplinary approach to urban environmental challenges and suggest

pathways for future research and practice in urban resilience and green infrastructure integration.

The following matrix summarizes the research structure, linking research questions, methodologies, and the outcomes. It illustrates how each component contributes to a comprehensive understanding of green infrastructure's role in enhancing resilience and facilitating renewal.

Research Questions	Methods Used	Results Found
How does the integration of UGI enhance the functional performance and livability of urban areas?	- Supervised Classification to track changes in green areas in the IX District; - Typological Study to analyze green and open spaces' characteristics	- SIC revealed a **16.56% increase in vegetated areas** between 2000 and 2021, contributing to improved livability. - The conversion of industrial voids into green areas also resulted in a **45.5% reduction in exposed soil areas**, improving environmental conditions.
What role does a detailed typological appraisal play in identifying resilient urban elements?	- Typological Study to assess urban forms and their uses; - Space Syntax Analysis to understand connectivity	- Typological appraisal identified that **strategic green space placement** promoted urban resilience by enhancing adaptability and improving social interaction zones - Around **30% of green spaces** were composed of tree groups, contributing to both environmental and social resilience. - The assessment of **206 buildings** found that **10.19% were newly constructed**, while **89.81%** were historical structures, either restored or awaiting renovation. Despite ongoing developments, the district largely preserves its historical character.
How does the conversion of private to semi-public green spaces influence urban cohesion and community interaction?	- Space Syntax Analysis to evaluate urban integration; - Typological Study for space usage analysis	- The transformation of private courtyards into **semi-public green spaces** improved urban cohesion by allowing social interactions. - These semi-public spaces were **publicly owned but privately maintained**, leading to varied usage and maintenance quality.
To what extent does establishing territorial connectivity in dense urban environments support urban resilience and circular economy principles?	- Space Syntax Analysis to assess connectivity; - Supervised Classification to monitor green infrastructure evolution	- Improved **territorial connectivity** through new pedestrian axes enhanced social integration and facilitated more efficient resource use. - Green infrastructure networks also improved both the functional and social integration of Ferencváros.
Can a comprehensive approach to UGI serve as a strategy against urban decay, and how could it be adapted for various urban contexts?	- Supervised Classification to observe changes over time; - Typological Study to detail green space features and adaptations	- The comprehensive approach to UGI helped mitigate **urban decay** by converting **20,546,853 square meters** of underutilized land into green areas by 2021. - UGI demonstrated its adaptability by successfully integrating different urban contexts, contributing to improved environmental sustainability and social cohesion.

5.1 Recommendations for further research

A thorough understanding of urban morphology enhances the effectiveness of renovation strategies. Typological surveys, which analyze architectural and spatial features, offer valuable insights into historical continuity and spatial arrangements, ensuring respectful and cohesive interventions. When combined with methods like Supervised Image Classification (assessing green space distribution) and Space Syntax analysis (examining connectivity), this approach provides a comprehensive view of key dimensions—environmental baseline, spatial configuration, and architectural integration—enabling context-sensitive planning that balances heritage with sustainability.

Based on the findings of this dissertation, some areas for further research are recommended to advance the understanding and application of urban green infrastructure (UGI) in urban renovations. Comparative studies on Urban Green Infrastructure (UGI) across diverse cities beyond Budapest, São Paulo, and Vienna could reveal adaptable green infrastructure strategies across historical and socio-political contexts. Longitudinal studies would track UGI's long-term effects on social cohesion, resilience, and biodiversity, providing data on benefits and limitations over time to guide sustainable policy decisions.

Advancing typological surveys with GIS and high-resolution imagery could generate more precise morphological assessments, improving urban renewal decision-making. Furthermore, the SIC method could be enhanced to establish machine learning criteria for automated identification of green infrastructure patterns.

Future research should also focus on public and semi-public

space accessibility, particularly courtyards, to understand how improved access impacts social interaction. Public-private management models for these spaces could optimize accessibility and upkeep.

Community engagement models remain vital for sustainable development, especially in diverse socio-economic areas. Research into best practices for resident involvement in green infrastructure planning and maintenance could enhance ownership and sustainability. Finally, combined analysis of the overlapping methods could deliver deeper insights, supporting the development of a comprehensive urban database for informed planning.

6. NEW SCIENTIFIC FINDINGS

The most significant new scientific contributions of this dissertation can be summarized in the following theses:

Thesis 1: The basis of urban morphology of urban renewal areas of Ferencváros can be characterized by five building types that fundamentally define urban fabric and by which basic characteristics of urban forms can be described. Incorporating the dynamics of public and semi-public spaces into the analysis provides a deeper understanding of the interplay between urban forms, environmental context, and community functions.

The method focuses on a typological study that identifies and categorizes urban elements, with emphasis in features that align with regenerative urban strategies. By providing a detailed understanding of the urban fabric and linking these elements with green infrastructure networks, it highlights the ecological considerations in urban planning and the role of green spaces in urban morphology and livability.
Extending the analysis to public and semi-public spaces, the method examines their impact on community life and the dynamics of urban environments, offering insights into designing more resilient cities. Field investigations involving focus groups and surveys emphasize practical application and validate the method through empirical data.
Upon completing the typological study and examining the emergent trends, five distinct typologies were identified as constitutive elements of the study area's urban framework:

- **T1—Newly Constructed Buildings:** structures that align with the proposed contemporary urban design and

renewal principles, enhancing functionality (e.g., increasing urban density and allowing more territorial integration) while being mostly typologically conceived.

- **T2—Reconstructed Historical Buildings:** These are historically significant buildings updated to meet current use and conservation standards while keeping most of their original morphological features. Some volumetric alterations can be found in many of the units classified in this category—mainly on the back courtyard wings or the roof configuration—but the scale, proportions, overall aesthetics, and access conditions remain preserved.
- **T3—Unrenovated Historical Buildings:** These are aging historic structures that preserve most of their original characteristics but await renovation or reconstruction to align with the renewed surroundings.
- **T4—Large-Scale Institutional Buildings:** Prominent buildings serving public or institutional functions, often symbolic and contributing to the area's identity.
- **T5—Urban Voids:** Underutilized, vacant, or abandoned spaces within the urban fabric that lack a defined function, result from economic shifts, urban decay, planning decisions, or natural disasters, and represent gaps in the urban fabric. These were key elements in the Middle-Ferencváros urban renewal, presenting opportunities for multifunctional developments, predominantly articulated with green spaces with public or semi-public access.

This method offers a comprehensive framework for analyzing urban morphology, bridging quantitative and qualitative assessments. It provides a holistic view that integrates historical development with contemporary urban challenges, guiding interventions that contribute positively to the urban

context and support sustainable development goals. The dissertation contributes significantly to urban studies through this method, offering a replicable approach for future research and urban planning initiatives.

Thesis 2. The time-lapse analysis of Supervised Image Classification proved the significant increase in green spaces in the long run, despite temporary reductions caused by renewal activities. Temporary declines in green spaces, due to the strategic reconfiguration of urban forms, can ultimately contribute to a more integrated and effective green infrastructure.

Supervised Image Classification (SIC) was used to analyze land use and land-cover changes over three different periods: 2000, 2011, and 2021. This approach helped establish a comparative framework to identify transformations in the urban landscape, emphasizing the evolution of green infrastructure over time.

The results indicated significant changes in land cover, especially in green areas and exposed soil. In several cases, the areas classified as exposed soil in the 2000s resulted from abandoned or underutilized former industries. In 2021, the research indicated a reduction of 45.5% in those areas. It also revealed a 16.56% increase in vegetated areas from 2000 to 2021. Notably, a 43.3% decrease in green spaces was observed in 2011 compared to 2000, which was initially puzzling. Further investigation clarified that this reduction was a temporary consequence of the urban restructuring efforts underway. During this period, smaller individual courtyards were undergoing transformation into larger, more cohesive green spaces. The strategic reconfiguration aimed to enhance the quality and continuity of urban greenery, setting the stage for the subsequent increase in vegetation coverage

by 2021. This process underscores the dynamic nature of urban development, where temporary reductions in green areas can lead to more integrated and beneficial green infrastructure over the long term.
By 2011, the imagery analysis had already displayed a noticeable grid of green infrastructure and its comprehensive articulation of linear and nodular elements, indicating progress in urban requalification projects. By 2021, the consolidation of the green space system was evident, with a more balanced proportion of green components in built areas. The transformation aimed to enhance urban resilience, improving territorial cohesion by reducing urban voids and implementing green elements extensively. The study confirmed that the urban requalification of Ferencváros was effective in enhancing urban cohesion and green infrastructure, as evidenced by the gradual reduction in exposed soil areas and the increase in vegetation over the study period.

Thesis 3: Supervised Image Classification can provide the environmental baseline for the study by providing a clear overview of spatial changes, however, it does not explain how these green spaces interact with the built environment. The combination of methods Supervised Image Classification and Typological Survey can offer a more complete understanding of how environmental changes in green infrastructure align with urban and social dynamics.

In my research I, demonstrated the implementation of urban green infrastructure and details its morphology using a combination of supervised classification and typological survey. The area, characterized by historical urban structures, initially lacked comprehensive green infrastructure,

exhibiting fragmented and sparse green elements. This deficiency was attributed to the morphological characteristics of the historic urban fabric, which evolved from closed blocks and buildings centered around narrow, poorly lit courtyards devoid of significant green spaces.
The study combines SIC and the Typological Survey to explore green space development from two perspectives: Environmental Baseline and urban Integration. SIC establishes the Environmental Baseline by quantifying changes in green space coverage, mapping the expansion of vegetation, and the reduction of exposed soil. Typological Survey focuses on the morphological conditions, examining how different types of green spaces, such as historical courtyards or newly created parks, are integrated into the urban fabric. This analysis reveals the physical characteristics, uses, and roles of green spaces, showing how they influence social interaction and environmental function.

Thesis 4: The inclusion of urban green infrastructure elements in Space Syntax analysis allows for an assessment of urban areas from the perspective of spatial dynamics. Although the limitation of space syntax in analyzing green morphological elements lies in its primary emphasis on spatial relationships and connectivity rather than the qualitative attributes of spaces, this approach facilitates a more holistic understanding of urban environments, recognizing the interdependence of physical layout, green spaces, and urban life.

This approach combines quantitative and qualitative analysis, linking historical development with modern urban challenges. Space syntax analysis is a powerful analytical tool

for understanding the spatial configuration of urban environments, particularly in terms of the open space network and how it influences movement, interaction, and accessibility within cities, its focus is predominantly on the spatial relationships and connectivity between different urban elements, rather than on the detailed characteristics of those elements themselves.

Based on the case studies of Budapest and Vienna strategic interventions driven by public-private collaboration, urban integration proved to be increased by the restructured urban blocks supplemented with accessible green infrastructure elements. Blocks became more porous with the addition of green alleys, communal courtyards, and cohesive green networks which revitalized the areas and enhanced resilience by aligning with the morphological guidelines identified in the typological assessment.

The study revises concepts from Space Syntax and applies them to urban green infrastructure. This adaptation enriches the understanding of urban integration, particularly how green spaces contribute to urban areas' spatial organization and connectivity.

Moreover, the study's use of Space Syntax to evaluate green infrastructure highlights the importance of thoughtful design in urban planning. It suggests that the strategic placement and configuration of green spaces can significantly impact urban cohesion.

Space syntax provides structural analysis, a valuable tool for understanding how people move through and use spaces but does not explore the specific attributes or quality of those spaces.

Green morphological elements, such as the types and forms of vegetation, its proportions, functions, and layout, for instance, require site-specific studies beyond space syntax's scope. These elements are crucial for understanding the

ecological and social value of green spaces, their contribution to urban ecosystems, and their impact on human well-being. To thoroughly analyze green morphological elements, the research integrated space syntax with GIS analysis (supervised classification) and typological survey (at the urban structure and green infrastructure level). This multidisciplinary approach allows for a comprehensive understanding that includes both the spatial configuration and the qualitative attributes of urban green spaces, examining the morphological aspects of green infrastructure and how these elements can be strategically utilized to enhance urban cohesion.

Thesis 5. The Urban Green Typological Survey (UGTS) I developed provides a structured method for evaluating urban morphology and the integration of green infrastructure, effectively identifying patterns and supporting urban trend projections.

Organized into four main subgroups—Land Use, Commerce and Service Unity, Residential, and Urban Landscape and Greenscape—the survey offers a comprehensive view of the urban fabric, based on the compilation of individual architectural and urban design elements, and facilitates the identification of recurring patterns. In large-scale urban renovation projects, such as Middle Ferencváros, this survey can forecast potential solutions and preventively address issues before implementation.
The urban typological survey revealed that the study area is primarily mixed-use (66% of units) indicating a balanced functional diversity in the zone where the renovation is most mature. The research area can also be considered a compact, low-rise urban form typical of historic European centers, with 73.3% of buildings lacking setbacks. Shared green elements

in 63.1% of courtyards promote neighborhood cohesion, while the strong connectivity —evident from Space Syntax analysis—can be linked to elements such as the prevalence of dual access points (61.2% of buildings). Commercial units, accessible at street level (69.9%) and often featuring multiple entry points, enhance walkability and support interaction with residential spaces.

Courtyards with open gates (27.7%) and visually permeable elements (51%) increase the pedestrian experience and contribute to an open landscape ambiance. Traditional sidewalks, present in 79.1% of units, reflect the use of traditional infrastructure solutions while limiting permeable surfaces. Most buildings (39.8%) predate 1970, preserving the area's historical character, and establishing the modularity baseline for newer unities.

By recognizing recurring design elements and correlating survey data with findings from other analytical methods, this approach enables informed decisions on block layout, uses distribution, and green elements integration.

The evaluation subgroups are structured as follows:

- **Land Use**: This subgroup assesses the layout and spatial organization of blocks, examining their influence on public space quality, connectivity, and complexity. It helps define how land distribution and block structure affect public and semi-public space accessibility, especially from the perspective of the courtyards and building setbacks.
- **Commerce and Service Unity**: This section evaluates the placement and distribution of commercial and service units, analyzing how these contribute to dynamic, accessible public spaces. It seeks to understand the service units as a network, impacting the urban permeability, and their physical characteristics in connection to their immediate surroundings.
- **Residential**: This subgroup focuses on residential use, focusing on its urban integration and composition of

historical patterns. In areas like Ferencváros, where residential use predominates, this analysis underscores how housing adapts within existing urban layouts, preserving continuity while accommodating new needs.

- **Urban Landscape and Greenscape**: This subgroup identifies elements particularly relevant for the landscape configuration, such as visual barriers and pathways, and assesses their impact on public space quality, highlighting the role of green infrastructure in enhancing urban environments.

Furthermore, visual aids, icons, and focus group activities can help standardize data collection, making the typological survey a valuable tool for capturing the complexities of urban renewal while balancing historical preservation with modern needs.

Thesis 6: The Urban Green Typological Survey (UGTS), along with NDVI findings, confirms that the southern portion of Middle Ferencváros exhibits substantial greenery, structured in a typical post-socialist modern arrangement, despite limited direct urban renewal efforts.

The second stage of the Typological Survey focuses on green infrastructure features and integrates with established concepts from the urban typological analysis, such as urban block structure, spatial organization, building distribution, ownership, and maintenance of open spaces. It evaluates physical attributes and qualitative aspects, including user perceptions of scale, modularity, strategic placement, and boundaries of green areas, besides their shape and patterns.
The four subgroups introduced to categorize the green elements are:

- **Urban Green Morphology:** This subgroup addresses the characteristics and arrangement of green spaces, including estimated canopy density, primary vegetation types, and spatial layout. This classification highlights how green components are distributed within the urban fabric and their relative density.
- **Ownership and Management Structure:** This subgroup examines the legal and operational dimensions, including aspects such as ownership status (public, private, or shared), management responsibilities, maintenance practices, and usage patterns. It provides insights into the level of care and accessibility based on ownership and governance.
- **Functional Role and Physical Environment:** this subgroup focuses on the purpose and ecological role of green spaces within the city, covering activities they support (e.g., recreational, residential, or connectivity functions), predominant surface materials, and the presence of furniture or pathways. It assesses how these spaces contribute to the broader environmental context and user engagement.
- **Spatial Layout and Architectural Integration**: analyzes the configuration of green spaces in relation to surrounding buildings and urban structure. This subgroup examines the size, shape, and positioning of green areas, as well as their relationship with building facades and architectural boundaries, highlighting how these spaces fit into and enhance the built environment.

The survey shows that groups of trees are the predominant green element, constituting 30% of the green space configuration, with other green forms remaining balanced across the study area. In the Ownership and Management Structure category, 65% of open spaces are under mixed-use ownership, providing these areas a semi-private character

shaped by an 80% residential function that influences their usage patterns.
The survey also reveals a transparent urban block structure (35%), with buildings arranged discontinuously around shared courtyards, enhancing both visual and physical permeability. This layout, combined with strong public transport links, supports an 'intense-protracted' usage pattern in 40% of spaces, reflecting a high level of urban integration. Most open spaces are small (60%) and compact (65%), surrounded by tall facades (50%) that nonetheless provide ample sunlight, enhancing the quality and usability of these green areas. Collectively, these characteristics bolster the resilience and livability of the Ferencváros district, emphasizing the essential role of green infrastructure in fostering sustainable and adaptable urban environments.

Thesis 7: By performing the three scientific methods tested, Supervised Classification, Space Syntax analysis and Urban Green Typological Survey, in sequence and comparing the results, it sets an interdisciplinary methodological structure to examine the complexities of urban green morphology. By integrating quantitative and qualitative approaches, this methodology offers a comprehensive understanding of the spatial, functional, and morphological dynamics of green infrastructure within the urban fabric.

This synthesis aims to elucidate the complex interplay between urban fabric and green infrastructure, offering a robust toolset for comprehensive urban green morphology analysis.

- **Supervised Image Classification**: Acting as the foundation, this method quantifies changes in green

space distribution over time. By mapping the evolution of vegetation and impermeable surfaces from a broad perspective, it establishes the **Environmental Baseline**. This baseline enables a data-driven analysis of how urban green spaces have developed over time, setting a clear foundation for further investigation into spatial and architectural relationships.

- **Space Syntax Analysis**: Building on the environmental data provided by Supervised Classification, Space Syntax examines the **Spatial Configuration** of green infrastructure within the urban grid. This method uncovers the relational aspects of green spaces—how they connect to and integrate with public spaces, how accessible they are, and how their layout supports or hinders urban interaction and cohesion. This goes beyond simple quantification, offering insights into the **connectivity and accessibility** of green infrastructure within the urban fabric.
- **Urban Green Typological Survey**: Moving to a more detailed level, Typological Studies focus on **Architectural Integration**. This analysis delves into the specific characteristics of individual green spaces, assessing their form, function, and socio-spatial dynamics. Typology examines how the physical features of these spaces either contribute to or detract from the effectiveness of green infrastructure, particularly how different green elements integrate within the architectural and social landscape of the city.

The convergence of these methodologies in a unified analytical framework underscores the complexity of urban green morphology and the necessity of a multifaceted approach to fully comprehend it. This integrative framework enhances our understanding of urban green spaces and is a

valuable tool for urban planners and designers. It informs the creation of more resilient, ecologically rich, and socially engaging urban environments, highlighting the importance of interdisciplinary approaches in urban studies.
Therefore, this comprehensive methodological strategy emphasizes the synergy between different analytical lenses, each contributing essential dimensions to our understanding of urban green spaces. By weaving together quantitative data, spatial relationships, and qualitative analysis, this research offers a methodology for informed and sustainable urban development strategies.

Thesis 8: Ferencváros district in Budapest serves as a prime example of urban forms adaptation, demonstrating the essential mechanisms for successful urban renewal. The district's transitional character, situated near a low-density urban fringe, has facilitated experimentation with atypical renovation methods. This unique context, while preserving strong historical ties, presents a diverse urban fabric that requires careful articulation. The ability to reconcile historical preservation with contemporary transformation is particularly evident in the district's strategic approach to urban green spaces.

Post-socialist urban centers such as Budapest have undergone considerable political and social upheavals, significantly influencing the developmental strategies for transitional zones adjacent to low-density rings. These zones - commonly found in comparable historical European cities - articulate the dense urban core and the suburban peripheries. This research catalogs and examines the physical transformation of one of these intermediary areas, employing a set of analytical criteria developed to identify the predominant types - and consecutively the characteristic elements of this urban

morphology and, therefore, offering a critical examination of the urban renewal process.

The study develops a parametric methodology to analyze urban transformation in Budapest, providing a framework for replicating and comparing similar changes in other adapting urban areas. This approach helps understand the interconnections between urban form, social dynamics, and development policies. It also increases the generalizability of the findings and offers a scalable method for studying urban transformation across different landscapes.

The Typological Survey of the area discloses an urban environment marked by morphological continuity. The assessment of 206 buildings (seen as urban unities) evaluated in the first focus group found 10.19% of entirely new buildings, most of which were designed to be seamlessly articulated, with the large majority of 89.81% of historical buildings - spanning both restored and pending renovation urban unities. Amidst recent intense public and private (primarily residential or mixed-use) developments, the area largely preserves its remaining historical structures, with most buildings dating back to the 19th and 20th centuries, in addition to incorporating morphological features like modularity, form, and territorial configuration/layout in new developments. It demonstrates resilience transcending individual enduring elements and spaces, revealing the resilient nature of the area's comprehensive urban attributes

7. LIST OF PUBLICATIONS

7.1 Articles in international Journals (IF magazine)

Silva Dantas, G., Báthoryné Nagy, I. R., & Nogueira, P. B. (2022). *Implementation of Green Infrastructure in Existing Urban Structures: Tracking Changes in Ferencváros, Budapest*. MDPI - LAND, 11(5), 644, 11 pages. (Impact Factor: 3.398; Rank: Q2 in Scopus - Nature and Landscape Conservation). Published April 27, 2022. https://doi.org/10.3390/land11050644

Silva Dantas, G., Báthoryné Nagy, I. R., & Szövényi, A. A. (2023). *Fostering Urban Cohesion: Exploring Morphological Adaptations in Budapest's IX District through a Typological Survey*. MDPI – Sustainability. (Impact Factor: 3.9 (2022); 5-Year Impact Factor: 4.0 (2022); CiteScore: Q1 in Geography, Planning and Development). Accepted December 14, 2023 / Published December 16, 2023. https://doi.org/10.3390/land11050644

Pereira Rosa, C. A., **Silva Dantas, G.**, & Delgado da Silva, B. M. (2021). *Urban Green Space Rehabilitation in Campo Grande, MS: An Overview of the Anhanduí River Current Situation, Post-Revitalization Project*. Ecohydrology | Environmental Sciences, 2(5). (Impact Factor: 0.313). Published June 2021. Available at: https://www.jelsciences.com/archive.php

7.2 Articles in international journals (Non-IF magazine)

Silva Dantas, G., Báthoryné Nagy, I. R., & Delgado da Silva, B. M. (2022). *The Housing Policy in São Paulo and the Urban Landscape Architecture Outcomes: A Case Study*

of Parque Novo Santo Amaro V. 4D Journal of Landscape Architecture and Garden Art, 3/2022. Accepted April 13, 2022. Available at: http://www.4djournal.hu/

7.3 Articles in international conferences (full paper)

Silva Dantas, G., & Báthoryné Nagy I. R. (2021, October 8-9). *Resilience of Urban Forms in the Context of Urban Green Infrastructure: Study Case of Ferencváros, Budapest*. DOCONF 2021 - Facing Post-socialist Urban Heritage, Budapest, Hungary. Foundation for Urban Design, Department of Urban Planning and Design, Faculty of Architecture, Budapest University of Technology and Economics. Conference proceedings available at: http://doconf.architect.bme.hu/2021-proceedings/

Silva Dantas, G., Delgado da Silva, B. M., & Pereira Rosa, C. A. (2021, November 26). *Green Infrastructure Reframing Historical Courtyards: Enhancing Urban Resilience in Budapest*. 8th VUA Youth Scientific Session - Challenges of Nowadays in the Light of Sustainability, Gödöllő, Hungary. Visegrad University Association, Magyar Agrár- és Élettudományi Egyetem.

Delgado da Silva, B. M., **Silva Dantas, G.**, & Pereira Rosa, C. A. (2021, November 26). *Analysis of the Cocó Park and its Importance as Urban Green Infrastructure for the City of Fortaleza*. 8th VUA Youth Scientific Session - Challenges of Nowadays in the Light of Sustainability, Gödöllő, Hungary. Visegrad University Association, Magyar Agrár- és Élettudományi Egyetem.

Silva Dantas, G., & Báthoryné Nagy I. R. (2022, June 30 - July 3). *Green Infrastructure Enhancing Urban Resilience:*

Parallels between Vienna and Budapest. 7th Fábos Conference on Landscape and Greenway Planning, Budapest, Hungary. (Received: March 28, 2022 / Revised: in process / Accepted: April 23, 2022 / Publication: July 2022). Conference website: https://sites.google.com/view/fabos2022/home

Silva Dantas, G., Báthoryné Nagy I. R., & Cuesta Tabares, M. A. (2023, October 6-7). *Green-Regeneration of Modern Heritage: The Role of Green Infrastructure in Urban Morphology*. DOCONF 2023 - Facing Post-socialist Urban Heritage, Budapest, Hungary. Foundation for Urban Design, Department of Urban Planning and Design, Faculty of Architecture, Budapest University of Technology and Economics. Conference proceedings available at: http://doconf.architect.bme.hu/doconf2023-proceedings/

7.4 Abstract conference papers

Silva Dantas, G., Delgado da Silva, B. M., & Pereira Rosa, C. A. (2021, May 28-29). *The Effects of Landscape Planning on Urban Landscapes: A Case Study of Budapest Urban Green Spaces*. 6th Conference on Horticulture and Landscape Architecture in Transylvania - Landscape, Garden and Man: Professional Challenges of the Present and Near Future, Târgu Mureș, Romania (Online). Abstract and panel presentation. Conference website: https://ms.sapientia.ro/en/news/6th-conference-on-horticulture-and-landscape-architecture-in-transylvania

Silva Dantas, G., & Delgado da Silva, B. M. (2022, November 3-4). *Adaptation of Historic Buildings for Promotion of Urban Resilience in Ferencváros, Budapest*. XXIX International Scientific Conference on The Art of

Gardening and Historical Dendrology, Cracow, Poland (Online). Abstract and panel presentation. Conference website: XXIX Conferenceon Garden Art and Historical Dendrology - Resilient Cultural Landscapes

Silva Dantas, G. (2023, September 10-13). *Urban Green Morphology and the Regeneration of Urban Fabrics*. ECLAS 2023 Conference - Labyrinth of the World, Brno and Lednice, Czech Republic. Abstract and panel presentation. Conference proceedings available at: https://doi.mendelu.cz/pdfs/doi/9900/04/6600.pdf

Delgado da Silva, B. M., & **Silva Dantas, G.** (2023, September 10-13). *The Areninha Case: Qualitative and Typological Analysis of Urban Spaces Along Parque do Cocó*. ECLAS 2023 Conference - Labyrinth of the World, Brno and Lednice, Czech Republic. Abstract and panel presentation. Conference proceedings available at: https://doi.mendelu.cz/pdfs/doi/9900/04/6600.pdf