



**City as a Palimpsest: Combined Typo-
morphological, Configurational, Historico-
geographical Methodology and
Aspects to Model the Town Development**

Thesis for the Degree of Doctor of Philosophy (PhD)

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Abstract

Cities are not static; they are composed of complex couplings of several components, more particularly between the current and past urban form, and act as a kind of palimpsest. Their evolution and interaction involve leveraging, layering and retaining history while incorporating the emerge of new urban forms. Transformations and spatial patterns of physical forms are the basis of urban morphological studies. These studies aim to understand and interpret process-based transitions, transformations, and spatial patterns of physical components. The concept of palimpsest explains continuous construction over time (historical stratification), but the scale of urban palimpsest is more than that.

The field of urban morphology has been used the concept of the palimpsest through a qualitative approach (traditional urban morphology), with diachronic and evolutionary aspects. However, there is a challenge in conceptually integrating quantitative insights that could acknowledge numerical and longitudinal characteristic. The examination of urban form at various scales have been analysed in both qualitative and quantitative ways. Yet, the lack of a systematic and comprehensive investigation of morphology often anticipates a systematic distinction between different levels of complexity during processes of formation and change. Since, morphological evolution occurs at different levels of scale, the result is that the variance of persistency of change is a spatial aggregation of processes. Cross-examinations with qualitative and quantitative methods can help obtain information about different types of form in different categories. This information can then be compared with other possible information.

This thesis is therefore devoted to establishing a more robust, and comprehensive method. It uses existing qualitative knowledge of urban morphology and integrates it with new approaches to urban morphology, science and technology. The aim is to address the link between the qualitative features and quantification of urban form through temporal and spatiotemporal layering. As the complexity of cities increases over time, the large amount of data obtained makes pattern identification challenging. This difficulty is addressed in this thesis by linking urban morphology with machine learning and artificial intelligence.

The content of the thesis first focuses on explaining the concept of palimpsest by introducing the origin of the “palimpsest” term. It then reviews the term of urban morphology, different approaches to urban morphology, and different disciplines that have the potential to be methodologically linked with palimpsest concept. Based on this literature review, the gap in knowledge is identified. After that, the thesis introduces three Ottoman capital cities in Türkiye: Bursa, Edirne and Istanbul. These

three case studies have previously been investigated morphologically, but without integrating a longitudinal and diachronic frame.

The proposed method is applied to two former Ottoman capital cities in Türkiye, Bursa and Edirne. These cities demonstrate historical heterogeneity and morphological variations of Ottoman urban structures. Therefore, they are used to validate inherited patterns through qualitative and quantitative analysis. The last Ottoman capital city, Istanbul, demonstrates the historical and cultural heterogeneity of different empires. It is integrated as a case study site to test the morphological validity of Ottoman patterns. Furthermore, the robustness of the proposed method is tested through the assessment of different case study sites from different continents, including the USA and Europe.

The research is accompanied by GIS and Python for quantitative investigation of urban patterns. This provides a computational frame to empirically confirm whether patterns of changes are truly positioned at different levels of scale and periods.

Lastly, the results produced by human and urban morphological analysis are incorporated with artificial intelligent technologies for better reasoning in the process of pattern identification. The robustness of this method may shed new light on future urban studies by integrating different approaches, methods, and technologies to understand the formation and transformation process of cities.

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Chapter 1: Introduction

The historical and geographical character of a city is determined by functional and structural significance at several scales within a regional context. Historic settlements represents inherited patterns of a places within a contiguous urban structure (Conzen, 1960). They leave distinct patterns about how they evolved and how they were used (Batty and Longley, 1994), even if many features at different scales are destroyed or transformed (Whitehand, 1981).

Constantly remaining patterns in the urban fabric, those are streets, plots, buildings, open spaces, and green spaces, or some core aspects, such as natural environment, human movement, and built or planted features, are embedded in the form. These patterns signify the past of the urban fabric as inherited patterns in the urban landscape (J. W. Whitehand, 2009). The urban fabric absorbs those patterns and maintains them as evidence of retrospective value and as a guide for the future development. Morphologically, the urban fabric is shaped by the compounds of different periods and is multi-layered in the contemporary city, thus acting as a palimpsest.

The analysis of urban fabric patterns from a temporal perspective has been presented in a wide range of studies on layered or palimpsest cities. These studies have focused on specific topics, such as tendencies of changes at different levels, the derivation or degree of persistence of variables (configuration), the degree of historical stratification between periods (scale/size), the constancy of relationships, and the distinctive residues of past periods (types). Approaches to urban morphology address these variances and deviations between the temporal and spatial dimensions of the cities. However, the tools and methods used in these approaches do not always make it possible to identify patterns of change, especially considering the changes in the size and scale of the today's cities.

Urban morphology, as an interdisciplinary field, investigates patterns of formation and transformation of cities. It aims to capture traces of a long series of patterns, to understand whether these are continuous, and to recognise their underlying rules during their complex interactions in formation and transformation processes (Rossi, 1984). Depending on the scale of interest, several approaches and principles can be used to study urban morphology.

At the spatio-temporal scale of historical geographical change, and at the lowest levels of resolution, temporal and spatial patterns are recognizable through qualitative interpretation and quantitative description. This is based on two approaches: Conzenian (British geographer) tradition in urban morphology, which is based on the structural

organization of the plan elements (streets, plots, and buildings) and their historical development; and, the Italian tradition of Saverio Muratori and other Italian scholars, which considers buildings as elements in the formation of the urban tissues, whose aggregation process forms systems and later cities (Caniggia and Maffei, 1979).

At the multi-level scale, the system of connections between temporal and spatial relations can be recognized through several principles. These include the principles of coexistence and derivation of patterns (Caniggia and Maffei, 1979), the delineation of geographical spaces according to their position, outline, and internal arrangement in the spatio-temporal setting (Kropf, 2017; Kropf, 2017; Kropf, 2014), and the mutual relationship between the human environment and human movement based on the configurational properties (Hillier, 1996; Hillier and Hanson, 1984).

At the high-level scale, the specificity of the patterns and the detailed characteristics of the elements have been analysed using computational tools and statistical analysis. These analyses are based on measurable characteristics (morphometric) such as size, shape, length, height, density, and compactness, and on discrete variables used for classification (Dibble et al., 2019, 2015). They are also based on clustering types according to their similarities and differences in relation to morphometric parameters (Fleischmann, 2021; Fleischmann et al., 2025).

Therefore, while traditional approach describes the geographical and architectural characteristic of cities through a descriptive frame, contemporary approach provides quantitatively robust metrics. These metrics can describe the structural complexity of the city in the process of formation and transformation. In recent years, the combination of different approaches and principles in urban morphological studies has contributed to grate advances. These advances make it possible to evaluate urban form parameters at different levels of scales, to identify patterns, and to identify changes within a descriptive and analytical framework.

Yet, the challenge remains in processing large datasets for cities (cartographic sources, satellite images, vector-based maps), handling their changes, and capturing patterns and delineating areas within those data sources. In recent years, advances in digital computation, new technologies, and artificial intelligence have created significant interest in the field of urban studies. These developments enable the large-scale analysis of different data source. However, to the best of our knowledge, there is no methodological contribution in the field of urban morphology that fully integrates these new technologies.

Hence, this dissertation comprises integrating different urban morphological approaches with a qualitative and quantitative frame. Each

of them proposes a distinct but complementary method to identify patterns at different scales and with different temporal dimensions. The dissertation also leverages deep learning and artificial intelligence to discriminate and identify variables in contemporary urban settings.

Initially, a novel methodology was developed based on this methodological link at the multi-level scale. The research analyses historic cities, namely three Ottoman capital cities located in different parts of the Türkiye; Bursa, Edirne and Istanbul. The integration of different urban morphological approaches was used for the Bursa and Edirne case study sites to identify inherited patterns. New technologies, such as deep learning and artificial intelligence, were used for Istanbul to recognize inherited patterns that had already been identified from the two pre-established capital city samples.

In case of Istanbul, a Convolutional Neural Networks (CNNs) based approach was used for automatic segmentation with OpenCV and NumPy in Python on both historical and contemporary map sources. The recognition of patterns or types was achieved through urban morphological analysis and AI-based reasoning. The contribution of the AI here is methodological novelty. It is not used as a replacement for urban morphological reasoning, but as a reasoning and validation layer. In this framework, deep learning and AI-based reasoning extend the capacity of pattern recognition at different scales beyond human based assessment.

1.1 Research Aim and Objectives

This thesis aims to create a new method (palimpsest method) for the evaluation of cities as palimpsest, so the contribution is precisely formulated based on the main objectives as follows:

1. To develop a more robust, and more comprehensive methodology, this methodology is integrating traditional and new approaches to urban morphology (science and technology) to the different approaches within the disciplines to address the link between the qualitative features and quantification of urban form through temporal and spatio-temporal layering.
2. To integrate the palimpsest method with a multi-level spatial data framework that combines cartographic sources, earth observation data and vector-based maps in order to identify spatial and temporal patterns, support the qualitative description of morphological types, quantify relevant variables, and delineate regions that reflect the morphological persistence.

3. To provide an automated frame and easily identify patterns to define where the patterns (spatial hierarchies of features) are truly positioned developing Python code and libraries in Python like OpenCV and NumPy used for Automatic Segmentation analysis based on Convolutional Neural Networks (CNNs).
4. To empirically confirm how the observed morphological changes are related to changes in the perceptual metrics in already delineated regions.
5. To test proposed method in different context with different spatial temporal variations.
6. To compare the results produced by humans and urban morphological analysis employing with the prompts-based strategies to AI for better reasoning in the process of pattern recognition.

1.2 Structure of Dissertation

This dissertation is organized as follows: Chapter 2. explained the literatus was used for this study, especially establishing the methodological structure of the palimpsest method. Chapter 3. introduces detailed descriptions of the study site context, and material used for this thesis. Chapter 4 explains the steps, tools, methods and approaches used for the proposed methodological structures Chapter 5. provides the results that obtained from the different level of scale (resolution). Chapter 6 addresses the empirical testing of the palimpsest method and provides results related core analysis within different study context, as well as provides the comprehensive exploration of the findings and provides AI-prompt-based results. Chapter 7 discuss the findings. We draw the summary and conclusion in the Chapter 8.

Chapter 2: Literature Review

2.1 Existing approaches to establishment of new methodology

To start the journey towards the proposed palimpsest concept, we first begin to investigate the origin of the main idea behind the literature and need to look at the idea's state within the approaches to urban morphology. Therefore, this literature chapter aims to understand the theoretical foundation of the palimpsest term and the definition of urban morphology, principles of the palimpsest concept in various disciplines, its

use in urban morphological studies, and existing criticism and its relations with different urban morphological approaches from a theoretical and methodological framework. Later, the focus shifts to the details of different aspects of palimpsest in alignment with the main scope of the research, to conceptualize the idea on a descriptive and analytical framework of urban morphology based on the numerical and structural parameters of urban form. In addition, this chapter highlights the need for some remote sensing approaches to create bridges between the different fields and to reach a higher understanding of the palimpsest layering. Following this, a research gap is identified regarding the need for combined approaches, integrating qualitative insights with quantitative approaches to urban morphology, to overcome some limitations of traditional methods and a desire to understand these apparent lacks and to provide a rigorous descriptive and analytical frame of reference for investigating the historical stratification of cities.

The aim of the investigation is set out in the three chapters of the literature review. The first one explores the origin of the palimpsest term, the term of urban morphology, and explores the core aspects and principles that define the palimpsest concept and different approaches from relevant fields such as urban morphometrics, longitudinal studies, and artificial intelligence and deep learning, taken in applying a set of principles which should form a model that breaks down the purpose of the theoretical investigation towards gaining numerical and analytical aptitude to improve rigor and comparison in urban morphology and extend the applicability of the palimpsest methodology. The second part of the chapter gives an examination of the relevant patterns, concepts, tools, and methods used in the literature to date. And the last part gives a synthesis and comparison of the literature and different applications to illustrate the gap in the current knowledge that fails to adopt quantitative and qualitative investigation and fails to integrate different approaches across different fields while studying layered cities.

2.2 The origin and source of the term “palimpsest” and definition of the urban morphology

The concept of the palimpsest has its roots in ancient Greek culture. In the given historical period, there was little parchment available, so it often happened that an older writing was erased, scraped off the parchment and something else was written on top. However, the disappearance of the old writing was rarely perfect, and the old writing was visible under the new writing. In other words, the knowledge and tradition of successive eras formed layers on the parchment. The concept of the palimpsest is used as a

metaphor in the science of urban morphology in geography and tries to indicate that just as the old writing cannot be completely removed from the paper, the past of cities also partially survives in the structure of the settlement even if many buildings are demolished or significantly transformed.

This metaphor was first proposed by André Corboz in the early 1980s. Corboz started from the fact that today's large cities appear in the geographical space as a very complicated and complex structure (Corboz, 1983). He believed that in the scientific analysis of cities, researchers need to place settlements in a multilayered context and a four-dimensional space that also considers changes over time. Corboz's palimpsest metaphor challenged the early *tabula rasa* thinking that urban planning required creating something radically new by completely abstracting from the city's past and heritage. Corboz believed that the city carries a long series of signs, traces, and voids, and that these signs, traces, and voids must be considered in the planning process. Corboz claimed that modern processes should not aim to completely erase the past, but rather emphasized the importance of selective erasure, that is, to preserve each city's own identity and values (Cavalieri and Cogato Lanza, 2020).

Gerard Genette is a French scholar who initiated the use of the palimpsest method (layering old documents) in literary research, mainly focusing on poetics for the understanding and examination of continuities and transformations of the different elements of texts and how they come together over time (Genette, 1997, p. 147). Genette points out that literature can be described through formal features/pragmatic features (Genette, 1997, p. 240). He indicates the palimpsest nature of texts by arguing that we cannot make sense of any individual text without situating – parchment – links with other texts (Genette, 1997, p. 5). He investigates literary transformation (Genette, 1997, p. 25) by identifying the narrative discourse and themes (shaped by cultures and historical circumstances) that tend to persist through time (Genette, 1992, p. 64). Genette's approach to the objects of poetics is the understanding of the hidden/visible aspects of formations, to recognize them as continuing "genres/types," and thus describe the persistent links between particular modes and themes (Genette, 1997, pp. 66–71).

Cities can be understood as a layered palimpsest, where the monuments of different historical periods - especially buildings, building complexes, streets and squares - coexist in a unified urban fabric. Given such a city, consisting of several layers but behaving uniformly, it is necessary to establish a conceptual parallel between the methodology of urban morphology and analytical tools. By broadening the analytical

framework of urban morphology, a multi-level system is created, which allows the city to be examined from both a qualitative and quantitative perspective (Sarihan and Lovra, 2024).

The palimpsest can also be interpreted as the presence of invisible elements and visible configurations in the city, of which the invisible elements are the memories, values and traditions of the city's past. Both the visible and invisible elements are closely related to the lives of today's city dwellers, determining their movement and behaviour within the city. Thus, an organic interaction is created between people and the built heritage, which serves as the basis for the dynamic changes characteristic of cities (Azimzadeh and Bjur, 2007).

The challenge for the urban morphology scholar in applying this multi-level methodology is to quantify historical geographical changes. In this work, Geographic Information Systems (GIS) are at the researcher's disposal, the significance of which lies in their ability to express differences in the language of numbers and to demonstrate a definite quantitative difference between the state before and after modernization. The use of GIS focuses on transformation, drawing a parallel between historical continuity and urban development (Sarihan and Lovra, 2024).

The transformation within cities does not stop at the juxtaposition of premodern and modern. In the case of many large cities, a further layer of palimpsest can also be observed, where the effects of the post-modern era can be examined and the answer can be sought as to how the contemporary, recent urban structure, urban fabric and the current spatial distribution of urban functions came into being (Sarihan and Lovra, 2024).

One of the most important goals of applying the palimpsest method is to examine the resilience and persistence of the various units that make up the urban fabric. It can be stated that the location of the streets within the cities is the most constant element. In many cities of Roman origin, such as Pécs or Győr in Hungary, the forum, *cardo* and *decumanus* are still clearly recognizable and can be interpreted as busy routes of the historical cores of the given cities. Plots and the buildings on them are much more vulnerable than streets and squares, i.e. they change their location, size or appearance more often (Sarihan and Lovra, 2024).

The palimpsest method views the urban fabric as a kind of sponge that is able to absorb the traditions and the usual street network of the settlement and synthesizes and preserves the values from these traditions. By clarifying these values, good foundations can be created for the later development of the city. The stratification according to the palimpsest also implies that these memories and values are spread out in the built-up area,

which also implements the principle of preserving by erasing (Sarihan and Lovra, 2024).

The ultimate goal of palimpsest methods is to map constant connections within urban space. Constant connections can be defined as systems within cities that persist despite the passage of time and dynamic changes. It can be observed that, in addition to certain elements of the street network, clusters around monumental buildings play such a role. Monumental buildings are typically built for a long time, represent significant cultural, and in many cases economic and political value, and their demolition and replacement with something else requires significant resources. Thus, these monumental buildings are more resistant even without formal protection, and they make smaller, but also valuable buildings in their environment more durable. This constancy can be demonstrated not only by qualitative but also by quantitative means (Sarihan and Lovra, 2024).

André Corboz, who introduced the concept of the palimpsest to urban geography, also made a lasting impact in the field of mapping urban morphology when he published his *Atlas du Territoire Genevois* in 1993, which compared the morphology of the Swiss city of Geneva in several historical periods. He compared three major development plans (the Napoleonic cadastre 1806-1818, the 1935-1959 plan, and the 1991 plan) and classified the changes into three categories: permanence, persistence, and disappearance (Cavalieri and Cogato Lanza, 2020).

The impact of the concept of the urban palimpsest on everyday experience can contribute to the design of urban spaces. Understanding the local palimpsest can help preserve history and develop a unique local culture and can serve as an anchor point for the entire city. Since palimpsests can only be identified on foot, exploring their connections can be used to create cultural heritage trails (Flint Ashery and Stadler, 2021).

Another important goal of palimpsest theories, beyond mapping past layers, is to actively support urban planning practice. However, in many cases there is a large gap between research based on palimpsest theories and urban planning practice, especially in terms of adaptive spatial structures, heritage integration and participatory planning. The goal would be to guarantee a kind of morphological continuity and build a resilient urban future on this. The better cities preserve their morphological traditions, the easier they will find answers to environmental and socio-economic challenges (Kurtulmus and Beyza, 2025).

Although the involvement of the population is indeed important in flexible urban planning, including in the case of successful waterfront development, it should not be forgotten that in many cases external factors,

independent of the city and its residents, also positively or negatively influence the development of the palimpsest. These external influences are mostly embodied through the spatial dynamics and configuration of the elements that make up the city (Vâlceanu et al., 2014).

Those critiques of the palimpsest metaphor focus on a micro-scale investigation in a structural way and a wide scale in a narrative way, but within urban morphology there is only form-based attention. Urban morphologists have encouraged the use of this concept to investigate town development in a diachronic way (by layering maps), unravelling the relationships between different element – streets to, buildings, and buildings to construction materials–, and the underlying substratum (forms and their types) to better understand the processes of urban formation and the relationship between pre-existence urban structures and contemporary conditions.

The concept of palimpsest encompasses different dimensions and can be examined through various aspects for different purpose. The palimpsest concept in this study should reflect the following aspects:

- Diachronic
- Evolutionary
- Layered
- Interpretive (descriptive and analytical)
- Multi-Scalar
- Specificity (micro-level)
- Empirical (falsifiability and testability)

However, there is a need to evaluate how the term “palimpsest” can be applied within the field of urban morphology.

In order to better understand the structural changes of settlements throughout historical periods, it is necessary to review all the theoretical explanations developed by different historical geographical schools, such as the Conzenian historical-geographical approach, the Muratorian school, and the Space Syntax theory. Within this, it is necessary to focus on the principles and methodological approaches that describe how different historical periods left their mark on the appearance of settlements, and how these characteristics are stratified. To this end, some results of historical science and archaeology should also be called upon. In the course of this work, both the static elements of urban morphology and the dynamic changes resulting from human activities should be critically approached.

Muratori and Caniggia in Italy, and Conzen in Britain approached the question of urban morphology in very different ways. Conzen’s historical geographical approach was particularly fruitful for British scholarship, and

those who followed his methodology can be called the Conzenian school (Unlu, 2021). The Conzen tradition is an advanced approach to English morphological urban geography, which derives the city's current form from historical development and assumes the existence of complex formal layers (Whitehand, 2001).

Conzen sees urban morphology as the imprint of the accumulated knowledge of engineers and architects of different historical periods, from which today's professionals should also learn. Conzen's criticism is directed at the people of his own time, because they are often concerned with what should be done to a city in order to renew it and not with what the city is made of. He interprets the city as a layering of fundamental phases of formation and transformation on top of each other and thus proposes a much more holistic approach than before. According to Conzen, the historical geographical approach, the correct interpretation of fringe belts and morphological regions allows the development of the city to take place in a more sensitive way, so that modern districts can fit more organically into the fabric of the settlement (Unlu, 2021).

The cycles of a city's development and the changes that accompany them can be understood by examining its morphology more closely. This is especially true for the outer and inner fringe zones. These so-called fringe belts determine where the city's borders will be and how much of the natural geographical environment will be urbanized (Whitehand, 2007).

Since Conzen studies structure rather than form, he says his method focuses on the structure and development of urban morphology, not just quantitative data. For all this, the palimpsest (the possibility of layers) is given, since urban form is like a multi-layered manuscript, where new constructions layer the old ones, just like a multi-level historical trace. Within a city, urban changes are not only visible in the transformation of buildings, but also in the changes in spatial structures and how space is used. The interactions between spatial structures and space use determine the development of the urban fabric (Whitehand, 2007).

According to Conzen's view, the researcher is not only faced with an organic historical geographical development but can also perceive other spatial and temporal processes. Urban growth cycles, such as leapfrog or spiral expansion, are also key to the morphological development of the city. This is also visible in the case of the functional change of former industrial zones, the so-called rust zones (Whitehand, 2001).

It is very important that, in addition to theoretical studies, the results can be documented and depicted in a way that is characteristic of the geographical space. Through city maps and morphological mapping, the internal structural patterns of the city can be revealed, which show the

development paths characteristic of different periods. These maps help a lot in ensuring that future urban spatial planning is successful. Mapping also contributes to the preservation of the city's historical and cultural values without hindering the organic development of the settlement (Whitehand, 2007).

The Conzen tradition and the English urban morphological approach can be contrasted or paralleled in certain aspects with the school of Saverio Muratori and the Italian scholars. In both cases, it can be said that the given scientists were motivated by a historically inspired approach, but Muratori and the Italian public did not find the key to the topic in the description of the layered historical heritage but put the Process Typological Approach to the fore. The essence of this is that the development of the city is determined by its life cycles and their internal logic (Cataldai et al., 2002).

According to the Italian school of urban development, the dynamic changes that determine the image of a settlement are multifaceted. According to Muratori, social, economic and political events all leave their mark. These marks are not just stylistic elements, but also determine the identity of the city and its inhabitants, which means that during the development of a city, not only functionality plays a role, but also how the city's inhabitants experience being an integral part of the historical and cultural whole of the settlement (Cataldai et al., 2002).

A city not only gives its inhabitants an identity but also allows for a broader framework of interpretation. According to Muratori, the different architectural forms that become dominant within a city can be inscribed in a complex urban narrative. This historical-geographical explanation is particularly important in understanding how a settlement moves from one historical development phase to another, how the process takes place within the framework of how different architectural expressions manifest themselves (Strappa, 2018a).

Similar to the English approach, Muratori also speaks of historical layers, but these layers are interesting not only because of their time-based superposition, but also because, according to Muratori, the development of forms is not random, but a succession of processes that are structured and identifiable with scientific methods (Cataldai et al., 2002).

Muratori also emphasizes that within the framework of an analysis, different types of cities can be compared, which are created in geographical space as a result of different historical developments (Cataldai et al., 2002).

Muratori also speaks in his works about the importance of urban planning. According to him and his Italian school, the goal of urban planning is the best possible integration of multi-storey buildings, which

include the heritage of several historical periods, into the urban space. He emphasizes that it is not a mass of static elements that should be examined, but the complex products of the organic historical development of the city as parts of a system that functions as a whole (Cataldai et al., 2002).

The Italian school does not get stuck in the examination of individual buildings, but always looks for broader interpretive frameworks, streets, squares and other public spaces, and tries to integrate different buildings into their complex system (Strappa, 2018a).

Similar to the English school, Italian scholars also speak of the importance of mapping urban morphology. In this process, Muratori's followers consider the study of living spaces, routes and central elements (polarities) as primary. The result of this scientific work is a multi-level, complex map representation, which presents each urban layer separately. The purpose of the map is to prepare adequate urban planning steps (Maretto and Scardigno, 2015).

In addition to the English and Italian schools, the French so-called Versailles school is also significant, characterized by names such as Philippe Panerai, Jean Castex, and Jean Charles Depaule. This trend spread in the 1960s and 1970s and became internationally known as Space Syntax. The name of the trend can be explained by the fact that they seek connections and correlations between building types and urban spaces. Although they were influenced by Muratori, the French experts focused on urban design practice and not on historical-cultural development. The French school also uses a multidimensional approach that examines both material and intellectual development, but emphasizes the theory of formative urban therapies, thereby placing geographical, historical, and social interactions at the centre of the study (Mosharraf, 2023).

The French school focuses on urban pattern and fabric and examines how it came into being. Panerai and Castex created the concept of the Island and the Vertical Island. Their aim was to examine the temporal and spatial changes in urban morphology in a three-dimensional manner. Another characteristic of the French school is that it views urban geography as a complex science, which must integrate knowledge from the social sciences and art history. They also believe that urban research cannot be the work of one person alone, but that several experts must work in teams to achieve results (Mosharraf, 2023). Relying on the sociologist Henry Lefebvre and the architectural historians Boudon and Chastel, the Versailles School sought to strengthen its holistic approach with impulses from other disciplines.

By the 1990s, the substantive criticisms of the three schools had reached the point where a revision of urban morphology research

methodology was necessary. This search for direction resulted in the English, Italian and French schools increasingly seeming to merge within the framework of the International Seminar on Urban Form (ISUF). This fusion created an interdisciplinary research field that focused on better understanding the historical geographical development of cities through diverse methodologies. ISUF has an ambitious mission to provide a forum for thought and action that encompasses related disciplines and professions across cultures, with the aim of addressing real and current issues related to urban morphology (Moudon, 1997).

So, the process of the urban morphology term also reflects evolution, investigated across various geographies and built environments by various academic backgrounds, which have been approached differently across various countries, languages, and conceptual frameworks. The common point is to understand morphology in terms of the formation and transformation processes of urban form. The scope of urban form is narrower than urban morphology, as the study of urban form mostly focuses on understanding and identifying form complexes based on their spatial configuration, which is closely related to scale.

The accepted term “*urban morphology*” is defined by the geographer Jeremy Whitehand as “*the study of urban form.*” (Whitehand, 2011, p. 55). This definition highlights that the primary focus of urban morphology is the form of urban areas. However, Whitehand argued that urban morphology is a multidisciplinary field, and current morphological thought suffers from a lack of integration across the various disciplines and approaches connected to it. Anne Vernez Moudon also supports the idea that the emergence of the urban morphology field is interdisciplinary, and defines it as the study of the city as a human habitat (Moudon, 1997, p.3), highlighting that the field should be considered a multidisciplinary framework.

Karl Kropf, rather than concentrating on defining urban morphology, has focused on explaining built environment by incorporating Goethe’s principles of morphological assessment. Kropf integrates core concepts of urban morphology, such as pattern and structure, processes of formation, type, and hierarchy, in light of Goethe’s understanding (Kropf, 2017; Kropf, 2009, Kropf, 1993). However, Kropf argued that the study of urban morphology emerged independently across different academic and professional disciplines, rather than solely from Goethe’s principles. Nevertheless, he emphasizes the importance of understanding the result of the process of formation of built form by integrating different approaches and coordinating various perspectives in a rigorous way (Kropf, 2009). These approaches, which have evolved within urban morphology, support

each other to provide a more comprehensive understanding of human settlements.

He explains this purpose as follows:

“In the same way that we seek to understand built form in terms of its process of formation, we can seek to understand urban morphology in terms of the way it has developed as a discipline or field of study.” (Kropf, 2017, p. 16).

The literature review of this study will comparatively examine how historical stratification in urban morphology, or process-based approaches, have been conceptualized since the foundation of ISUF. The leading approaches and tools in urban morphology used to examine process and types-based urban forms can be classified into two main categories: descriptive and analytical way.

Descriptive:

- Historico-geographical approaches to urban morphology (German-Angol school - M.R.G. Conzen).
- Complementary approaches to urban morphology (individual scholars like Kevin Lynch, Aldo Rossi, and Gordon Cullen).

Typo-morphological approaches (Italian and French schools - Gustavo Giovannoni, Saverio Muratori, Gianfranco Caniggia, Gian Luigi Maffei; Anne Vernez Moudon; Karl Kropf).

These approaches primarily provide a descriptive framework for urban morphology, focusing on the processes of formation and transformation of the built environment, the historical roots, and the significance of places and patterns of relationships. They are often considered either cognitive or normative, addressing the qualitative aspects of urban morphology.

Analytical:

- Configurational approach and Spatial analytical approach (Christopher Alexander, Michael Batty, and Hillier and Hanson).

Analytical approaches are more mathematical and quantitative, focusing on the geometric and topological attributes of urban forms. The aim is to investigate built forms through mathematical and quantitative methods to understand the interrelationships between different attributes and measures, uncover the principles and relationships underlying system dynamics, and predict spatial configurations to improve function and performance (Kropf, 2017) (See the following subsection for a detailed review).

Although not all scholars working on cities or towns engage with the palimpsestic aspects, the terminology remains ambiguous, and a clear,

functional analytical description is missing within the field of urban morphology. Furthermore, existing accepted definitions have not been sufficiently discussed or critically examined. This research focuses on establishing a new methodology for understanding palimpsest concepts, with particular emphasis on their relevance to urban morphology.

2.3 Review of relevant works

In urban morphological agenda (Christopher, 1977; Caniggia and Maffei, 1979; Conzen, 1960; Cullen, 1961; Lynch, 1964; Lynch, 1972; Muratori, 1960; Rossi, 1984), the central concern about cities is how places emerge, evolve, and transform over time, often explored through theories that increase our understanding and interpretation of the genesis and function of cities in the recursive process of formation. These theories dealt with these issues from various perspectives, concerning the formation of physical urban forms, their constituent elements, development, and transformation processes, and the resulting pattern recurrence that appears over time in response to many factors shaping the cities. This investigation, known as traditional urban morphological approach, framed primarily descriptive judgment and is prompted by qualitative matter. Although, there is an ongoing growing out analytical methods of analysis in urban morphology field, lacks an integrated framework about comparison, quantitative, comprehensiveness and coherence on urban morphology and rigour is not sufficient for understanding of the urban form and process.

Among the work reviewed from the International Journal of Urban Form, three key patterns of research emerged in urban morphology: 1) “concepts” used to recognize and interpret the built environment; 2) development of “approaches and tools” to understand built form through its process of formation and transformation; and 3) the analysis of “aspects” of physical form for the systematic investigation of a place.

These three patterns incorporate a wide range of criteria, drawn on different schools of thought, use different methods and techniques, and employ different tools for analysis.

The following sections outline concepts, approaches and tools derived from traditional qualitative urban morphology, as well as quantitative morphological applications, which are utilised to evaluate, study, understand and compare urban form.

2.3.1 Descriptive (Qualitative) Framework of the Urban Morphology

In the study of cities as palimpsests, the pioneering works and schools in the field of urban morphology, namely M.R.G. Conzen’s “*Alnwick, Northumberland: A Study in Town-Plan Analysis*” (Conzen,

1960) and the school of the geography; and Saverio Muratori's "*Studi per una Operante Storia Urbana di Venezia*" (Muratori, 1960) and the Italian school of building typology, stand out as fundamental reference points for this approach.

A central concern of Conzen's research on towns (Conzen, 1960), is the description and understanding of the processes that shape their physical appearance. The approach is based on a historical and evolutionary perspective, often linked to the concept of a palimpsest, which reflects the layers of change – a way of seeing the character of towns and cities (urban landscape or townscape) derived from the physical and social processes of change (Whitehand, 2009) in their formation. The initial step of Conzen's town investigation is to distinguish five general aspects of urban form:

- Function;
- Social and economic context;
- Site;
- Townscape;
- Development.

Conzen's central aspect of investigation is focused on townscape assessment, which is the identification of regions based on different time periods that generate distinct form complexes of varying spatial characteristics.

According to this, Conzenian historico-geographical townscape analysis consists of:

- *Town plan*;
- *Building fabric*;
- *Land and building use*.

The town plan is a pivotal aspect of the Conzen's analysis, which conceptualising the structural organisation of towns ground plans. Conzen's concept of the "*town plan*" includes three basic urban elements that are hierarchically related (Conzen, 1960, p. 5; Kropf, 1993):

Street-system (streets): the space is defined by street lines (street-blocks) and their arrangement, which is defined by the plots boundary; plot pattern (plots); the arrangement of plots, which are divided by the street-blocks; building pattern (block plans of buildings): the arrangements of buildings and their block plans within the plots.

Conzen's investigation follows systematic investigation of these elements over time. These elements are dependent in a hierarchy, with the relationship of time, where their distinct arrangements are identified as plan units by Conzen, which are level distinct residues in townscape that are

associated with different morphological periods. Therefore, each element within the hierarchy and development of plan units reflects different rates of change and varying degrees of persistence in the evolution of towns: among the complexes, streets are the most resistant feature to time in the process of development and transformation, compared to the plot system. In this order, the building system has less stability than the first two systems (Oliveira, 2016; Unlu, 2018). The building fabric provides the most visually obvious connection to history in a town, with its historical signs written into its structure.

Moreover, Conzen's morphological analysis of towns is also grounded in the concept of palimpsest where he notes that "*A town, like any other object of geographical investigation, is subject to change. Towns have a life history. ... When one period has achieved the manifestation of its own requirements in the urban pattern of land use, streets, plots and buildings, another supersedes it in turn, and the built-up area, in its functional organization as well as in its townscape, becomes the accumulated record of the town's development.*" (Conzen, 1960, p. 6).

Conzen's method of analysis focuses on the recognizing distinct periods and interpreting the changing pattern by tracing the most resistant morphological complexes: street lines (street-blocks) and plots. This approach is providing the basis for classifying types according to their periods. He conceptualised changes through the "*Burgage Cycle*" which refers to:

"Yard is clearly cyclic. Produced by factors ..., it represents a general phenomenon in English urban morphology and may be recognized as the burgage cycle. Its final stage is marked by the state of urban fallow accompanied by the complete or partial obliteration of the original burgage units and their buildings. This effacement of traditional plan features represents a major morphological change and terminates the burgage cycle. At the same time the urban fallow forms the initial stage of a succeeding redevelopment cycle, being a necessary prerequisite for effective investment of new capital in the site." (Conzen, 1960, p. 94).

In this sense, burgages are conceptualized as the basic "elements" in the analysis of medieval towns, analytically describing how the growth, decline, and redevelopment of plot structures (changes in measurements and properties) can reveal the spatial and functional dynamics of the town's history. Further, Conzen's layering analysis of town plans leads to reveal developmental zones that shaped at the edges of towns. During a period when the built-up area is uneven growth process or slow growth, this expansion led to the creation of "*fringe-like*" areas on the peripheries of the built environment. Three distinct levels of the town's growth according to

their spatio-temporal aspects is determined by Conzen: the historic core is encapsulated as the inner fringe belt, the buffer between the historic core and its outer expansion is the intermediate fringe, and the present edges of the town (mostly newly developed zones) are characterized as the outer fringe belt.

Conzen's approaches to the development of burgage plots and fringe belts are further developed by comparative analysis of town morphology by Slater (1981, 1989), based on the principle carried by Conzen that combines the direct measurement of the field with historical analysis of maps. Two key developmental parameters – plot boundaries and plot dimensions – are crucial in Slater's descriptions of identifying towns. This descriptive framework on variations in changes in plot properties provides excellent contribution to understanding and specifying the origin of towns. (Scrase, 1989)

This descriptive frame is further extended by the research done by Scrase (1989), *"Development and Change in Burgage Plots: The Example of Wells"*, which focuses more on archival records of the plots by investigating medieval and early modern town plans, particularly focusing on the trace changes and continuity in the arrangement of plots such as records of subdivision, amalgamation, and accumulation. The aim of the work is to identify the signature values of property attributes for medieval structures that contribute to modern urban development direction. Her approach is important to the distinction between class, relation, and property that is behind deductive inference and able to collaborate with rules of previous logics.

But some limited attention on the fringe belt remains. Especially, the definitions of urban green spaces remain limited in scope, as does their process of changes in urban morphology. Urban green spaces are a crucial component of the urban fabric and important to consider in capturing the relation between the pairs of two core aspects such as the transformation of the natural environment into the built environment. This problem is highlighted with respect to the need for attention to the evaluation of urban green spaces from historical and geographical perspectives by J. W. R. Whitehand (2019)'s research, *"Green Space in Urban Morphology: A Historico-Geographical Approach"*, in the criterion of urban green spaces' specificity within fringe belt concepts. The principle of his investigation is the distinction of the green spaces and non-green areas and identification of their relative positions in the growth and transformation process of cities.

His approach to urban green spaces is based on two principles: *"position and outline (size)"*, and he classifies them into two categories. The first is the continuous fringe belt, often found in stratified cities,

typically associated with the inner fringe belt, which is generally located around city walls. The second is discontinuous fringe green spaces, which are more common in urban areas where urban growth is limited and distinct urban planning policies are usually implemented.

Whitehand's study clearly reveals his contribution to the literature on urban morphology and argues that green areas should be considered in the investigation of different levels of urban form when examining cities as a palimpsest.

Nevertheless, Conzen's approaches to towns is evolutionary, focusing on the spatial and temporal relationship between forms by tracing exiting forms back to the formative processes that shaped them. The aim of Conzen's methodology is to systematically analyse the townscape by overlaying historic maps to map its structure. This involves recognizing and delineating areas to explain the spatial distinctions of settlements at different levels of the hierarchy, and associating changes with social and cultural processes (such as distinguishing areas where different policies are applied or identifying the spatial grouping of form ensembles). Therefore, Conzen's historical-geographical approach is crucial for this study investigation to provide a rigorous descriptive framework for understanding the transformation of the city and the spatial organization of settlements. The morphological structures of the urban landscape can be investigated according to Conzen's principles, as follows:

From complexes: the townscape can be examined through three distinct "*form complexes*": elements of the "town plan" (including streets, plots, building plans), and building fabric, and land utilization (Conzen, 1960, p. 4; Whitehand, 2010, p. 104) The historical stratification of cities is significantly influenced by plan units and building types (Conzen, 1988, p. 254).

Degree of form persistence: the form complexes display varying degrees of persistence over time, with the layering or palimpsest effect resulting from different morphological periods. The town plan tends to be the most persistent feature, while building fabric shows less persistence across layers.

Range of Morphological Period: The historico-geographical structure of urban landscapes reflects specific historical, cultural, political, or technological contexts. Urban development can be conceptualized into distinct "morphological periods" that capture the residues of past periods in the stratified townscape (Conzen, 1960; Gu, 2018).

Constitutive aspects of historical Stratification: The recognition and delineation of residues on historical maps (through map layering) varies between different parts of an urban area, resulting in the

identification of “morphological regions” or “spatial groupings of form ensembles” that emerge from this stratification.

Contribution to hierarchy (rank): The inherited features of the townscape can be delineated across different parts of an urban area. This contributes to understanding “how strongly or extensively the units” have influenced the historical development of the urban area and shaped the character of the townscape.

Interrelation of time and space is inherently complex, so resembling a kind of palimpsest in cities where historical layers overlap. Remnants of previous periods often appear as traces of erased parts of history or are scattered over the built-up area, where the character of some traces has been preserved (Conzen, 2004, p. 51). It is obvious that the physical aspect of the process (physical substance and its arrangement) is resistant to change and persistent.

The matter is getting more complicated since another part of a town, or one part with other parts, is itself linked in patterns of past and present (levels of resolution) – patterns of elements, types of form complexes, and resulting plan unit (urban tissue) types – which constitute configurations that repeat within a series of processes.

Saverio Muratori, Italian architect, introduce “process-based approach” that how buildings (building types) and urban forms evolve over time to interpret different parts of cities and for understanding the relationship between the physical form of cities and their historical development.

Caniggia follows the principles of aggregation of towns, which is Muratori’s idea and approach, as a basis of his work. The interpretation of the historical process of formation and change in town structures over time is the fundamental involvement of (Caniggia and Maffei, 1979) researched on towns. Caniggia and Maffei acknowledge that building are intelligible element for aggregation process of towns (aggregation progression of buildings), whose formation is constituted to concept of urban fabric (creation of the urban fabric), and whose composition resulted in urban organisms (towns) (Strappa, 2018b).

Muratori, Caniggia and Maffei’s principles of the aggregation for the four level of hierarch as follows:

- Elements – Buildings;
- Structure – Tissues;
- Systems – Districts;
- Organisms – Towns.

Caniggia pursues to reveal the time (temporal) and space (spatial) relationship within the built environment by distinguishing two aspects:

- copresence;
- derivation.

Copresence is determined by spatial relations, while derivation is determined by temporal relations.

Anne Vernez Moudon conceptualized typology and urban morphology by following Conzen's, Muratori's, and Caniggia and Maffei's conception of the hierarchy into typomorphological approach, or the concept of urban tissue, in her study "*Built for Change: Neighborhood Architecture in San Francisco*". She analytically investigates the physical transformation of blocks and building types in the American neighbourhood of Alamo Square (Kropf, 1993) to understand the relationship between physical form, continuity, and change.

Further, Karl Kropf deeply evaluated and simplified the concept of hierarchy within the levels of resolution or levels of specificity, according to Muratori and Caniggia's approach to the built environment. He explained these two essential concepts through a multi-level diagram to represent the relationship between and within levels in the complexity of built form analytically and systematically, according to Conzen's, Muratori's and Caniggia's conception of hierarchy.

Kropf's multi-level diagram is a guide to interpret urban fabric as a palimpsest in an analytical and qualitative way and can be used as parchment (in metaphor) to model the process of formation and transformation of a settlement over time. The diagram provides greater detail in identifying specific types of built forms, which is able to reveal hidden meanings and rules at different levels of resolution within the generic structure through element separation morphological analysis.

The degree of complexity in the generic structure corresponds to the levels within the hierarchy and the diagram (Kropf, 2017, p. 41). The diagram of the generic structure—incorporating both vertical and horizontal dimensions – reflects the abstract 'dimensions' of the configuration (Kropf, 2017, p. 165.7). According to Kropf, the vertical dimension illustrates the complexity of the interaction between parts and the whole, while the horizontal dimension represents the juxtaposition and relationship between the parts (Kropf, 2017, p. 165.7; Kropf, 2014, p. 47). Kropf follows three principles while investigating the specific types within generic structure via its "*position, outline and internal arrangement*" (Kropf, 2017, p. 43).

The approach and studies on the Italian school have created a significant impact on architectural and urban field, introducing new

theories about the understanding of their relationship. The most important scholar and architect, Aldo Rossi, adopts a typological approach that guided him to define the concept of permanence in the city's physical structures as visible/reflected features on the basic layout (street or simple urban tissue) and monuments. He points out (Rossi, 1984, p.60) that cities are far from preservation while they are constantly evolving, and he considers monuments as primary elements to bridge the past and present because of their consistency during this evolution. Thus, monuments act like a palimpsest of memories within different layers of formation in the urban landscape, serving as important representatives and aspects when tracing the character of places.

Differences in spaces or overlapping patterns are recognised through human perception and pattern recognition. It should be noted that the complementary approaches to urban morphology emphasise that the formation and transformation of settlements is cognitive and experiment-based and therefore occurs in an aesthetic manner. Within these experimental approaches, attention is drawn to the highest level of specificity within the built environment by focusing on the observation of the evolution and transformation of the smaller scales of spaces.

Most significant research has been done by the British architect, Gordon Cullen, who brings an aesthetic investigation of the townscape structure. Cullen evaluates townscape based on his experimental investigation, such as photographs and sketches of historical places in the cities. His perceptual approach emphasized that the combinations and configurations of streets, buildings, and public spaces make up the urban landscape and reflect the historicity of urban landscapes. Cullen identified all elements that make up the urban landscape as being interrelated and grouped these elements under three basic concepts to bring them together in a broader context (Cullen, 1961):

- Serial vision (experiential and evolving view of urban landscape)
- Place (the spatial and configurational structure that is experienced)
- Content (the material characteristics of the fabric, which contribute the overall perception of a space).

The most influential theory ever made on how people perceive and experience physical structures of cities was published as "The Image of the City" by Kevin Lynch (1964). According to his theory, form and use relationship is significant, and dynamic elements of cities, especially human activities, are essential elements that complement the identity of the city, besides the structural elements that define the view of the city.

Lynch identified five essential elements of urban forms as; paths, edges, districts, nodes, and landmarks for analysing and explaining how these elements work together to create a mental map that integrates our perception of the city.

In recent research, scholars such as Vitor Oliveira (2016) and Éva Lovra (2016), who are followers of the Conzenian historical-geographical approach and the research method of Jeremy Whitehand, integrated different qualitative methods of urban morphology to analyse cities and towns in a systematic way. Éva Lovra's most significant contribution in urban morphology field is that the integration of the spatial-temporal clustering approach into urban morphology and the initiation of creating a taxonomy of towns. Her classification reveals the relationship between urban morphological features and periods based on the historical stratification approach (Lovra, 2018, 2016).

2.3.2 Analytical (Quantitative) Framework of the Urban Morphology

Quantitative approach among urban morphologists towards scientific approach applied to cities, while passing through numerical data analysis and rigorous mathematical language in details of complex morphological features, despite the limited predictive power of the historical context of the cities, quantitative approaches with qualitative knowledge and data availability of urban components make it more robust to our ability to understand and explain the formation and transformation process of urban elements.

The recent works in urban morphology have tended to be more quantitative about re-evaluating urban form, especially the pioneering and recent works (Batty, 2013, 2009; Batty and Longley, 1994) of Michael Batty on cities. His approaches and methods are some of the most robust research on analytical approaches to urban morphology. Although his ideas on cities were not qualitatively neglected, he believed the new science of cities theory, with the principles of scales and relations of complex layered city systems, provided a more predictive way.

More critical scientific research on scales and hierarchies is Batty and Longley (1994), "Fractal Cities", which claims hierarchies are a fundamental element to identify the complexity of cities through mathematical models and analytical tools to be quantitatively measured to address the importance of cities' functions at different scales. Their hierarchical model is based on the bottom-up approach. According to this idea, the model considers the building block as the basic level to model urban development, and their aggregation over time increases to the upper levels of hierarchy, such as into plots or plot series. Communication

between these units is organized by network patterns at the same or lower levels of complexity.

The work “*The social logic of space*” by Hillier and Hanson, (1984) is a significantly important contribution to the analytical approach to urban morphology, as it developed Space Syntax theory for the quantitative assessment of urban form and architectural space. Space Syntax is a pioneering, unambiguously analytical method to urban morphology. The theory centres on the idea of a mutual relationship between the spatial configuration of the built environment and human experience. This includes analysing the street network and configurational properties by employing syntactic analysis to divide urban spaces into segments, which are then transformed into graphs for numerical analysis (Sarihan, 2021a). It enables the “reading” of a city, revealing how its different parts come together (integrate) or remain distinct (segregate).

In one of the classic works on the streets of cities from Stephen Marshall, (2004) – *Streets and Patterns* – it is argued that new street patterns do not follow the structure of traditional street patterns in the developments or transformations of historical cities, and therefore, the evaluation of historical settlements and their form is important in better understanding the past and present. Further work by Marshall and Gong, (2005) follows the more analytical approaches to streets and their configurational properties by arguing that there is no single correct way of classification; there is a need to have an adequate definition of a variety of street patterns, to compare and obtain distinctive information about them, and to generate meaningful types in order to establish an effective typology by creating a choice among them. As stated below, the connections of street pattern diversity/variance depend on the resolution of scale, and as a result, include different types of routes – regional connections with major routes, neighbourhood-level connections with streets, or settlement-level connections with roads.

This analytical and systematic rigour is obviously critical in urban studies, but the systematisation requires more urban morphological knowledge. The recent works of Vitor Oliveira (2013) emphasize a more robust quantitative construction in the examination of urban form elements at different scales, creating and formalizing their various attributes within his “*Morpho*” formula on urban morphology, related to the modelling of the synchronic and diachronic quantity of cities.

The use of attributes of urban form elements is formulated by further researchers through mathematical formulations on key urban form metrics (spatial, connectivity, or topological) in relation to evaluating and quantifying urban form, and in order to provide statistical and mathematical

models of the spatial and temporal evolution of urban form. This language model was carried on by Dibble et al. (2015) in light of the tradition of descriptive approaches to urban morphology, which contribute to the literature as the “morphometric approach” in a more precise analytical representation of cities.

The most striking example of morphometric approaches such as integrating with the social aspects of urban form, was applied by (Venerandi et al., 2017) in a gentrified neighbourhood in London to analyse the physical transformation of five London neighbourhoods that have undergone gentrification, comparing changes in morphometric patterns over time. The statistical analysis is used to defined morpho metrics to detect where the similar and recognizable patterns in gentrified areas.

Recent writers have tended to be more systematic in applying morphometric properties to urban form. For instance, Schirmer and Axhausen (2016) present a multi-scalar analysis of urban morphology through a set of quantitative attributes of forms to classify complex urban systems by clustering and statistical analysis to detect different perceptions of urban morphology across multiple scales. Similar to urban morphometrics approaches, Alice Vialard (2013) developed an analytical method for urban form, suggesting a block-based analysis to provide tools and parameters in urban design.

The most significant and novel approach is very close to the quantitative reading of the palimpsest concept, evaluated most recently by Reades et al. (2025), in their research titled as “*The city as text*”, who investigated attributes of textual data for cities in a numerical way to increase our knowledge about cities through recent advancements in computational tools. Research reveals the importance of the study of cities through a quantitative lens that enhances our capacity to extract new (urban) knowledge from the unstructured data by integrating AI developments with cross-fertilization from cognate disciplines.

The current methods of spatial analyses utilize urban geometry as data to define and understand of the urban landscape as visually. The historical urban landscape is established by spatial–temporal, natural, cultural, and social processes, which contribute an attitude to the urban context in the historical conceptual framework. Van Oers (2010) regards this concept as built upon different aspects of spaces, each covering the other through local knowledge such as building practices, cultural heritage, and physical heritage, which have inherent significance through the past and the present. So, the protection of cultural heritage sites is significant according to definition of historic urban landscapes in UNESCO (2011) for the preservation of the built environment, as intangible urban heritage is

the living expression of people who reflect their traditions, beliefs, or knowledge. For this reason, perceptual treatment of the built environment as urban heritage may better define the layers of the urban palimpsest by integrating tangible and intangible pattern knowledge into a more decisive language.

If we enlarge the overview of urban heritage more globally, it becomes more explanatory within the concept of the urban palimpsest, related to its numerous definitions and contexts. Olsson (2008) claims that monuments and historically protected areas do not solely define urban heritage sites; it is a system and an integration of different systems that have values from the past within the broader environment. However, Karlström (2020) claims the importance of urban heritage in a broader way, stating that physical remains as tangible characters and human beings as less tangible characters should work together. Blake (2000) bases these two characters of urban heritage on two principles: natural and cultural features and indicates that cultural heritage is identified by bringing together elements of seemingly ordinary characters.

As tangible objects in the heritage environment, listed buildings (landmarks) are products of the natural, cultural, and historical processes; attraction on human interests (Ogburn, 2006). This is obviously related to the visibility or perceptual nature of urban heritage, displaying the characteristics of the built environment. The revealing of this idea is generated from Michael Batty in an analytical perspective that human perception depends on the geometrical properties of spaces. This perceptual model of space depends on an observer and the geometric properties of the environment, from which visual patterns could be generated. When urban planners such as Micheal Batty, (2001) drew on perceptual models of spaces within the quantitative perspective, he made a pivotal movement for the representation of the physical environment in statistical and visual form by generating the isovist analysis method. According to his method, the isovist, or field of view, parameters were obtained by simple sampling from urban morphology.

Architect Michael L. Benedikt (1979, p. 47) defined and explained isovists in his research *"To Take Hold of Space: Isovists and Isovist Fields"* as follows: *"The set of all points visible from a given vantage point in space and with respect to an environment."* In the search for a unifying law of the urban environment, O'Sullivan and Turner (2001) shared an approach to isovists, claiming that understanding the visual representation of spaces requires a series of isovists from different positions that can generate a reciprocal visibility graph of the spaces. Their method was based on producing a graph analysis that yielded visibility results in both the local

and global states of the urban system. Although Bill Hillier (2014) argued that statistical analysis of the visual qualities of three-dimensional space has begun to attract growing interest within the complexity science of cities, current studies tend to focus instead on the visibility of landmarks in the preservation of urban and built heritage.

A method of enhancing visibility modelling within the urban environment attempted by Bartie (2011) aims to enhance spatial perception, orientation, and awareness of location-based services. This visibility model generates real-time descriptive information relevant to the complex urban landscape that enables users to access it. The most significant metric of his approach is the calculation of the Field of Interest (FOI) in visibility, which recognises semi-transparent obstructions like vegetations in the urban environment that block the field of view.

The properties of visibility analysis were object-based, but the focus was on the impacts on urban development since Lopes et al. (2019) developed the first covisibility analysis in an attempt at the preservation of the cultural landscape, which in turn helps to assess effective forecasts on visibility issues within cultural heritage protection zones. This method showed a modelling of visibility in urban layout forms that attempted to explain the structural visual interrelationship of the urban landscape, focusing on their appearance conditions. However, their analysis emphasizes the visibility of heritage elements that are part of the co-visible elements within the urban scene.

The current methods of spatial analyses lead towards understanding the urban landscape as a whole by using urban geometry as data, defining and reflecting all elements visually. The methodologies provide the adaptation of deep learning of the two-dimensional spaces to evaluate the elements that must be protected or included in the heritage sites.

On the other hand, the spatial analytical approaches deal with the top-down approach model (cellular automata, aggregate clusters and fractal), the new way of the looking urban form, and see cities as a complex system, that emerge from local actions.

There is common/overlapping principles used in the spatial analytical and remote sensing approach. The satellite imagery provides jurisdictions store and records of the parcels and their uses, and remote sensing approaches provides a basis for the identifying/classification of features. The spatial analytical approaches use the individual parcel of the land (cell) and their use/activities. By turn, the remote sensing approaches undertakes feature of the cell as a region of the interest to establish spatial signature of the formation. The co-ordinating and combination of the two approaches help to improve accuracy of the results and our understanding

of the urban form. It is clear that activities and the land use are analytical tricky and less suitable as reference aspects, their presence depends on the human decisions and acts. Relative the other aspects, physical form/built environment is the most tangible and persistence class and make it possible to point of the reference aspects for co-ordinating and comparing aspects.

Remote sensing – closely related to urban morphology discourse – provides a rigorous frame to investigate and assess the physical and natural environment characteristics concerned to various purposes and conditions by bringing together different methods and tools in a wide range of fields.

The longitudinal treatment of urban structures has become more and more sophisticated but is not much oriented towards the bottom-up approach. It is more oriented towards a quantitative way, for instance, (Herold et al., 2002) researched the complexity of the urban landscape, focusing on the evolution of land use types based on satellite imagery by comparing landscape metrics such as shape, size, and density to detect and quantify changes, in order to understand the process of change dealing with the emergence of the various components of the urban form at different levels, with the help of statistical and computational models of urban structures and satellite imageries.

Huang et al., (2007) apply this quantitative investigation of the spatial metrics on urban forms from satellite imagery on comparing and primarily focusing on the patterns at global scales, fragmentation, compactness, and density, to identify differences in cities around the world through GIS spectral analysis.

But there is limited attention in urban morphology devoted to the remote sensing of spatial principles of places and the pixel-based image analysis used to investigate different aspects and properties of urban form from multispectral imagery.

Remote sensing image classification methods have been employed since the 1980s (Li et al., 2014) to define clearly class borders between different feature types in n-dimensional space (Di Gregorio and Jansen, 2005), through remitted properties or spectral reflectance information of the earth's surface (Al-Doski et al., 2013); such as forest, vegetation, built-up area or water. As Lu and Weng, (2007) come up with, because of the complexity and diversity of the natural and built environment might affect the accuracy of the classification process; some classes could appear similar at different scales.

These processes commonly used for the landcover classification, but the differences between natural and built environment is not strict. Even, the difference manifests themselves explicit visually and there is gradual transformation through the urban areas. Further, the cities are

products of the recursive act of aggregation (hierarchy) that different elements come together over time, thus the structure of the system and elements in the structure is in complex relationship. There seems to be crucial paradox/uncertainty of the knowledge (Batty and Longley, 1994, p. 58) and blurring of the distinctions between physical form and use at different spatial scales (Kropf, 2009, p. 110).

Batty and his colleague (Batty and Longley, 1994, p. 47) claimed that hierarchies as a fundamental element to explain this fuzzy context could be identify and quantitatively measure importance of function of the cities at different level of the scales. The basic unit of the urban development is building blocks, which is smaller than the neighbourhood, that are aggregate - layered over time - of plots or plot series and the communication between these unit is organized by the network pattern in the same level/low level of the complexity (Batty and Longley, 1994, p. 44).

2.4 Summary – the gaps in the knowledge

Within a relatively short span of time, the layered cities or palimpsest cities have been assured in most of the existing literature applied in the field of urban morphology, but the interdisciplinary body of concepts, along with different approaches and methods, is not reported in papers. It appears that there is a growing gap between urban morphology and spatial analysis, as identified in the examined literature reviewed and reported in the Appendix 1, and demonstrates how the scientific knowledge direction of the concept has not crept into the different approaches within different disciplines that address divergent aspects and dimensions that cover it.

Most of the descriptive frameworks of urban morphological approaches support the concept of the palimpsest through diachronic and evolutionary aspects without quantitative insights by acknowledging hierarchical and multi-layered characteristics. As discussed above, the examination of urban morphology at various scales is analysed in both qualitative and quantitative ways, but often the lack of systematic and comprehensive investigation of morphology cannot make a systematic distinction within different levels of complexity during processes of formation and change. Because the evolution of morphology occurs at different levels of resolution, the result is that the variance of persistency of change is a statistical aggregation of processes. It is therefore necessary to make cross-examinations to keep the information about different types of form in different categories, which is then correlated to others where information exists. For this reason, greater levels of investigation cannot be

measured or achieved without the integration of different methods and approaches while studying layered cities.

Furthermore, Karl Popper (2002, pp. 4–6) argues in his book “the logic of scientific discovery” that all inductive evidence is inherently uncertain (probable inference or probability logic). This struggle is apparent in different cases and periods, as the objective knowledge of urban phenomena is inconsistent, so there is difficulty in quantifying qualitative knowledge. Thus, we can suggest that the use of inductive inferences should be minimized when studying the evolution of cities, yet the cognitive knowledge in urban morphology depends on the completeness inductive reasoning. For this purpose, the palimpsest concept should make predictions that can be tested through inference and deductive reasoning (hypothesis – observation and experiment – confirmation/falsification).

The methods pendulum to the quantitative side, such as network analysis, spatial metrics and remote sensing, fractal analysis, visibility analysis, and morphometrics, empirically derived through the direction of the hypothesis process and validation of results, have the potential to be integrated into the palimpsest concept in urban form in an analytical way. The variables of the spatial analysis are continuous, and urban morphology must be supported within the empirical methods. But these quantitative empirical methodology groups point out that struggling with qualitative descriptions of the cities, and the lack of adaptation of diachrony and scaling hierarchies of the phenomena, and far more, see larger details than smaller ones. For instance, remote sensing research usually aims to capture large-scale patterns rather than focusing on the distinct characteristics of individual components (Fleischmann, 2021). However, traditional urban morphological approaches, in turn, are not sufficient to quantitatively formulate the transition process of the cities and test the hypothesis that relates the pre-established elements – stability of possibility of a state or an element – to include the new variables – predictive models – which are essential to uncovering regularities of urban layering.

The palimpsest concept itself has the potential to bring together a variety of aspects, methods, approaches, and techniques. However, the common point across both the present and previous literature is that the examination of layered cities should follow the principles of hierarchy and the principles of process. This also enables us to establish a model of cities as palimpsests. Thus, the model should be multi-scalar, should address the level of specificity, and must be supported by empirical analysis with different methodological propositions. The next chapter of this thesis is devoted to developing a new methodological framework for urban morphology. This poses a challenge, as the complexity of cities increases

over time. However, with the cooperation of computational, generative, and AI tools, this difficulty is planned to be overcome.

Chapter 3: Materials and Methods

3.1 Study Sites

This chapter presents the investigation done on the three Ottoman capital cities in Türkiye: Bursa, Edirne and Istanbul. Figure 1 demonstrates the geographical location of the selected cities and the location of the analysed built-up areas in Türkiye. The research is conducted in Edirne, Bursa, and Istanbul, located in the Marmara region of Türkiye. Edirne is situated in the north-western part of Türkiye and the northern Marmara region, at approximately 41°40' on northern latitude and 26°34' of eastern longitude. Bursa is situated north-west of Anatolia and southern Marmara region, at approximately 40°12' on northern latitude and 29°04' of eastern longitude. Istanbul is situated north-western of Türkiye and the northern Marmara region, at approximately 41°01' on northern latitude and 28°58' of eastern longitude.

The requirement for the investigation of the palimpsest concept within this thesis is the historical richness and morphological variations within the case studies.

The reason for the selection of Bursa city is that it has experienced an evolutionary history of traditional Ottoman-Islamic urban fabric, and it has sustained Turkish-Islamic urban heritage elements. The city was built upon the traces of ancient roots by the Ottoman Turks in the 14th century. The urban tradition was structured according to Islamic rules lasting until the medieval era started with the construction of the Ottoman social complexes/Külliye, urban structures were incorporated – not only physical it also created the social fabric of the city – with these masterpieces that led to formation of the unique historic Ottoman Turk urban fabric. The oldest (core) urban fabric was revealed around the Orhan Gazi Social Complex at beginning of the 14th century, covers 368.236 m² area with surrounding of social and commercial structures (Khans Area), which have been constructed between the years 1326–1339 and formed within the time period covering 14th century through the 16th century. After that, social complexes have been built towards an axis that urban quarters extend from the west to the east: In the east; Murad I (Hüdavendigar) social complex was built towards the western part of the city between the years 1363–1366 (87.570 m²) which was characterised as the first urban fabric extension, Yıldırım Bayezid I Social Complex in 1390 (78.881 m²), and Yesil (Mehmed I) Social Complex between the years 1419–1424 (91.553

m²) was built the eastern part of the city that reflect the second urban extension, and Muradiye (Murad II) Social Complex in 1426 (135.475 m²) was built between the core and Hüdavendigâr (I. Murad) (Municipality, 2021).

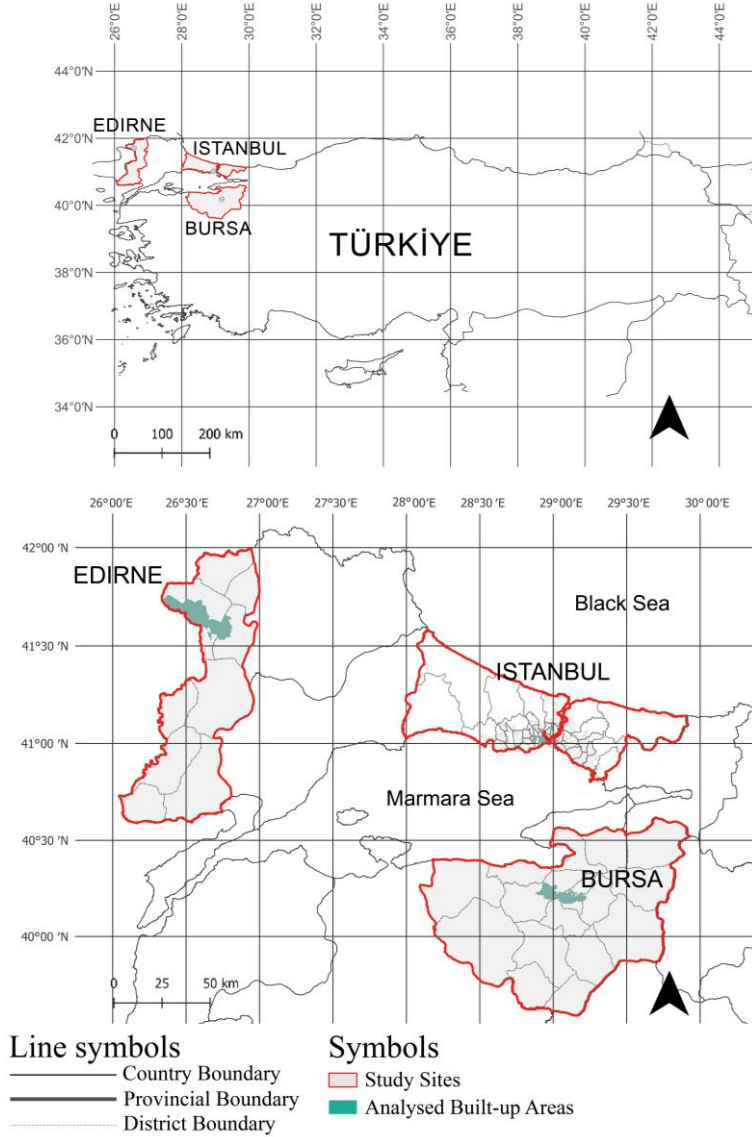


Figure 1. Location of the study sites and analysed built-up areas in Türkiye. The graticule shows geographic coordinates in TUREF, EPSG:5251. Author's own work using the Türkiye Yapı Yoğunluğu Haritası from the Republic of Türkiye Ministry of National Defence, General Directorate of Mapping, <https://www.harita.gov.tr/urun/turkiye-yapi-yogunlugu-haritasi/786>.

Indeed, when looking at the urban fabric construction activities had impact on the population increase over time (Ergenç, 2006; Günay, 2021) and city could no longer accommodate the demands of a growing city during the era of Ottoman reform, known as the “*Tanzimat*” (1839–1876), as well as during the last Ottoman period and the post-war republic era (1922–1960), leaving a large part of the transformation within the historic core of Bursa, the Khan area, and its surrounding historical neighbourhoods. Furthermore, major fires and earthquakes appeared during the era of Tanzimat and almost destroyed the entire historic core of Bursa. The city was rebuilt with new planning decisions offering modernization of the historical cores, together with other areas. Consequently, the built environment in the Khan area coexists with patterns from the past and present and has become a complex organism.

Edirne city is recognized as the second Ottoman capital city, and the second study area, was conquered by Ottoman Turks in the 1360s around the uncertain date of the city conquest and remained as the capital until the conquest of Istanbul in 1453 (Sannav, 2019). During the years, Edirne city has rapidly developed and the organization of the city is almost the same with Ottoman Bursa urban planning principles; külliye, bazaar, madrassas, mosques, bedesten, and palaces, differentiated with Bursa that the function of bedesten (covered market) is külliye and trade is the core of the city function (Kontolaimos, 2020).

Tunca and Meric are two significant rivers within Edirne city which held great importance for the city defence. So, topographical and hydrological characteristics of the city play a significant role in shaping its urban tissue and typology and urban development as well as the urban landscape, relatively having a more compact and dense urban fabric which evolved throughout the Tunca river.

The urban morphology and typology of the city is a long story and characterized by predominantly mixed ancient, Ottoman and modern urban structures and spatial organization. Distribution of the neighbourhoods was grouped on both sides of the Tunca river and Meriç river. The old city centre (core), which is also known as the “Kaleiçi” or “inner medieval fortification,” developed nucleus of the Tunca river dating back to the Byzantine Empire, and Ottoman neighbourhoods were developed in this Kaleiçi region and on the banks of the Tunca and Meriç river. But with the same destiny of the Ottoman cities, Edirne faced disasters (fires and earthquakes) and most of the neighbourhoods were destroyed or demolished significantly – 1728, 1746 and 1905 fire and 1752 earthquake (Sarioğlu, 2021). At the end of the 19th century with Ottoman–Russian wars, Russians occupied cities and resulted in the loss of several of the

Ottoman architectures and neighbourhoods were demolished in the Kaleiçi. After that, the fire in 1905, which was the last disaster in the city, almost destroyed the entire Kaleiçi region (Ahunbay, 2012).

Despite this, the character of the city has somehow preserved the ancient core, and disasters brought different spatial order that Ottoman-Muslim neighbourhoods were developed surrounding this region. Furthermore, at the beginning of the 20th century, Edirne suffered from the bombing of the Balkan wars and economic depressions at the end of the 20th century and followed adaptation of the 21st century new planning paradigms. The study area has the Selimiye Mosque Complex, from the 16th century, and its surrounding area (37.5 ha) was declared as the UNESCO World Heritage List in 2011. This regional complex well maintains its historical significance and reflects the outstanding value of the Ottoman urban culture. Combinations of these aspects led to the formation of Edirne city and defining the city's current characteristics.

In conclusion, Bursa and Edirne were chosen for their historical, natural, and hydrological characteristics and heterogeneous urban fabric, as well as the spatial distributions of existing heritage sites, to be fundamental to understanding early Ottoman cities and served as great study areas for the investigation of the transformation of Ottoman cities. This selection was also reflected in the qualitative and quantitative morphological analyses of the study sites. More detailed spatial information is provided in Figure 2 for Bursa and Edirne, where the locations of the analysed built-up areas and locations of the World Heritage Sites are demonstrated. The selected World Heritage Site coordinates in Bursa are represented by points A–E, ranging from 40°10.90' to 40°12.13' N latitude and from 29°01.27' to 29°04.92' E longitude. In Edirne, the selected World Heritage Site is represented by point X, located at 41°40.67' N latitude and 26°33.57' E longitude.

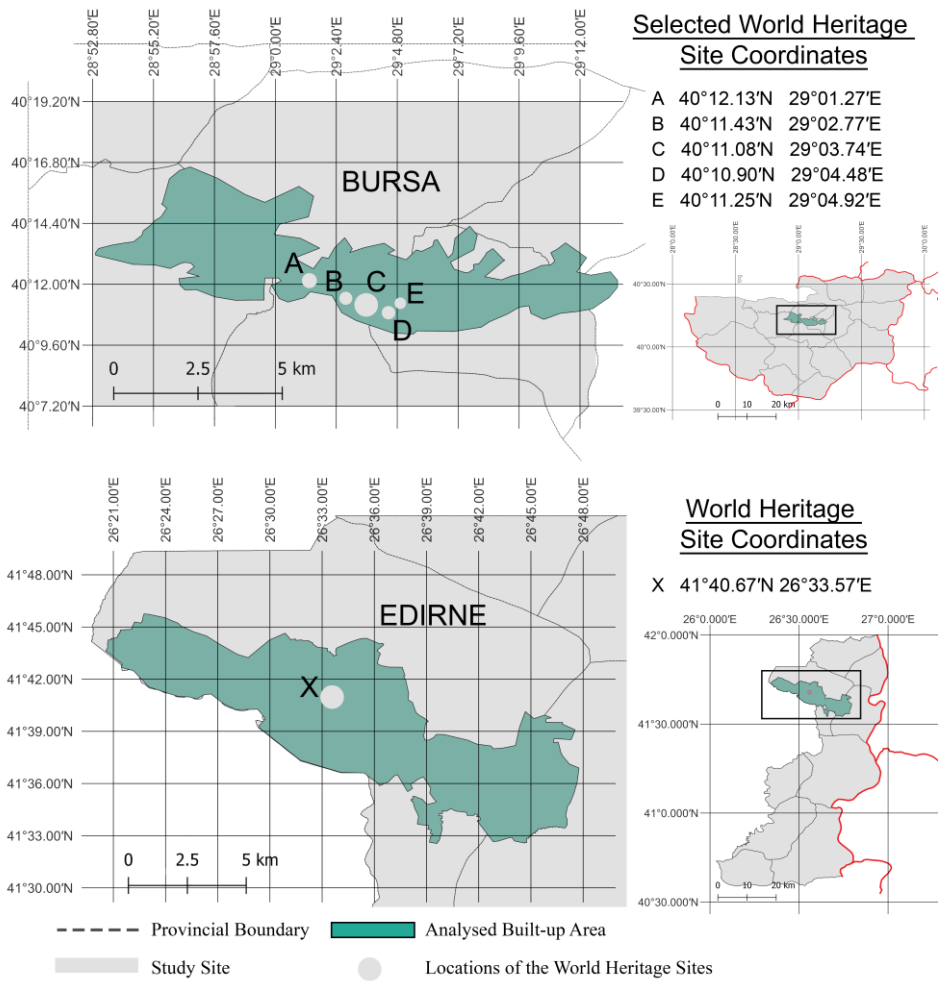


Figure 2. Location of the study sites, analysed built-up areas, and selected World Heritage Sites coordinates for Bursa and Edirne. The graticule shows geographic coordinates in TUREF (EPSG:5251). The selected World Heritage Site coordinates in Bursa are represented as A: Murad I (Hüdavendigâr); B: Muradiye (Murad II); C: Khans Area; D: Yıldırım Bayezid I; and E: Yesil (Mehmed I). The World Heritage Site coordinate in Edirne is represented as X: Selimiye Mosque. Author's own work using provincial map data from the Republic of Türkiye Ministry of National Defence, General Directorate of Mapping, <https://www.harita.gov.tr/urunler/downloadable-provincial-maps/18>.

Istanbul, its historical peninsula, was chosen for empirical testing of the palimpsest method since its morphological structure is the combination of the different urban planning principles. Its neighbourhoods were structured same as the Bursa and Edirne city with the consideration of the "patrimonial-hierarchical order" (Inalcik, 2019). So, foundation of this system can be tested within the historical peninsula. But, localization

of the urban elements (architectural heritage) is preserved, Byzantine and Roman Empires traces remained and directly influenced today's form of the peninsula. Moreover, new urban management and urban planning policy carried out after the city was conquered by the Ottomans.

The city structure was reshaped with Islamic rules and most of the buildings transformed through Islamic building types, but most of the Byzantine samples were preserved but transformed as mosque. The urban landscape of the city was reflect heterogeneity of a high proportion of Byzantine urban structure with integration of the Ottoman urban planning system at the end of the 15th century. Thereafter, the great evolutions were emerged in the urban architecture between the 16th and 18th century, especially Islamic ornamental arts integrated to the buildings, that gave a new character to the urban landscape of the city (Denny, 1970).

So, the urban landscape of Istanbul in the last Ottoman period was characterised by major monuments which exhibited the creative works of Byzantine and Ottoman architects, including Hagia Sophia, reflecting 6th century Byzantine imperial architecture; the Pantokrator Church, today known as Zeyrek Mosque, remaining from the first quarter of the 12th century; the Süleymaniye Mosque, Mimar Sinan's major 16th century work whose külliye complex significantly re organized the surrounding urban tissue; the Sultanahmet Mosque, built opposite Hagia Sophia in the 17th century. Despite the riches in the monumental tissues from past, the urban landscape of city was dramatically changes through the continuous additions of the new layers to the historical urban pattern with the political, economic, and migration related issues had emerged at the 19th and 20th century in Türkiye. Since after, new urban tissue phenomena were dominated the structure of the urban landscape.

More detailed spatial information is provided in Figure 3 for Istanbul, its historical peninsula, where the location of the analysed built-up area and locations of the World Heritage Sites are demonstrated. The World Heritage Site coordinates in Istanbul are represented by points I–IV, ranging from 41°00.50' to 41°01.50' N latitude and from 28°59.00' to 28°55.50' E longitude.

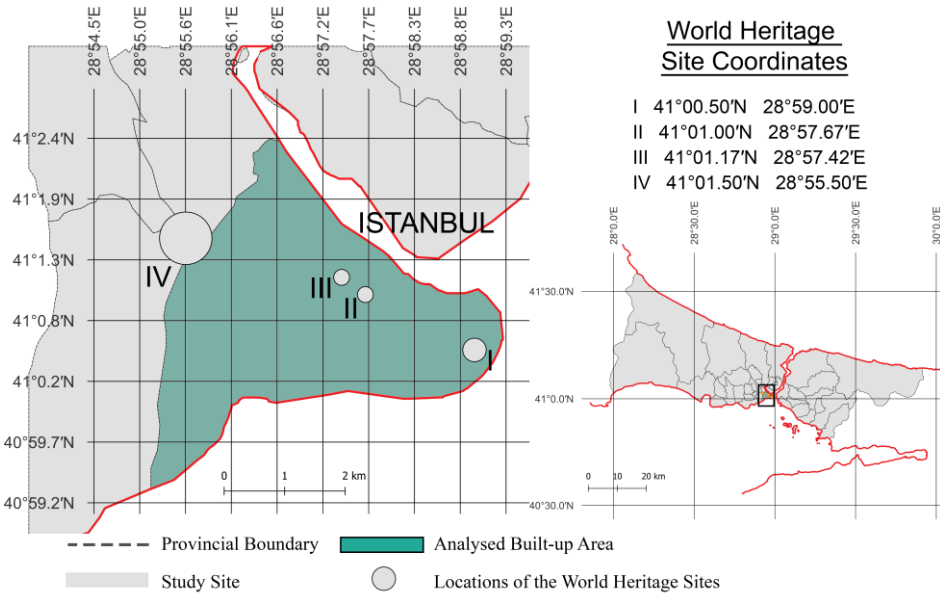


Figure 3. Location of the study sites, analysed built-up areas, and World Heritage Sites coordinates in Istanbul Historical Peninsula, Türkiye. The graticule shows geographic coordinates in TUREF (EPSG:5251). The World Heritage Site coordinates in Istanbul is represented as; I: Sultanahmet Mosques; II: Suleymaniye Mosque; III: Zeyrek Mosques; and IV: Landwalls. Author's own work using provincial map data from the Republic of Türkiye Ministry of National Defence, General Directorate of Mapping, <https://www.harita.gov.tr/urunler/downloadable-provincial-maps/18>.

The process of formation and transformation of the Istanbul city is high complexity and has multilayers from different eras. The characteristics of urban complexity can be revealed by the empirical evaluation (recognition of elements) and confirmation (testability/falsification of elements).

The integrated methods of urban morphological approaches is base of empirical analysis to examine every step (different dimensions at different scale levels) in the process between the past and the future. The method will find the types of urban tissues added, changed, or remaining the same (between continuity and change) within the complexity of urban form. As such, four world heritage sites and an urban conservation zone were analysed in this study.

3.2 Types of data and Sources of data

This chapter outlines the data models employed to collect and structure the data/codes necessary for the palimpsest layering of the three case study sites. Given the research focus on multilevel systems and the combination of different urban morphological methods and integration

with different potential approaches, data collection procedures follow the organization of data that corresponds to its resolution level and level of operations on the palimpsest concept. It is essential to integrate both primary and secondary data, combining qualitative and quantitative data to adopt a more comprehensive understanding of the research objective.

The data structure is organized through source-based data categories, primary and secondary, and descriptive and analytical data categories, qualitative, and quantitative data and their relevant variables (attributes) to represent the elements investigated (the way the data is stored) at each level, also considering their relationships in a logical way.

The first section of this chapter covers the types of data and their sources. The second section then explains the tools, and software used for data processing and analysis.

3.2.1 Primary Data

Primary data lies in most quantitative spatial models to the remotely sensed data, which should directly reflect the resolution level that follows the methodological proposition for palimpsest reading. This should also be reflected in the urban form at the lowest scale of resolution, corresponding to the historical geographical approach. The research proposes, as primary data, the integration of remote sensing data with historical maps and global (Google Earth and OpenStreetMap) as well as local datasets (Plans of Municipalities).

Copernicus – Corine Land Cover (CLC), is a freely-accessible resource containing high-quality satellite information on land cover classes, which is use as a primary data source. It was chosen for immediate mapping of land cover classes for cities, Bursa, and Edirne, with focus on the administrative areas of interest that covers NUT3 region. The datasets include a three-level thematic hierarchical classification structure, ranging from broad categories (Level 1) to fine-grained subcategory thematic details (Level 3 – 44 thematic classes), which have been updated every six years since 1990.

Data set of the past recent land cover change of the cities was obtained from the Copernicus Land Monitoring Service (<https://land.copernicus.eu/en>) for the years 1990, 2006, 2012, and 2018, as vector format.

The thematic datasets are needed for identifying and quantifying clusters of changes numerically, allowing statistical modelling and computational synthesis of changes between the periods. However, before generating the analysis, the differences between the contemporary datasets and historical maps should be measurable. Therefore, the data structure of

broader level of CLC categories is reclassified, as highlighted in Table 1, and the details of thematic labels are summarized.

Table 1. CORINE Land Cover dataset structure, bold highlighted with the reclassification category of Level 1 for this study.

Level 1	Reclassification	Level 2	Level 3	Corine Code
Artificial surfaces	Built form	Urban fabric	Continuous urban fabric	111
			Discontinuous urban fabric	112
		Industrial, commercial and transport units	Industrial or commercial units	121
			Road and rail networks and associated land	122
			Port areas	123
			Airports	124
		Mine, dump and construction sites	Mineral extraction sites	131
			Dump sites	132
			Construction sites	133
		Artificial, non-agricultural vegetated areas	Green urban areas	141
			Sport and leisure facilities	142
Agricultural areas	Agricultural Landscape	Arable land	Non-irrigated arable land	211
			Permanently irrigated land	212
			Rice fields	213
		Permanent crops	Vineyards	221
			Fruit trees and berry plantations	222
			Olive groves	223
		Pastures	Pastures	231
		Heterogeneous agricultural areas	Annual crops associated with permanent crops	241
			Complex cultivation patterns	242
			Land principally occupied by agriculture, with significant areas of natural vegetation	243
			Agro-forestry areas	244
Forest and semi natural areas	Natural/Forest	Forests	Broad-leaved forest	311
			Coniferous forest	312
			Mixed forest	313
		Scrub and/or herbaceous	Natural grasslands	321
			Moors and heathland	322

		vegetation associations	Sclerophyllous vegetation	323
			Transitional woodland-shrub	324
		Open spaces with little or no vegetation	Beaches, dunes, sands	331
			Bare rocks	332
			Sparsely vegetated areas	333
			Burnt areas	334
			Glaciers and perpetual snow	335
Wetlands	Water features	Inland wetlands	Inland marshes	411
			Peat bogs	412
		Maritime wetlands	Salt marshes	421
			Salines	422
			Intertidal flats	423
Water bodies		Inland waters	Water courses	511
			Water bodies	512
		Marine waters	Coastal lagoons	521
			Estuaries	522
			Sea and ocean	523

3.2.2 Secondary data

Secondary data for this study consists of the historical map records and contemporary vector maps that were collected from the desk research of the digital archives of the libraries, institutions, municipalities and academic studies.

Historically, the most comprehensive representation of Bursa city is the cadastral plan created in 1857 by Suphi Bey, derived from the Salt Research, Harika-Kemali Söylemezoğlu Archive (2013). The scale of 1/16000, 1857 map provides information about the four main urban form complexes – streets, blocks, buildings, and land use types. The 1912 plan, which is derived from the Salt Research, Harika-Kemali Söylemezoğlu Archive (2013), provides critical insights into the layout of streets and solid representations of several protected official buildings. 1/1000 and 1/500 scale current states spatial base maps were requested from the Bursa Municipality database and delivered digitally as in ncz. and dwg. format.

In the case of Edirne, General Osmont's Plan d'Adrianople (1854), as reproduced in Yerolympos (1993), was used as one of the earliest historical cartographic references providing insight into the Ottoman urban tissue. It was examined in conjunction with Mehmed Selami's map of Edirne (1885), as reproduced in Darkot (1965), which documents the later urban expansion of the city. Contemporary spatial base data for Edirne

were obtained digitally from Edirne Municipality in NCZ format at 1:1,000 and 1:500 scales.

For Istanbul, the most descriptive historical map of Ottoman architecture for the 19th century is Ekrem Hakkı Ayverdi's maps (1875–1882), supplemented by Charles Edouard Goad's Istanbul Insurance Maps (1904–1906) and Jacques Pervititch's insurance maps (1922), which illustrate the city's transformation. These maps were also derived from the Salt Research, Harika-Kemali Söylemezoğlu Archive. Contemporary spatial data of the Istanbul Historical Peninsula was received from the Fatih Municipality in dwg. and shp. formats.

The source and the original historical map details for Bursa and Istanbul are provided in Appendix 2.

3.2.3 *Qualitative data*

Qualitative data for this study involve the analysis of historical urban context through the interpretation of the urban form based on the historico-geographical approach to urban morphology. The qualitative analysis also involves interpreting descriptive information on historical maps, such as map symbols and any text-based records, that guide to identify available elements of the town plan and components of the townscape.

In the case of Bursa, three components of the townscape – town plan, building type, and land use pattern (Conzen, 2018, 1960) – and landmarks (monuments) can be identified and traced from Suphi Bey's maps. However, for the period of 1912, only the street structure (simple tissue) and landmarks are available. Therefore, landmarks can be considered as common reference points on both historical maps and the contemporary map.

The Osmont plan depicts the simple urban tissue (streets and blocks) of the city of Edirne, with its ancient fortifications and landmarks, and allows the tracing of the townscape organization and spatial hierarchies of the city. The elements of the Osmont plan also contain information about the geographical features of the city, which are important for the research, as it is covered with hills and rivers. The map of Mehmet Selami exhibits a clear distinction of the land use patterns and urban form elements, which provide evidence to trace the functional distribution of the city.

For the city of Istanbul, streets, blocks and plots and their division can be traced from fire insurance maps and Jacques Pervititch's maps. These maps offer typomorphological detection of the city - the identification of built form elements at higher resolution level.

3.2.4 Quantitative data

In this study, quantitative measurement of the morphological indices is distinguished according to principles of the hierarchies such as streets, blocks, greenery, and buildings, and their corresponding key dimensions like area, elongation, linear measures, ratios, and element density measures.

The area and elongation measures correspond to the total land coverage, block area, block elongation, green area, building footprint area, and total building coverage. The measurement of the street width, block dimensions (street segment width), and building depth/width are used as the linear size of the urban form.

The indices are developed based on the ratios of street integration (angular segment integration), the number of street segments, the ratio of street nodes to edges, and the number of block frontages.

3.3 Data Processing and data analysis: tools, and software

In order to define the procedure of the collection of the quantitative parameters from the case studies context and their relevance historical dimensions, is addressed in this data gathering and data processing step. The data processing is performed on the basis of the selected primary and secondary data parameters by means of the desktop-based investigation with combination of the GIS tools like ARCGIS and QGIS is employed to anticipate all the features and accurately compare and capture the results in different time periods as fully and accurately as possible. The database and the descriptive spatial statistics are conducted by means of Orange Data Mining Toolbox in Python and Python 3.11.7, and visualizations and simulations of the parameters are conducted by means of the DepthmapX software.

To process secondary data for the relevant case studies, the scanning and georeferencing process is a principal starting point, combining information from the historical maps, which is based on the processing techniques to link between the contemporary data sets through the available any retained features as points of reference. Further step is segmentation and digitalisation is to investigate actual built form with transformation of the pixel information to vector and georeferenced data into structured geospatial datasets that reference statistical analysis. Thus, the geospatial dataset is structured by the digitisation process with assigning of the thematic attributes to it, adopted for the statistical analysis and analytical rigour to the methodological frame of the palimpsest.

Chapter 4: Methodology

The proposed methodological approach relies on through knowledge of the literature analysis with respect to the different urban morphological approach and with respect to address their lack of systematic and rigorous framework. The tangibility and ubiquity of physical form is the best reference aspect for layered palimpsest cities, where the changes of previous forms and additions persist in present elements of the urban fabric.

This methodological approach aims to bridge qualitative and quantitative approaches, positioning different urban morphological approaches as a key resource for descriptive analysis and positioning the different applications in cross-disciplinary urban studies to the concept of palimpsest. It is novel approach and against to traditional investigation of the cities. But it requires a establishment of a simplified methodological framework to address the complexity of palimpsest approach.

Figure 4 present general methodological framework that contains five main stages in Step (I) and one complementary stage in Step (II) (empirical analysis) of the proposed method for investigating city as palimpsest in qualitative and quantitative way.

Section 2.1 describes the collection of the data stage, which is detailed in Section 2.2 for the processing of data. Data preprocessing is the initial stage for Step (I) and Step (II) to transfer map resources into the GIS. The tool used for preprocessing the data is QGIS, with aim of georeferencing the different kinds of map resources and overlaying historical maps with contemporary data sources. Once the maps have been georeferenced, the second step is to segment and digitize the elements and assign attributes to them in QGIS. The choice of the most relevant features is based on information of both historical and contemporary maps.

After selecting and identifying relevant features, data transformation stage is applied in Step (I) to describe quantitative parameters, each of them scope of the process of segmentation and digitalization of historical maps to identified features to be defined as attributes (layers) with aim of the providing quantitative measurements; which include the following: land cover (types); street network (street age, street geometry, street length, integration, and road segments); blocks (area, elongation, perimeter, block faces, and number of frontages); buildings (areas of building footprints, number of buildings, and building types); and green spaces (area).

Third stage in Step (I) follows data integration, which is designed according to hierarchical principles carried out in cities by Batty and Longley (1994) and Kropf (2014), to systematically carry out the analysis,

which depends on the determination of the resolution level to be investigated throughout the layers. Based on their understanding, the complexity of the urban form can be understood by moving between the levels. Through moving down the levels, the more detailed explanation aims to be obtained, and by moving up the levels aims to detect more detailed information. The levels are determined in this respect as: levels of abstraction, levels of aggregation, and levels of complexity, that will be able to translate to descriptive analytical and analytical framework of the urban morphology. In this respect, a statistical analysis is carried out with respect to quantitative approach of the study through the computational tools of the Geographic Information Systems (GIS). In order to visualize, and identify results, Python 3.11.7 packaged by Anaconda and Orange: Data Mining Toolbox in Python 3.35 (Demšar and et, 2013), is used for as pivotal analytical and conceptual tools to identify, analyse, detect, and visualize complex spatial relationships across temporal scales.

The final stage in Step (I), data processing, is designated to interpret the results of the overlaid layers with the procedure of spatial correlation analysis and clustering analysis to define whether the clusters exhibit continuity or change over time in relation to the historical development of the cities. Using tools like Python and Orange: Data Mining Toolbox in Python 3.35 (Demšar and et, 2013), the research further refine the clustering results in GIS by applying K-means and hierarchical clustering methods.

Morphological, qualitative, and quantitative analysis is based on multilayered model – temporal layering, spatiotemporal layering, and aspect and element separation – which are used to define each specific level of resolution. The model is conceptualized to align with the combinations of different methods and tools and to reveal different aspects of each principle through each level.

Each level can be resolved through integration of multiple methodologies. Therefore, morphological analysis is applied to identify and analyse structured spaces, with combinations of the different approaches to urban morphology, remote sensing and generative models, aiming to provide a descriptive and analytical approach in a qualitative and quantitative way that enhances understanding of the formation and transformation process.

Morphological analysis typically focuses on understanding the historical characteristics and significance of places, as well as identifying and classifying specific features and their differences within different parts of the built environment. This understanding should extend to higher levels of specificity and resolution.

Morphological analysis is starting point to bridge with the qualitative and quantitative analysis. The analysis follows three processes: first, the land cover change analysis to determine the areas with significant change for narrowing the research area; second, the characterization of the morphological unit and configurational analysis to identify these units based on the land cover, street ,blocks, buildings and green spaces; third, urban tissue analysis (levels of resolution) combined with Kropf's (2014, 2017b) multi-level diagram and Conzen's (1960)'compositional hierarchy', along with Saverio Muratori (1960), Caniggia and Maffei, (1979) 'principle of aggregation'.

Step (II) follows the characterization of the boundaries of urban heritage sites to represent the heritage contexts and its immediate surrounding for the empirical testing. The identification of the outline of the space is crucial to create isovist (visible area) in generation of perceptual information from any point where an observer will create several visible area and recognised heritage environment settings with buildings. This observational approach with spatial isovist and visibility analyses aid to be verified testability of the palimpsest method to recognise and measure the rules behind the heritage setting.

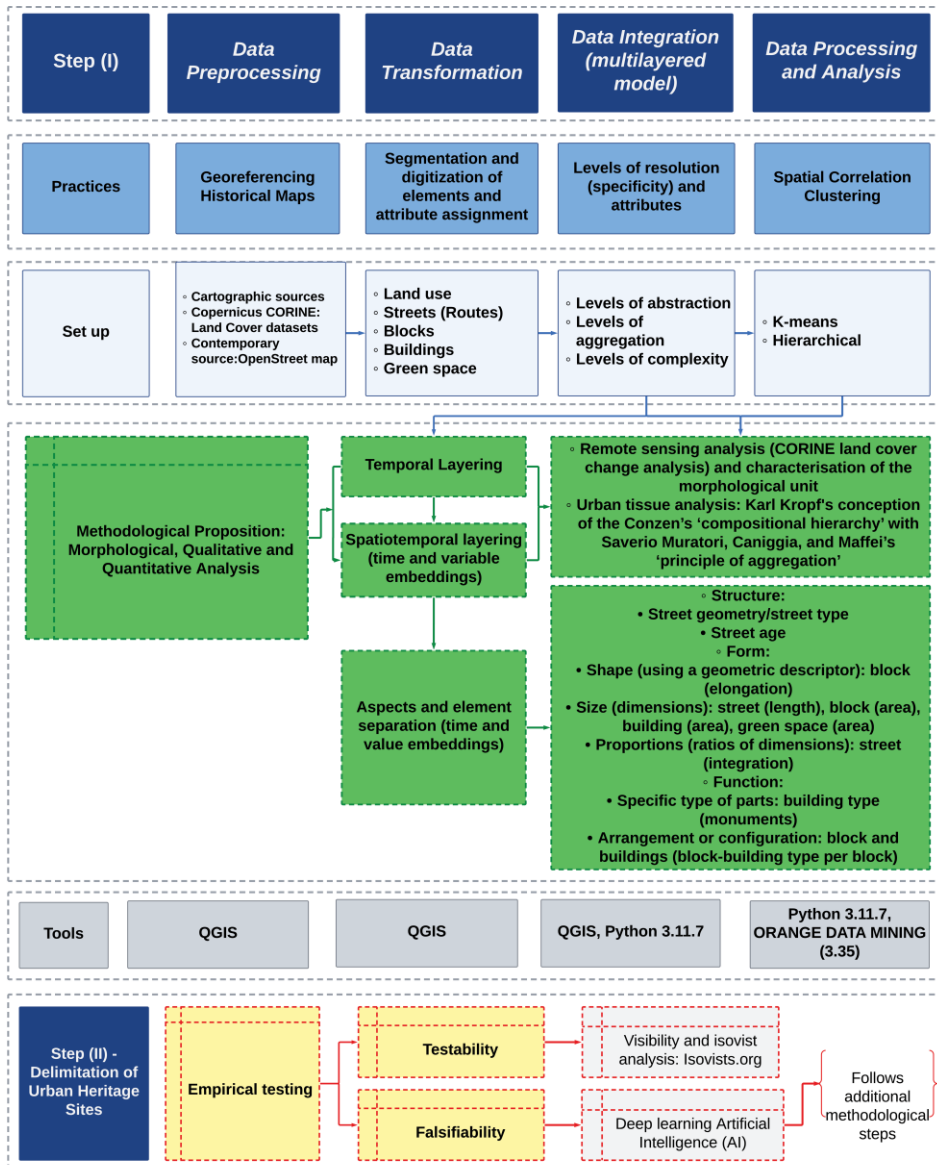


Figure 4. The main methodological framework for palimpsest method.

After having characterized the boundaries of urban heritage sites, understanding cities historically is accomplished as a new investigation layer for recognition of elements in urban heritage sites at different levels of resolution through integration with the urban morphological approach to deep learning. The falsifiability step proposes to gain direct knowledge on processes involved in the emergence of the urban form through identifying patterns, by introducing a model of urban heritage site morphogenesis

which aims at recognizing types by empirical investigation and artificial intelligence reasoning.

The general principles of the model are as follows successive stages that presented in Figure 5. As first stage, the implementation of historical (inherited) variables requires data preparation steps, georeferencing, and aligning cartographic maps in GIS to the projection system of the study areas. The model structure is planned based on the principles of the different levels of resolutions/specificity. The second stage follows the layering map process with the aid of the GIS. These two stages have been already done in data preprocessing and data transformation stage in Step (I). The detailed explanation of the CNN based automatic segmentation analysis have been included in Section 4.2.

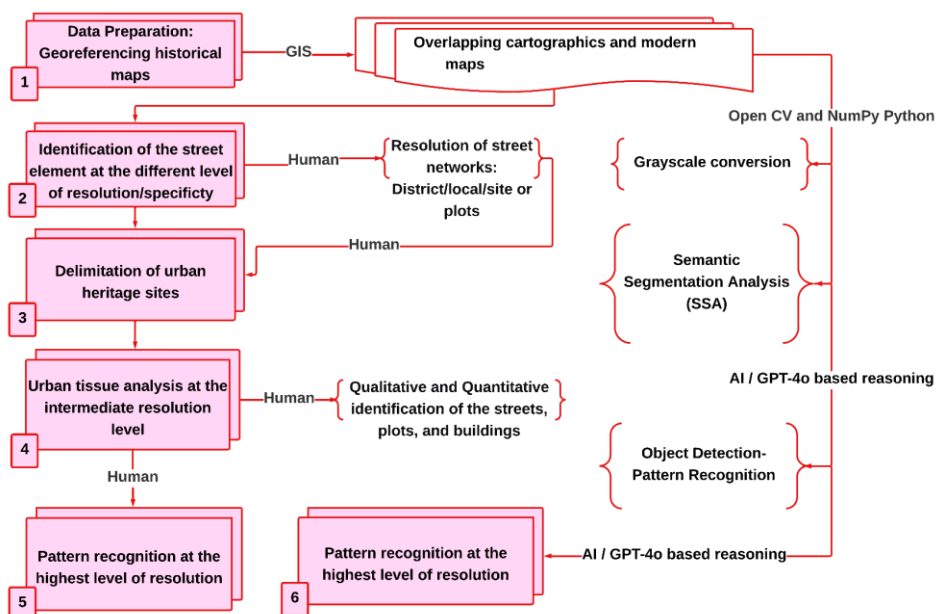


Figure 5. Complementary stage to the falsifiability of the palimpsest method for the AI based pattern identification.

Third stage covers the identification of the patterns in the very lower resolution; street or road structure was considered as the preliminary phase to investigate patterns within these levels of specificity.

There is a need to narrow the research areas for the identification of the variables at the highest levels of specificity to achieve a greater detail about the urban heritage environment. To do this, the research areas boundaries were re-defined with focusing on the ability of the model to capture types more particularly.

The urban tissue is considered as unit of development, as smaller-scale elements (streets, plots, and buildings) come together to create place characters. So, urban tissue analysis is added to independently classify types of elements within the tissues of urban heritage sites.

After this preprocessing stages and preliminary urban tissue identification with human aid, the method will apply the AI reasoning phase to recognize patterns. Segmentation maps were uploaded as input data into the GPT-4o environment, as well as supported with textual information that gained by the human based urban morphological analysis. Finally, several prompts have been developed to identify types of elements within the different resolution levels across the different time periods based on AI based reasoning.

4.1 Data Preprocessing (Georeferencing historical maps)

Georeferencing process in this study, is applied to ensure the accuracy of the coordinate systems of overlapped maps, and it is applied as a preprocessing step to perform the spatial data integration of historical sources with modern geospatial datasets in GIS. Each cartographic maps need spatial assessment with Ground Control Points (GCPs) to achieve the georeferencing process.

The coordinate adjustment needs to be made to accommodate accurately aligned spatial features of cartographic maps with the desired coordinate systems. For this purpose, the minimum number of GCPs must be selected based on visible spatial and temporal permanent features in historical maps and contemporary reference base maps. In the case of cartographic city maps, landmarks are the most permanent map elements

Different tests were performed to determine the minimum number of GCPs with minimum impact on image distortion and transformation error. The identification process is carried out in QGIS by conducting the Georeferencing tool. The suitable number of GCPs is obtained as 10, and the transformation model is considered as Polynomial 1st order, in order to reduce local scanning distortion parameters within maps.

For the diachronic analysis of the urban palimpsest, the spatial datasets were harmonized using coordinate reference systems appropriate to each case-study site. Bursa and Istanbul were processed using TUREF / TM30-based projected systems, while Edirne was processed using a TUREF / TM27-based projected system. The historical and cartographic maps were aligned in GIS into the relevant projected coordinate reference system to make the temporal layers spatially comparable. CLC was used as a separate recent-year land-cover layer and as a reference classification framework for comparable land-cover categories. It was not used for

morphometric analysis. Therefore, CLC and local vector datasets were not measured in mixed projections.

4.2 Data Transformation (Segmentation and digitization of elements and attribute assignments)

Data transformation was employed for identification of the land use types in georeferenced historical maps. The procedure involves defining clusters of signature pixels, which are related to actual world data, and does not exceed a parameter value, and then classifying them. The parameter value was subjected to mean shift segmentation algorithm, capture spectral similarity range in the minimum neighbourhood size. The transformation was conducted to segmentation processing procedures in Orfeo Toolbox plugin in QGIS. This plugin provides large-scale mean shift segmentation algorithm that helps to perform matched land use boundaries aligned with actual data sets. The parameters of object-based image analysis were adjusted to eliminate the occupation of the ambiguity pixels that would be against obtaining inaccurate land use labelling.

Land use labelling procedure was then applied with supervised learning to assign semantic land use classes to the delineated regions. Algorithm were trained with training polygons, each polygon were related a annotated corresponding label in the actual datasets. Zonal statistics were applied to extract mean spectral values for validation polygons and the segmentation layer.

Then, the research was applied a supervised machine learning algorithm, Random Forest, built in Python. Random Forest learns classification labels from the mean band values in trained polygons, and it operates by building an ensemble of random subsets of features for each segment to assign the most probable class. Hence, classification results were obtained with different subsampling methods and were checked for classification errors to detect problems in validation polygons, and corrected manually in QGIS to achieve accurate classification results.

Data transformation is also applied for the extraction of the street, block, and building features from historical and contemporary map data with the aid of the CNN based automatic semantic segmentation. The pattern identification process was subsequently performed by integrating the resulting segmented layers with information obtained from human based urban morphological analysis and AI based reasoning within the different levels of scale.

For the pattern recognition process, first data standardization processing was applied – collection and georeferencing of historical maps – in a GIS environment. To detect patterns, CNN based automatic

segmentation using OpenCV and NumPy (Python) on both historical maps and contemporary maps was applied for edge detection to identify streets and contour detection was also applied to find urban blocks and buildings. To achieve this, a grayscale conversion image preprocessing step in the Python (OpenCV) environment was performed to reduce the complexity of maps. Finally, OpenCV and NumPy libraries in Python was used for image processing to perform automatic segmentation.

4.3 Methodological proposition (levels of resolution/specificity and attributes)

The methodological proposition was conducted to demonstrate that the level of resolution and the level of specificity are fundamental to improving our understanding of the urban form and to adopt a more comprehensive approach to investigating historical stratification. The rationale for this proposition is hence to achieve research novelty by demonstrating that three steps are required so that the time and space relationship can be established.

First, constitution of the evolution of the cities is spatially and temporally and involves set of relationships within multilevel systems across different periods, such as historical processes (temporal) and spatial structures (elements of urban form), which are shaped by complex relationships. So, a multi-level hierarchical framework of methodology strengthens the relationship between the time and space aspects, as it leads to tracing the transformation of spatial layers while keeping the actual formation constant and unchanged in its heterogeneity. Accordingly, the first step covers temporal layering.

Second, by incorporating qualitative approaches into quantitative approaches, the analysis obtains diachronic depth (spatiotemporal layering) and captures numerical context and unique characteristics through which transformation at one level propagates its effects and changes to the entire spatial system. Both processes can be reliably established through either morphological and GIS-based processing analysis with quantitative and statistical accounts of urban form metrics; rather, it requires an integrated approach that leverages the strengths of partly statistical models of historical stratification and interpretive morphological evidence.

Third, the integration of two processes allows for the triangulation of methodology, that is, to enhance both the internal validity of structural and geometrical variations with the temporal dimension, while constructing the ability for validation of the aspects and element separation (time and value embedding) analysis. Aspect and element separation (time and value embedding) analysis follows three principles in this study are: position–

structure; outline–form; internal arrangement–function. Structure is importance to define pattern distribution in particular spatial configuration at various scales. The form is expressed in terms of the geometric description of built form. Function is used to define the specific conditions presented by elements of the built environment. These principles are defined by the three main character categories – spatial configuration, geometric properties, and specific arrangement – to identify changes or continuity of their qualitative and quantitative properties over time.

The steps can be summarised according to principles of the multilevel hierarchical analysis that follows identifying broader patterns (land covers) and then characterizing morphological regions. Further, with enhancing resolution level, examination of the detailed elements will be achieved, and then re-evaluating the broader patterns based on these details.

The six resolution levels for morphological, qualitative and quantitative analysis are determined: land cover (1), morphological regions (2), streets (3), blocks (4), buildings (aggregation within the block) (5), and green spaces (6). The three key principles and their corresponding categories, grouped into six hierarchical levels and into their qualitative and quantitative metrics, are summarized in Table 2.

As the main idea of the palimpsest, methodological propositions (morphological findings with the quantitative and qualitative result - will be tested and confirmed in the higher level of the specificity into methods and tools in visibility analysis of the built environment (confirmation), and artificial intelligent (falsifiability).

Table 2. Categories of character and metrics used for the element separation analysis.

Principles	Category of character	Multilayered Model	Levels	Character variables (qualitative and quantitative)	Metrics	Unit of measure
Structure	Spatial configuration	Temporal Layering	1. Land Cover	Corine Land Cover Classification (CLC)	Class type	Category
				CLC distribution and transition	Class count	% grid count
			2. Morphological Unit	Land cover persistency	Score	Ordinal scale (1-4)
		Spatiotemporal Layering: Time and variable embeddings	3. Morphological Region (Size and Coverage)	Street age	Years	Unitless

				Street hierarchy	Street classification	Unitless
			3.1. Streets	Centrality	Closeness	Count
			3.2. Blocks	Block pattern (distribution)	Block area	m2
			3.3. Buildings	Building pattern (distribution)	Floor area	m2
			3.4. Green spaces	Green spaces distribution	Continuity	Unitless
Form	Geometric properties (shape, size, compactness, and proportion)	Aspect and element separation (time and value embeddings)	3. Streets	Angular segment length (distribution), street integration	Metric length of the segments, angular changes of street segments	Meter, n
			4. Blocks	Block area, block elongation	Shape, and size	m2
			6. Green spaces	Green area	Size of green area	m2
Function	Specific arrangement	Aspect and element separation (time and value embeddings)	5. Buildings	Building types	Use type	Category
			4. Blocks – 5. Buildings	Block-Building type per block, visibility	Function distribution, visual integration and mean depth	Percentage %, index
			6.Green Spaces	Green spaces type	Use type	Category

4.4 The combination of the historico-geographical approach, and remote sensing approach (longitudinal study) for temporal layering

From a conceptual point of view this research builds on the Conzen's historical geographical approach, which established the town plan analysis and townscape assessment – made the first conceptualisation palimpsest idea used in historical stratification principle in urban morphology. The town plan analysis is the core idea behind the historical stratification of the townscape, which has evolved by the combinations of three components – town plan, building fabric, and land use patterns. It is

obvious that, his method is based on the level of abstraction of urban form or hierarchy of elements in urban form in attempts to investigation of plan units. Pursuing this idea further, emphasized the form and structure of town is not static, and continually reshaped and varied over time, in response to the development of land use patterns during the formation and transformation of the townscape. However, Conzen's conventional approaches to the investigation of townscape are based on the qualitative examination of the aggregation process in urban structures, particularly grouped into types of land use patterns and urban elements according to their period.

The scale of the palimpsest is not fixed with the townscape analysis, if we acknowledge the complexity of the city. There is a scale gap within the historical geographical approach to urban morphology for detection spatial and morphological dynamics of built form, since the urban form is a transformation of the natural environment.

Hence, to improve spatial details in the most recent formation and transformation of the cities, a multi-sensor Earth Observation approach was incorporated, allowing for more precise detection and continuity, computation, and comparison of highly complex systems, by providing spatial urban and natural metrics through the acquisition of multi-temporal satellite and ground-based data. These contemporary Earth Observation tools are indispensable for uncovering the gaps between the levels of the resolutions in urban morphology and provide strong leverage for the identification of the transition types in built form with quantitative accounts.

The innovation of this approach is the identification types of urban transitions and validation of historically defined spatial organization using a combination of the Conzenian principles of historical stratification analysis and contemporary Earth Observation metrics, yet the novelty lies in the dual integration of the data outputs; where the ground control points were supplemented with temporally matched remote sensing imagery, providing a richer spatio-temporal validation than the conventional ground-truthing approach — manually — through overlapping map analysis. Ultimately, while this methodological novelty contributes deeper insights about the process of formation and transformation of the built environment defined through morphological approaches, it provides evidence of the urban palimpsest and contributes new insights for the detection of where and why the changes occur within the different levels of the complexity.

Historical stratification analysis is revealed for the determination of the morphological periods, including the process of modernization (urban transformation) and the persistency challenge in the three Ottoman capital

cities during the significant periods of the “Tanzimat” (1839–1876), the last Ottoman period, and the post-war republic era (1922–1960). Change detection relied on the layering of historical maps technique, which enables the identification of land cover transitions and the identification of the transformation direction in the urban fabric. The results of temporal layering of the historical maps reflect morphological regions. This makes the method complementary with the earlier periods to properly compare the relationship between the form and land cover changes. Therefore, a combination of the methods of the historical-geographical approach and remote sensing approach is formed to validate urban expansion with contemporary data. For this purpose, to identify areas exhibiting significant transitions at a higher level of complexity, the investigation focuses on land cover transitions (type and are based) through temporal analysis of the land cover data at 100-meter resolution which is obtained from the Copernicus Earth observation services, CORINE Land Cover (CLC) datasets.

CORINE land cover classifications for the years 1990 (t_1), 2000 (t_2), 2006 (t_3), 2012 (t_4), and 2018 (t_5) are layered, and perceived percentage change rates in area (ha) within the Level 3 category are analysed using linear trend plots (annual change rate) mapped across normalized time intervals (Figure 8-9). Trend slope is calculated across unequal time intervals and indicates the annual rate of change in land cover percentage (%/year), and confidence interval indicates average width of %95 confidence as a narrow band (≤ 0.05) implies a high confidence that means statistically reliable trend, and a wide band (≥ 0.15) implies low confidence, high uncertain trend in the change.

This regression analyses allows more accurate assessments on the Conzenian historical stratification practices about the direction of urban growth (trend slope/a) and rate of changes by normalization of the unequal time periods with confidence interval width for each land use patterns.

Because of the higher complexity level of the NUT3 region, the spatial resolution level is determined at the neighbourhood scale analysis to increase the interpretability of the aggregated land cover transitions. In addition, the 500-meter by 500-meter grid cell dimension was used to quantitatively detect CORINE transitions within each cell across time periods. Then, each CLC dataset is intersected with these grid cells, enabling the overlapping layers to be detected using a spatial formula within each grid cell in GIS to identify where the cell represents types of transitions, as well as changes and continuity.

These results will indicate the degree of persistence and change in land-cover types across different CORINE periods. The relationship here does not refer to a direct correlation with urban form metrics, but to the

correspondence between land-cover transition patterns and morphological persistence at the broad land-cover level. The change frequency will indicate whether each cell has a score between 1 and 4, guiding the mapping and delineation of the urban morphological regions at the highest level of complexity. A value equal to 1 persistency score indicates less stability, while a value equal to 4 indicates full stability.

For this analysis, each land cover period is joined with the grid cells layer and then intersected as separate layers. To avoid multiple overlapping land cover cells, the score is assigned when the types of land covers are valid in all 4 periods.

Then, the units of morphological regions are characterised at the highest level of specificity by the degree of land cover type persistency based on the layering results of the earth observation data.

Morphological units are delineated and characterised in the case study of Istanbul's historical peninsula by criteria determined by Conzen's historical geographical approach within a descriptive framework. The criteria considered by Conzen to delineate morphological units follow the historical stratification principle and are covered by the systematic form complex, degree of form persistence, range of morphological periods, constitutive aspects of historical stratification, and contribution to city hierarchy as rank.

To evaluate the criteria, the most descriptive historical maps of Istanbul – François Kauffer's maps (1786) and Ekrem Hakkı Ayverdi's maps (1875–1882) – are layered to assess where stratification is significant (Table 4). These maps are supplemented by Charles Edward Goad's Istanbul Insurance Maps (1904–1906) and Jacques Pervititch's insurance maps (1940–41), to determine where the degree of the historical stratification is less.

4.5 Combining with Caniggian Typomorphological approach to Configurational approach

The combination of the configurational approach and typomorphological approach is based on the Karl Kropf's method on the correlating the configurational analysis and urban tissue analysis. Cannigia's morphological practices based on the Muratori's work to understand cities by examining the historical process of its formation. Cannigia further developed typo-morphological approaches by integrating the type of theory to the urban morphological context. The process was carried out using the components of the city at different scales, but here it is clarified by the inclusion of the basic parts of a structure, typological

units, hierarchical layers, systems, and cities integrated, address the challenges in spatial configuration.

In case of Ottoman capital cities, historical stratification and spatial organization of elements played a large part, the assessment must take into account the principles of Caniggia's typomorphological approach. Each capital was subjected to different spatial hierarchies and spatial configurations, thus understanding the organization of the urban components within the Ottoman cities depends on the cases. However, Caniggia's methodological framework is lack for interrupting the Ottoman cities evolution. Meanwhile, the development of the historic cores consists of the planned organization of urban elements and follows strict traditional rules. The structure system does not follow simple geometry; organized as a complex organism (fractals) – according to local rules and conditions – differentiated from the typical urban system in Europe that develops around a centre. Accordingly, the application of Caniggia's concept can not be reliable for explaining Ottoman cities without integrating different methods is necessary to overcome the limitations of the typomorphological approach in the historical analysis of Ottoman cities.

Besides the Cannigian approach, the Bill and Hanson's configurational approach and Stephen Marshall's types based configurational work is applicable with limitation to the analysis, since the aim of the configurational approach is to identify the relationship between the elements and identifying types of route structures. Thus, determination of the urban tissue types (mahalle) requires identification of the route types, and then typo-morphological elements within the hierarchy.

The layers in case of the spatial correlation (continuity) can be sought in our case within the components are: (1) elements (building/monument/külliye), (2) structure of elements (organisation of buildings/mahalle/cluster), (3) systems of structures (combinations of mahalle/patrimonial–hierarchical order), and (4) organism of the city. The spatial hierarchy of the clusters (different configurations) formed by the integration with the “kulliyes” and “neighbourhoods” and can be explained through configurational approaches and space syntax analysis. The output of the connections between the clusters was integrated into spatial integration analysis with change indicators in connectivity degrees over time within the urban form, allowing for the process-based quantification of physical change and functional change.

To be noted that, Caniggian approach to historical stratification covers the horizontal and vertical dimensions. Historical maps in case of the Ottoman cities are not descriptive maps – layers of the vertical details often missing and can not be applicable within the Cannigian

typomorphological practices. Therefore, the study needs to report that the attention is the two-dimensional detection.

On the other hand, the elements that Cannigia put forward to explain the historical development of cities are sufficient to explain the Ottoman urban development model, they lack the ability to reveal the relationships between these elements in Ottoman cities. To do this, a combination with a configurational approach is needed to explain the structure of the mahalle and define the changes and permanence in Ottoman neighbourhood types and their relationships.

Further, the combined procedure allowed both aspect and element separation analysis where specific patterns of forms at each level in the hierarchy can be typified and defined.

Types will be defined based on the attributes of elements in relation to the analysed periods. All possible variants will be defined both qualitatively and quantitatively, lead to the extraction of leading types. To achieve this, Kropf's multi-level diagram were integrated to the combined approach, levels can flexibly adjustable, guide the investigation of patterns and relationships. The diagram will help to obtain specific types in the different levels of resolution within the generic structure. The two-dimensional plan view will be used to aspects and element separation analysis. Aspect and element separation analysis will be able to identify distinctive features (persistence, additions or change) found at different levels and periods, considering the "position, outline, and internal arrangement" principles that have given the Ottoman capitals their unique characteristics.

Qualitative and quantitative variables is defined based on the seven primary character categories and formulated based on the literature review:

Morphological unit; Street geometry: based on (Marshall, 2004, p. 47,92).

S_{geo} = as defined by the way they are connected to each other

Street age: based on (Conzen, 1960; Lovra, 2016)

S_{age} = as defined by the results of the layering historic maps.

Shape; Block elongation: based on (Vialard, 2013, p. 98).

B_{elon} = as defined by the diameter of the circle of the equal area a shape of the block ($D1$) and diameter of the smallest circle that circumscribes a shape of the block ($D2$).

$B_{elon} = D2/D1 = 2 \sqrt{(A/\pi)} / \text{longest axis}$

Size; Coverage:

B_{cov} = defined as an area covered with the boundary [m^2]

Street segment length: based on (Turner et al., 2005).

S_{leng} = defined as the length of the lines geometric distance in metres between the two nodes

Block area:

B_{area} = defined as the area covered by block in $[m^2]$

Block perimeter:

B_{per} = defined as sum of the lengths of a block geometry in m.

Green area:

G_{area} = defined as the area covered by greenery in $[m^2]$.

Specific type of parts; arrangement or configuration; based on (Martin and March, 1972)

B_{type} = Defined as the building types per block

The analyse gives the logical foundation of the values (streets, plots, blocks, buildings, and green spaces) at the level in the hierarchy and the distinguishment of inherited elements (specific types of forms); which are make up the Ottoman urban tissue. These basic elements reveal the Ottoman neighbourhood structure.

4.6 Integrated methodology: complementary approaches to urban morphology, spatial analytical approach, and generative models

Historically layered urban spaces, especially urban heritage sites, are synonymous with the concept of a palimpsest, built up by urban elements (tangible) and social and cultural habits or needs (intangible). In terms of the palimpsest concept, perception is the basis for investigating changes in the built environment in relation to human needs and the built environment.

As a complementary approach to urban morphology, Kevin (Lynch, 1964), used a pragmatic method for cities, focusing on defining the details of the built environment based on human perception and behaviour. According to his approach city image revealed through the sequence and combination of the paths, edges, districts, nodes, and landmarks elements. The influence of the city image is the basis for axial and lateral references (paths and edges) and area and point references (districts and landmarks), which are combined through the dimensions of time and space.

Similarly, Gordon Cullen (1961), investigate the details of urban elements perceptually and experientially in townscape assessment by, emphasizing how these elements relate to each other. These configurations of elements are associated with three basic concepts that bring them together in a broader context: serial vision, place, and content. Serial vision shares the same principle as Kevin Lynch's method.

Therefore, the process of urban heritage should be evaluated within the system of both intangible and tangible characteristics. This approach provides the basis for demonstrating the spatial compositions of the heritage environment and the various visual elements of its configurations.

For this reason, the assessment of an integrated, multilayered urban landscape should combine an integrated perception of both dynamic and static elements. The structural formulation, including the geometric and topological properties of built form, is defined and evaluated through the upper methodological section to guide the analysis of visual and perceptual properties of the urban landscape (intangible/semantic layers of the urban palimpsest). The outputs of elements related to perception can be evaluated and visualized through spatial analyses. This provides a way to connect the results of integrated visible models of the urban landscape – created by multiple isovists – by learning from the characteristics of the heritage environment. For this purpose, the integrated methodological practice offers the combination of complementary approaches to urban morphology with spatial analysis methods. These reveal the spatial compositions of the heritage environment and the various visual elements of its configurations, including both qualitative and quantitative assessments.

For qualitative investigation in this method is the integration of Kevin Lynch's and Gordon Cullen's explanatory methodological approaches to overcome the functional persistency challenges in cities. The novelty here lies for quantitative analysis, a combination of approaches by (Michael Batty, 2001), (Benedikt, 1979), and (O'Sullivan and Turner, 2001), on isovist and visibility analysis.

Serial isovist analysis was performed as the first step to obtain spatial and statistical properties. This procedure was generated for the identification of the "position and outline of the spaces," the "nature of the isovist boundaries," and the "points of view," according to the two qualitative approaches.

Quantification was conducted through isovist and visibility analysis based on the several aspects: the positions of the isovists (isovist sequence), the shape and size of the isovists. The shape and size of the isovist is defined based on the geometry of the environment, as outlined by Michael Batty. Thus, different types of isovist fields obtained from various viewpoints will be defined as a combination. Hence, the clustered heritage environment will be defined from any vantage point position. The visible character of the environment will be revealed by defining the cluster of visible isovists corresponding to all viewpoints.

Lastly, to evaluate the mutual visibility of heritage elements and their surrounding built elements, visibility graph analysis will be generated

based on Alasdair Turner's and his colleague's foundational methodology for visibility graph analysis using DepthmapX software.

The most important argument for using the palimpsest technique is that it involves recycling parchments/reusing previous formations. Patterns of palimpsest may be seen as a series of hypotheses in the arrangement of the current environment that are alive or evolving. Thus, the research problem is raised about how to reuse inherited elements within the contemporary urban setting and how to protect and adapt them. These recognition problems can be solved by adopting an algorithm that learns parameters from the historical data sets.

Generative AI is an innovative solution and can be adapted and negotiated between layers as an "intelligent palimpsest" to experiment with historic urban patterns, configurations, and future possibilities without ignoring the values of each historical period.

Christopher Alexander described the use of the patterns of towns to create possible pattern languages in his *A Pattern Language*, by explaining this quote.

"The sequence of patterns is both a summary of the language, and at the same time, an index to the patterns. If you read through the sentences which connect the groups of patterns to one another, you will get an over-view of the whole language. And once you get this over-view, you will then be able to find the patterns which are relevant to your own project."

This approach allows the structuring of the urban morphological algorithm the language of the "intelligent palimpsest".

The generation of these patterns is within the scope of a quantitative investigation and a generative model (deep learning) that learns from historical patterns. By using an algorithm that applies spatial configurations of historical patterns of modern cities, these patterns can be repeatedly interpreted in new urban orders. For generating patterns, the input of the historical patterns is established in the second methodological step for the pattern parameters of the three case study sites.

The deeply analysis of an Ottoman capital city was used to develop the a model and prove the testability of the palimpsest approach with the idea of the intelligent palimpsest, which will have the ability to read and reuse inherited values.

4.7 Statistical analysis

Statistical analysis was performed using different analytical approaches and were conducted using the Jupyter Notebook environment in Python for statistical computing and visualisation. The dataset in this

study consists of numerical variables describing levels of urban form and categorical variables are indicating temporal structure.

The descriptive statistical results are presented as mean $\pm$ standard deviation (SD), and median for the size, shape, lengths and integration metrics of urban form character variables. Distribution plots were used to demonstrate the shape and spread of the data for each map period. As several variables displayed skewed distributions and heterogeneous variance, $\log_{10}$ transformation were undertaken to related variables to reduce the skewness.

Because the variables did not meet the assumption of normality, non-parametric, Mann-Whitney U tests, a statistical method, were employed to identify differences in urban form variables across periods were statistically significant. Statistical significance was assessed at the $p < 0.001$ level. The results of Mann-Whitney U tests are summarised in a matrix table, demonstrating which urban morphological layers exhibit significant changes or not across periods.

Linear regression analysis was employed to normalized time intervals to detect changes in area values of land cover categories across multiple time periods. Regression slope value was used to quantify the direction and magnitude of changes in land cover categories. The width of confidence intervals was used as an indicator of the reliability or uncertainty of the trends.

4.8 Clustering

Based on the above explained in the methodological proposition section, the quantification of the variables depends on unsupervised learning by using different data tools. However, since there is still no specified relationship established between the layers, the degree of urban structural changes or persistence in the urban fabric over time needs to be highlighted (clusters) and quantified. The narrowing of the research area to reach a high level of specificity to see details more accurately primarily needs to be based on statistical clustering analysis. Therefore, the statistical representation of similarities and differences based on attributes in different time periods builds a basis for revealing the results of the methodological proposition.

Spatial clustering analysis was carried out based on the K-means clustering and hierarchical clustering methods, widely adopted in GIS. The centroid-based K-means clustering was used to ensure spatial consistency of morphological elements clustered in multi-temporal analysis, based on the attributes – size, shape, or configuration – and assigning them to the nearest cluster mean (centroid). The focus on quantitative statistical

clustering is on the K-means clustering approach, which should distinguish the permeability of variables and whether clusters reflect continuity of change over time.

The clustering analysis consists of several processing steps to subsequently subdivide the morphological region, block elongation and block area into groups based on the K-means clustering method. The method builds well-defined clusters based on two parameters where the method computes the distance between the data samples and divides them into predefined K clusters by minimizing cluster variance using a sum of squared distance metric (usually Euclidean distance). The optimal number of K clusters is determined based on the elbow method. K-means is well suited for the purpose of the palimpsest approach, as it can create clusters of similar size and reveal underlying patterns or structures within the data.

Hierarchical clustering was used to aid in merging or splitting variables based on their distance metrics until a cluster hierarchy (dendrogram) is built. The linkage criteria for the clusters and the desired number of clusters are determined by Ward's method to minimize variance within clusters at the appropriate dendrogram level. The aim is to validate clusters to establish typological similarities representing variations at the highest resolution level, such as building types are grouped into block clusters. This method is fundamental for capturing transitions in building types or clusters of buildings between the periods, determine those that either persisted or changed by comparing their distributions.

Obtained spatial clustering results from GIS were processed in the Orange Data Mining Toolbox in Python 3.35 to enable not only the exploration of patterns within the map but also the explanation of variables.

Chapter 5: Results

5.1 Results in levels of complexity: Spatial Configuration (temporal layering)

As explained in Section 4.4, this part of analysis applies palimpsest technique through a methodological combination of historical-geographical and remote-sensing approaches. The aim is to detect spatial configurational changes and transition at the lowest level of specificity, that is corresponding land cover layer formation, or transformation.

5.1.1 Land cover and Land use changes across periods, and Transitions in Land Cover Types

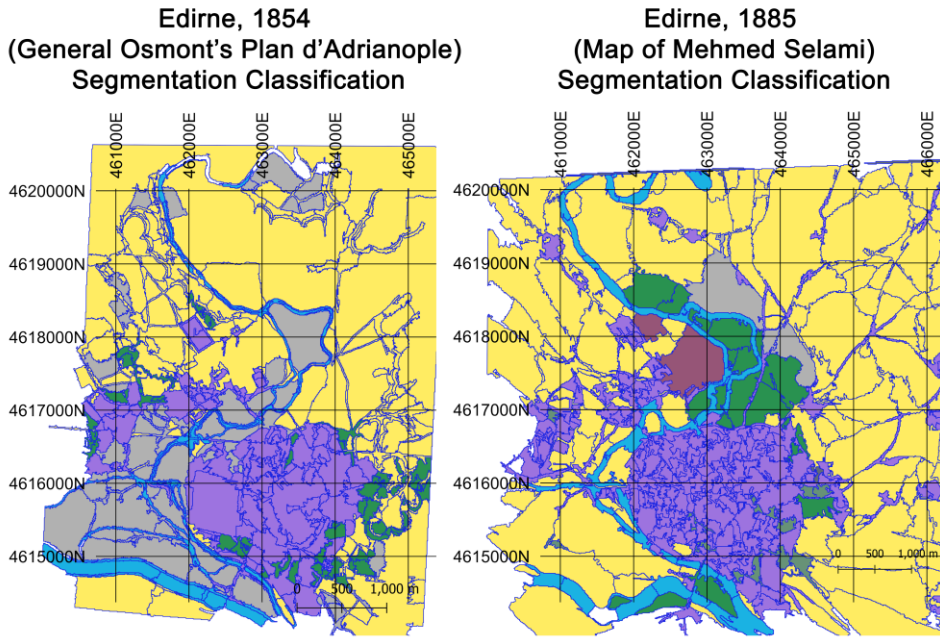
The examination of the land cover changes in this section is structured in two stages because cartographic maps and CLC datasets

represent different data types. In the first stage, cartographic maps and their corresponding periods were segmented to identify land cover types spatially and qualitatively. In second stage, CLC data were used to identify land cover category changes for the recent period between 1990 and 2018, since those categories were more valid for those years. These two different processes were used as complementary layers to interpret how historical land-cover formations correspond to, or help explain, recent land-cover change trends.

In the case of Edirne, the temporal layering of the 1854 and 1885 cartographic maps reveals the valid land cover types at the lowest level of resolution. Based on the classification results (Figure 6), the 1854 map includes land cover classes such as urban fabric, forest scrub and herbaceous vegetation associations, heterogeneous agricultural areas, and inland waters. Mehmed Selami's map reveals evidence of urban expansion, with previously unclassified land cover types. Two additional land cover types are identified. The first is artificial, non-agricultural vegetated areas, and the other is industrial, commercial, and transport units.

The resulting temporal layering of the two historical maps guided the research focus toward detecting segments of change and non-change between the two map periods.

Three major characteristics of the land cover types, agricultural landscape, natural/forest areas, and water features, each of which hosts the history of the city - distribution, and transition of the land use types - corresponding to each category. On the other hand, segmentation attached to the built form type layers was dispersed, tending to persist in a state and transform into another state according to nearest neighbour interaction on the layers. This assumption is indeed consistent with the overlaying principle of the maps, as the urban fabric segments are coupled and tend to persist at the city core or display transitions in areas having urban expansions or internal modifications.



Segmentation Classification Legend

Main Category	Sub-Category	Symbols	Line Symbol
Built form	Continuous Urban Fabric		Segmentation
	Artificial, Non-agricultural Vegetated Areas		
	Industrial, Commercial and Transport Units		
Natural / Forest areas	Forest, Scrub and/or Herbaceous Vegetation Associations		
Agricultural landscape	Arable land		
	Heterogeneous Agricultural Areas		
Water features	Inland Waters		

Figure 6. Author's segmentation and land cover classification for Edirne based on General Osmont's Plan d'Adrianople (1854), as reproduced in Yerolympos (1993), and Mehmed Selami's map of Edirne (1885), as reproduced in Darkot (1965). The original historical map images are not reproduced in this thesis; all analytical layers were produced by the Author. The grids show projected coordinates in TUREF / TM27 (EPSG:5253, metres).

In case of Bursa, the segmentation of the 1857 and 1912 maps used to detect spatial results of land use classification. Figure 7 displays the classification results of the 1857 map that recognize semantic identification of the building footprints and urban green spaces and the vegetation and water bodies. Recognition of those main categories demonstrates

significant reference in the determination of the land cover change. An identification of persistency of the continuous urban fabric states that the city was structured by the distinct land cover categories that maintained their significance throughout the process of urbanization and built form patterns. Despite the overall continuity of the urban fabric, changes and additions were observed in the street layouts that have resulted in the urban fabric expansion, as a result of transitions in the land cover types.

However, the urban fabric expansion was paralleled by the occurrence of development in the Ottoman suburban areas in the proximity of the Ottoman social complexes/külliyes, with the evidence of the axial geometry of the roads suggesting that the mobility of the individuals increased towards these heritage sites during the growth of the city. The detected segmentation on the 1912 map provides further evidence of the transitions of the land cover types, the pivot point of the spatial and social development and spatial organization that support the theory regarding the palimpsest nature of the cities.

The urban morphology of the Bursa and Edirne city has a long history and is characterized by a mixture of ancient and early Ottoman-era structures, late Ottoman or modernization-era developments in Türkiye, and contemporary urban structures and spatial organization. However, since the internal reforms of the late Ottoman period, the adaptation of new urban regulations has led to peripheral development and changes in land cover and land use types.

The areas investigated in this study include those where land cover changes and non-changes are significant in contemporary data sources, by quantifying the relationship between land cover changes in lower-resolution datasets and transitions in urban form metrics.

The result of temporal layering of two historical maps of Edirne, based on Conzen's town plan analysis, emphasizes land cover transitions towards contemporary datasets. Its impact is defined by transitions (changes) in land cover types and land cover patterns within the palimpsest, where perceived a change of one type in a given period resulted in a change of another type for another period. Given the findings, Conzen's traditionally qualitative assessment is empirically informed by quantitative land cover change detection in current data sources, specifically CLC datasets.

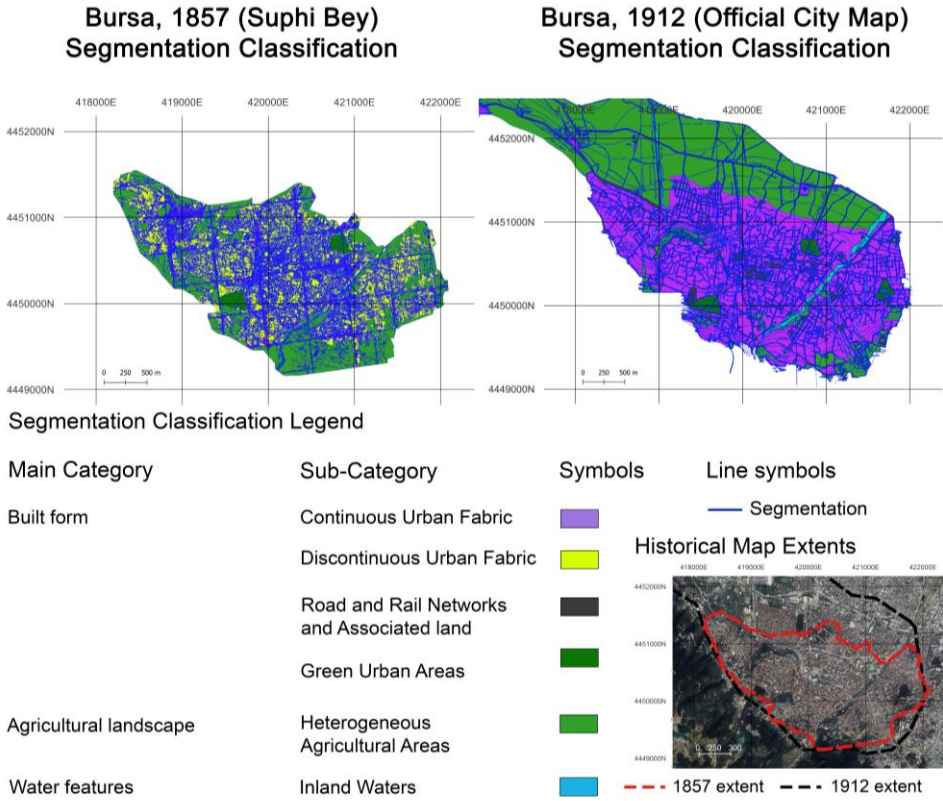


Figure 7. Author’s segmentation and land cover classification for Bursa based on historical maps from Salt Research, Map Archive: Bursa şehri harita mufasssalası (1857) (Identifier: APLMUHBUR001) and Bursa şehrinin harita-i manzûmesi / Plan officiel de la ville Brousse / Official city map of Brousse (Bursa) (Identifier: APLKIT001). Base map images used with permission following approval from the archive owner. Analytical segmentation and classification layers were produced by the Author. The grids show projected coordinates in TUREF / TM30 (EPSG:5254, metres). The inset map shows the different extents of the georeferenced historical maps used for the two classifications. Inset based map is Google Satellite 2026.

As depicted in the results of the normalized trend analysis (Figure 8) in case of Edirne which indicates that the highest percentages of land class coverage across all years are in agricultural landscapes, starting at 98.59% in 1990(t_1) and slightly declining to 92.8% in 2018(t_5). The low variability indicates that agricultural landscape remains dominant land coverage in Edirne over the period, suggesting a subtle indication that the land transition is relatively smooth rather than abrupt change. This is due to gradual decreases and increases within the level 3 classes, especially a strong decrease in non-irrigated arable land (from 94.66% ha to 26.09% ha) and a sharp increase in permanently irrigated lands (0.63% ha to 59.34%

ha). These suggest replacement of land uses by irrigated systems or other land uses.

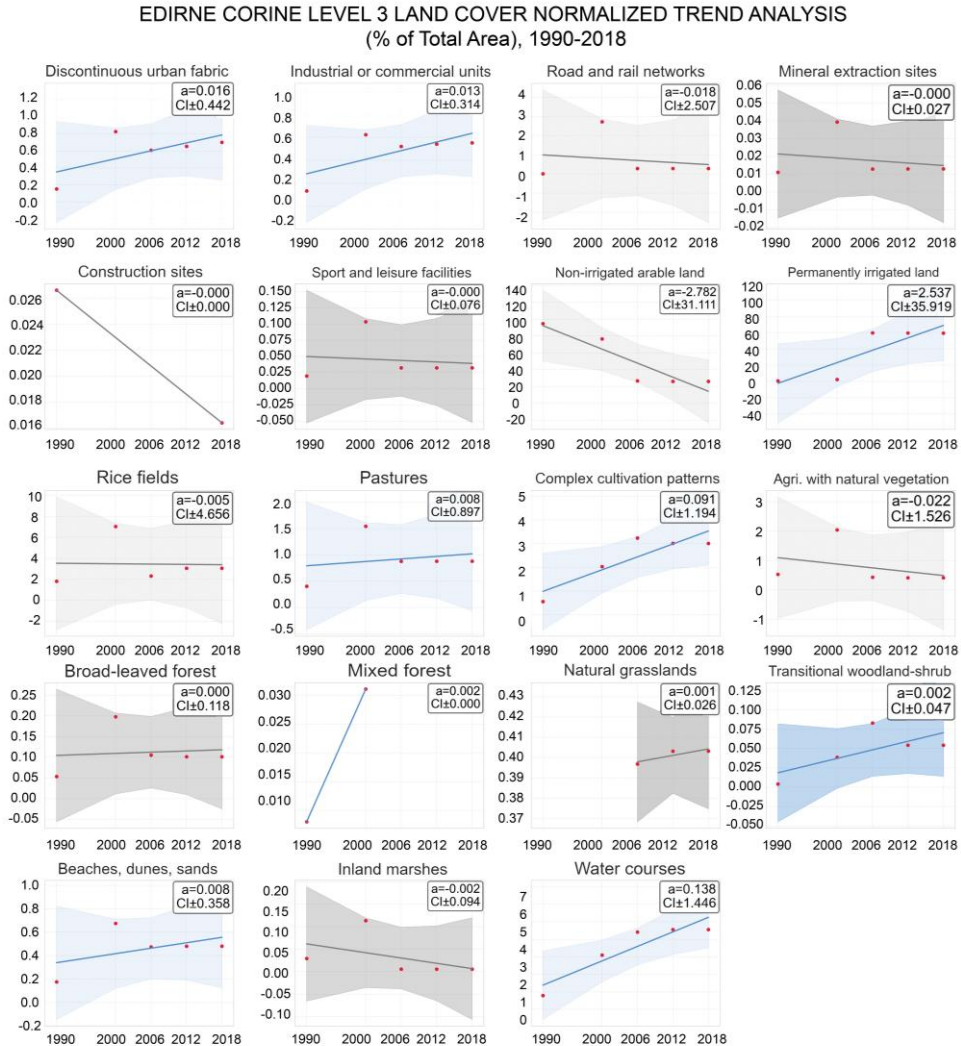


Figure 8. Trends of Level 3 land cover area across normalized time intervals. Increased direction is Blue, decreased direction is Gray demonstrated. Trend slope (a) is normalised time interval (%/year) and (CI) is average Confidence Width. Narrow width is high confidence (≤ 0.05), Wide width is low confidence (≥ 0.15).

The second significant static class is natural/forests area, demonstrating the least variation, especially as the median values hover around 1.05% over time. It is evident in minor declines and increases within its constituted patterns. These two lowest variations confirm that Edirne's

regional character is clearly coextensive with and remained by its agricultural landscape and forested areas, suggesting that those areas have not been a target for significant land transformation.

However, water features varied more significantly, indicating the relatively highest transformation over time, with increasing fluctuation in water courses from 0.79% in 1990(t_1) to 4.56% in 2018 (t_5).

The observed changed with certain land category is built form, ranging from 0.34% in 1990(t_1) to 1.59% in 2018(t_5), suggesting slow but incremental growth through urban fringes. It also confirms that urban expansion and suburban residential growth are underlain by slight decreases in natural environments in 2006(t_3), upon which built forms are created in certain zones, within the patterns of a gradual rise of discontinuous urban fabric from 0.15% ha to 0.83% ha, and a steady increase of industrial and commercial units (0.13% ha to 0.62% ha). The small increase is most probably due to preservation of the continuous urban fabric over time, which has shown very limited increase, suggesting a conserved city core with modest transformations. This incremental increase implies that the palimpsest structure of the city has been disrupted in lowest level of resolution, leading towards adaptation into new urban development zones.

Using the same analysis in the case of Bursa, the results can derive a reasonable time interval of land use pattern change or persistence (Figure 9). The linear regression analysis shows that there is one category that follows increasing temporal change trends: the built form percentage area rate (%13.98 to %35.23). This indicates that the urbanization forces driving suburban growth surpass the diffusive forces driving urban cluster growth, and these areas are gradually being occupied by various buildings. In this instance, the increasing change trend in continuous urban fabric, discontinuous urban fabric, and industrial and commercial units gives the city hierarchy a fractal structure. As demonstrated in the Table 4. increased trends and uncertainty (low confidence) within those levels depicted the rapid urban and industrial expansion. Similarly, the trends in green urban areas (%0.21 to %0.85) and road and rail networks (%0.9) show clear change rates.

BURSA CORINE LEVEL 3 LAND COVER NORMALIZED TREND ANALYSIS (% of Total Area), 1990-2018

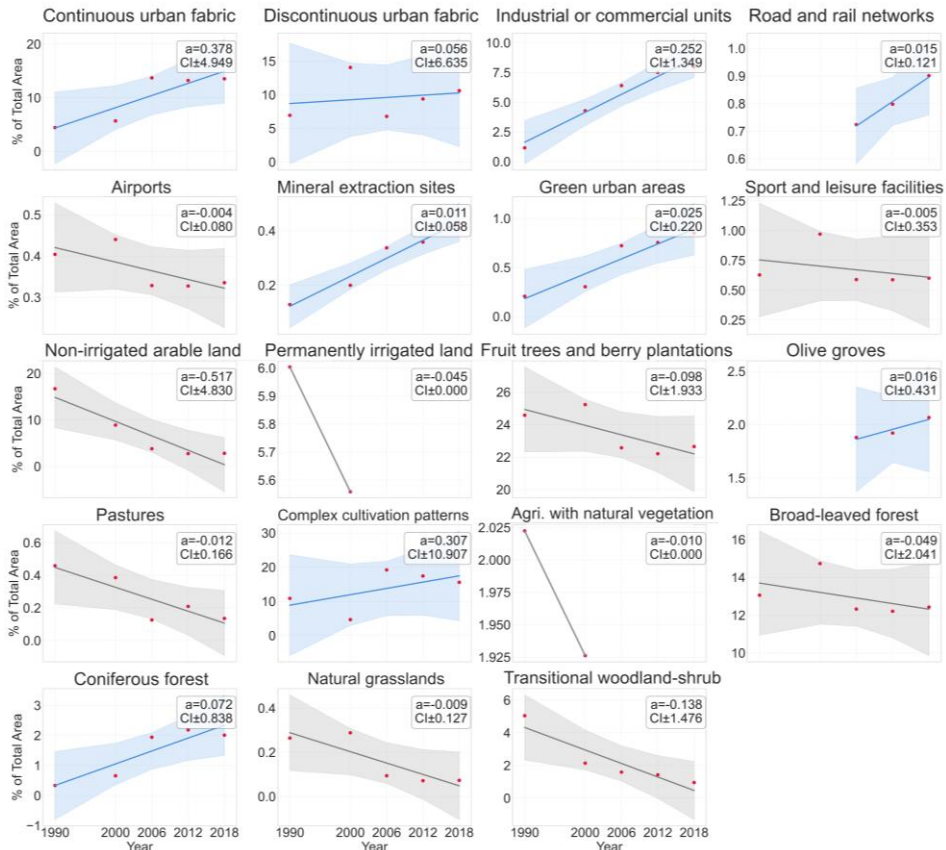


Figure 9. Trends of Level 3 land cover area across normalized time intervals. Increased direction is Blue, decreased direction is Gray demonstrated. Trend slope (a) is normalised time interval (%/year) and (CI) is average Confidence Width. Narrow width is high confidence (reliable trend) (≤ 0.05), Wide width is low confidence (uncertain trend) (≥ 0.15).

For forest and semi-natural areas, there is no clear overall change, which indicates that urban expansion does not override natural resources. The main way of city development is outward spatial extension into non-irrigated arable land and permanently irrigated land with high confidence, which has proved the agricultural loss that could be replaced with the built up.

At this depth, urban transformation falls within urban cores, or urban development occurs independently of the city centre; all the land cover categories correspond to this circumstance. This suggests that modifications or transitions can be observed in the urban cores, while additions can be identified in the suburbs. In addition, urban growth is

positive, and urban patterns are heterogeneous, as shown by the time interval changes in the percentage of the areas among the categories.

Transition between the periods within the CLC classification is divided into four phases: t_1-t_2 , t_2-t_3 , t_3-t_4 , and t_4-t_5 . The confirmation of the land cover class transition is demonstrated by using a Sankey diagram, which validates a variable flow from one class to another in the datasets with directional transitions between the periods. In the context of the level of resolution that is considered for this analysis, the complexity level is higher, which makes uncovering the capture of multi-temporal type-based transitions in detail (level 3 classification) more difficult, due to the increasing overlap of changes in type variables. In this context, by performing a traceable flow structure of spatial configuration within the Sankey diagram, the study operationalized the land cover palimpsests at the highest level of complexity and continuity into a verifiable structure.

The notable transition was found in the Bursa (Figure 10) case for the non-irrigated arable land type in 1990 (t_1) toward notably discontinuous urban fabric, construction sites, and industrial and commercial units by 2000 (t_2), even though it sustained significant urbanization according to the increased flow of the continuous urban fabric type by 2018 (t_5). This transition reveals early waves of neoliberal policies concerning urban expansion. The shift toward urban expansion directly corresponds to the primary transformation into continuous urban fabric and industrial areas in 2018 (t_5). Between t_2 and t_4 , the increased diversification of land cover types reflects a contraction in spatial configuration and fragmentation of urban zones as a decentralization of formerly established urban cores (heritage sites). The significant growth in these thematic areas compared to the year 1990 (t_1) implies that this expansion poses a significant threat to the foundational spatial land cover substrates, disrupting the natural palimpsest structure.

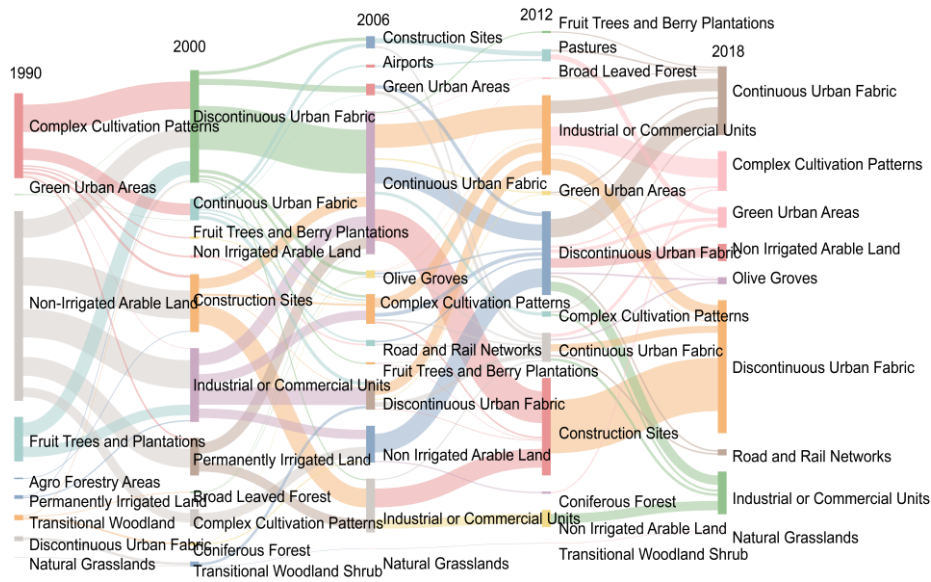


Figure 10. Bursa, the types of land cover transitions. Source: SankeyMATIC, <https://sankeymatic.com/>

Regarding the Edirne case (Figure 11), the transition is also significant for the non-irrigated arable land in t_1 , since it transformed into different types of uses by t_2 ; the most revealed pattern is the discontinuous urban fabric toward t_5 . The notable persistency types match with the discontinuous urban fabric by t_5 ; permanently irrigated land also remained among the types across all intervals.

It is noteworthy that the transition flow of one type – non-irrigated arable land – is increasing for both study areas with the expansion of the artificial surfaces. This can be explained by the constant agricultural landscape deterioration, which ensures that the built form has fertile land palimpsest traces that are co-evolved, but not functional.

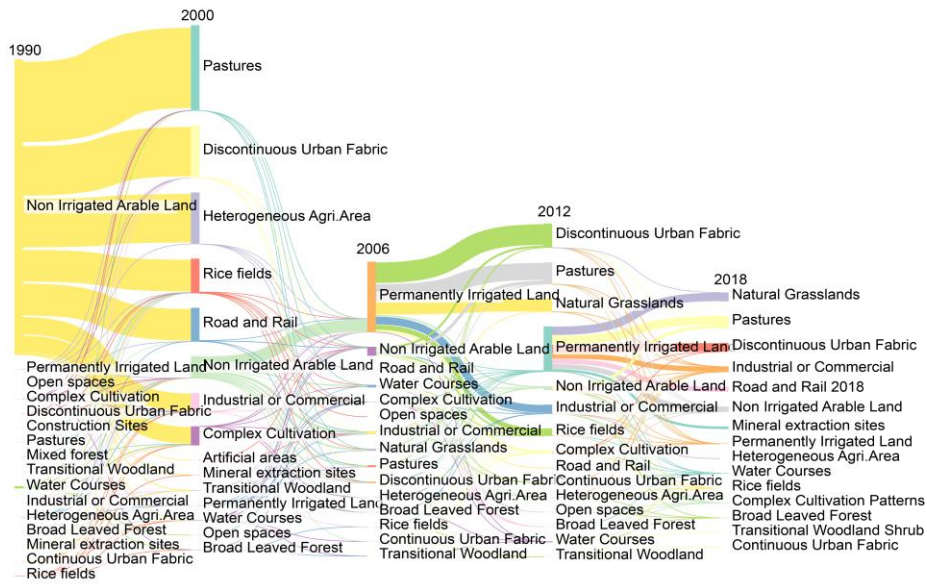


Figure 11. Edirne, the types of land cover transitions. Source: SankeyMATIC, <https://sankeymatic.com/>

5.1.2 The relationship between the persistence of the land cover types and urban morphological specificity - morphological unit

As explained in Section 4.4, the persistency analysis is based on the predefined qualitative investigation, where the results and transition matrix of the land cover types within the different categories serve as a guide for continuity at the highest complexity level and for the delineation of the morphological region at a very low specificity level. This subsection therefore presents the frequency of the land cover types retained as the same within grid cells over the observed CORINE periods, in order to show the persistency threshold in certain spatial units. Based on this frequency, the persistency score represents the spatial continuity of land cover types as clusters (Figure 12).

Results of the highest persistency score ($p=4$), significantly fragmented and isolated clusters, positions, and colour scores also reflected the strong morphological stability of the built form category, which had a higher threshold within the historic urban fabric compared to discontinuous urban fabric with ($p=2$). Persistency scores 2 and 4 were the only thresholds able to correctly discriminate morphological stability from the percolation margin in grid cells to the threshold of the change cells (positive transition for land cover pairs). Eleven morphological units in case of Bursa and thirteen morphological units in case of Edirne were isolated from the

highest persistent score ($p=4$) cells, which can be interpreted as the transition effects of the fractal dimensions of the morphology towards revealing a more complex structure of urban morphological regions.

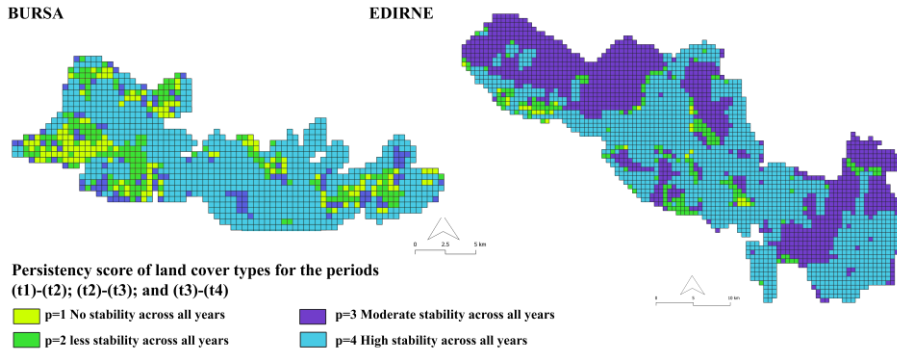


Figure 12. Spatial distribution of the persistency scores ranging from the 1 to 4, calculated within $500 \text{ m} \times 500 \text{ m}$ grid cells across the observed CORINE periods.

The examination of the progressive urbanization of the intensively growing in the study sites within contemporary data set is the logical tenet to define the historical morphogenetic structure where the formation and transformation patterns are coexisted. By merging Conzenian historical geographical practices on towns, observed degree of persistence in land cover types, validate the principles of historical stratification where the sustained land covers make visible the urban palimpsest through earth observation where contemporary land cover properties overlay and interact with historical natural and artificial forms.

Conzen's historical-geographical principle allows the detection of structures of morphological units and explains the spatial distinctiveness of regions at a very low-resolution level within the descriptive framework of spatial organization. It also addresses the persistence of regions in relation to land cover types, where the regions act like a palimpsest.

The integrated approach revealed an interpretable relationship and readability between the persistence of land cover types across historical and contemporary periods, with correlations summarized in the table. Among these, four relative built-form classes, Unit 1 to Unit 4, are identified as extensive units, where the continuous and discontinuous urban fabric, industrial and commercial units, and green urban areas show greater persistence and maintain maximal resistance to change across regions and, consequently, across land use types.

The degree of persistence polarised over the period from Unit 1 to Unit 4. The priority of persistence is in Unit 1 in case of Bursa (Figure 13) has high rank degree historically where is corresponding to urban heritage

sites and archaeological sites are exhibits mixed land use are relatively centred, forming clusters from place to place that is observed in the sites of architectural heritages are located in the contemporary urban setting. Unit 2 (Figure 13) characterised as neoliberal urbanization principles that sustained geographically and spatially dominant. One can further confirm that regions in Unit 3 are located mainly the near the boundary of the urban expansion site and easily distinguished from the industrial and commercial use's purpose. These three discriminative units reflect the spatially and historically composed of standardized units of the urbanized areas. Remaining units appears to play distinctive role in the pattern of formation as well, where those regions exist the urban alterations to the agricultural or forestry sites in current state.

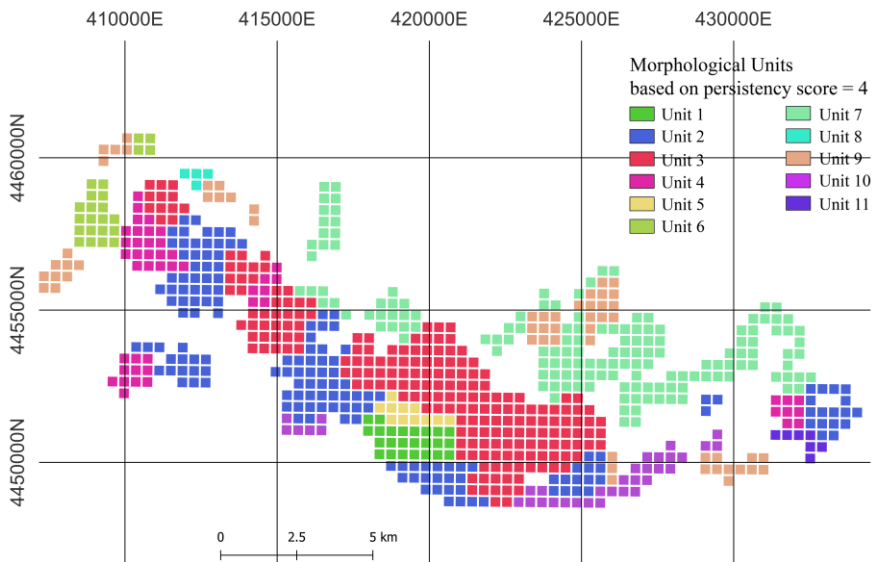


Figure 13. Spatial distribution of the 11 morphological units as identified by persistency score = 4 for land cover types in case of Bursa. Grid-cell size: 500 m × 500 m. Coordinate grid shown at 5 km intervals in TUREF / TM30 (EPSG:5254, metres).

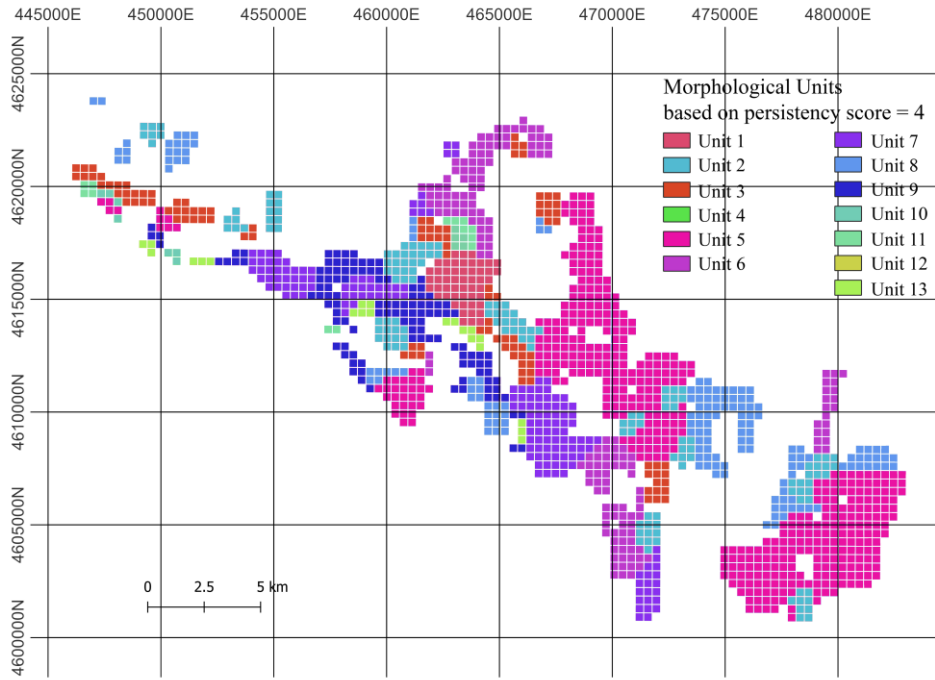


Figure 14. Spatial distribution of the 13 morphological units as identified by persistency score = 4 for land cover types in case of Edirne. Grid-cell size: 500 m × 500 m. Coordinate grid shown at 5 km intervals in TUREF / TM27 (EPSG:5253, metres).

When this procedure taken to in case of Edirne (Figure 14), Unit 1 is geographically observed in the historic Kaleiçi region, depending on its level of stratification. Unit 2 refers to the historic outer neighbourhoods (Ottoman suburban areas), which include both sites along the Tunca and Meriç rivers as well as the modernist belt of Edirne that typically emerged during the late Ottoman and Republican eras of Türkiye. After the Republican era, Unit 3 and Unit 4 appeared and were described in relation to the process of spontaneous formation of urban fabrics and its manifestations.

While the results reveal degrees of persistence in the regions at a very low-resolution level (land cover), the criticism of the palimpsest concept in geographical terms is accepted. However, it becomes necessary to recognize that persistence is also significant within the townscape. Thus, the descriptive and analytical approaches to the urban morphology of regions highlight the importance of analyses that, both quantitatively and qualitatively, identify changes or stability in urban form. These results can guide research toward the recognition of morphological regions and further

investigation of how spatial groupings of form ensembles show differentiated tendencies for “persistence” at higher resolution levels.

Encouraged the successful results of spatial temporal layering in the very high complexity level, the research is now in a position to examine degree of persistency in the urban morphological regions at the intermediate and highest level of the specificity by numerical measurements of urban form.

5.1.3 The relationship between the degree of historical stratification and morphological unit differentiation

This section describes a qualitative analysis for delineation of the morphological units based on the Conzen’s historical stratification principles. Table 3 shows the descriptive analysis of the layering of different maps within the different periods. The resulting spatio-temporal layering – Layer E formation (current state of Istanbul) – indicates units such as where the four World Heritage Sites are located and robust morphological persistency. In contrast, significant changes are determined in the urban conservation zones, where the most dramatic transformation is depicted, covering the Hobyar, Tahtakale, and Rüstempaşa neighbourhoods – the Eminönü coastal zone.

Table 3. The determination of the morphological units based on the Conzen’s historical stratification principle.

Layer A: François Kauffer (1786)				
Systematic form complexes	Degree of form persistence	Range of Morphological period	Constitutive aspects of historical stratification	Contribution to the inherited cityscape hierarchy (rank)
Ground plan	Short-term persistence	Early Modern reform 1751-1801 and the beginning of the breaking of traditional Ottoman reforms	Apparent medieval urban layout, settlements spread around the monuments or aligned through the historic land walls and seaport. The squares and courtyards of the mosques, social complexes, and administrative buildings are well defined. Irregular, narrow, mostly dead-ending, curved, and varying width road networks. Mostly irregular and variable plot patterns.	Mainly high and intermediate rank

Building fabric	Variable persistence		The architectural masterpieces – mosque, külliye, land wall, inn and palace – from the peak power periods of Byzantine and Ottoman have been exhibited on the city’s seven hills. Mostly rectangular-shaped complex buildings frame the edges of the plots and form courtyards in the middle. Large parcels cover more than one building, buildings in the form of palaces and their outbuildings. Sparse settlements in the mahalle/neighbourhoods. Predominantly wooden fabric Ottoman mansions in the settlements.	High rank: The period defines the pre-establish spatial organisation, and the urban heritage ensembles sustained/resistant to change.
The resulting maps have detected the morphological distinctive units and the localization of urban elements that tend to have resistance to change: surrounding the Sultanahmet and Hagia Sofia Mosque (located on the first hill of the historical peninsula), Suleymaniye mosque (located on the third hill of the historical peninsula), surrounding of the Çemberlitaş (the Column of Constantine: located on the second hill of the historical peninsula), Zeyrek mosque (located on the forth hill of the historical peninsula), Land walls and some Muslim and Non - Muslim mahalle – Fener and Balat (located on the fifth hill of the historical peninsula) Balıkpazarı (towards the shores of the Golden Horn), Kumkapı, Samatya Kapisı, Yedikule (Gate and Gardens), and Narlıkapı (towards the shores of the Marmara Sea).				
Layer B: Layer A + Ekrem Hakkı Ayverdi’s maps (1875–1882)				
Systematic form complexes	Degree of form persistence	Range of Morphological period	Constitutive aspects of historical stratification	Contribution to the inherited cityscape hierarchy (rank)
Ground plan	Short-term persistence	Internal reform 1801-1875, and the “Tanzimat” era (the modernization and	Transformation of the existing urban structure and street network - growth of the railway lines – construction of the bridges and new roads – the emergence of the grid-like street pattern (fire areas).	High rank: the first historical preservation legislation was designed during the “Tanzimat” period.
Building fabric	Variable persistence	transformation of the Ottoman capital under the influence of European cities)	Fires in the Istanbul, destroyed some areas – Aksaray, Hocaapaşa, Kumkapı, Fener, Ayvansaray, Yenikapı, Balat, Unkapı and Edirnekapı – and burned thousands of the buildings. Ottoman architectural façade fabric was set to change to the western neo-classical look. The construction material of the new buildings was stone or brick.	High rank: the period descriptive of the urban renewals and transformations in the demolished areas by fires.
The resulting maps have detected the morphological distinctive of settlements/urban landscape units and the localization of urban elements that tend to have resistance to change: the urbanizing elements from layer A tend to be variable.				
Layer C: Layers B + Charles Edward Goad’s Istanbul Insurance Maps (1904–1906)				
Systematic form complexes	Degree of form persistence	Range of Morphological period	Constitutive aspects of historical stratification	Contribution to the inherited cityscape hierarchy (rank)

Ground plan	Short-term persistence	Modern city 1875 -1922 and last Ottoman period	Regulation of the new transportation modes; the electricity tramway and tunnel, new ferry lines and ports – the building of the new railway stations and opening of the new main roads – the priority of the public parks and open spaces – well-defined plots (grid-like pattern) and some arranged laterally or linearly. Public parks in the historic quarters and the central areas.	High rank
Building fabric	Considerable persistence		New open spaces and public parks between the Hagia Sophia and Sultanahmet. Significant public and educational buildings in the centre of the historic areas; Vefa, Sirkeci, and Sultanahmet.	Intermediate rank
The resulting maps have detected the morphological distinctive of settlements/urban landscape units and the localization of urban elements that tend to have resistance to change: Layer B urban fabric has been resistant to change during the period.				
Layer D: layers C + Jacques Pervititch’s insurance maps (1940–41)				
Systematic form complexes	Degree of form persistence	Range of Morphological period	Constitutive aspects of historical stratification	Contribution to the inherited cityscape hierarchy (rank)
Ground plan	Short-term persistence	Post-war – Republic Era 1922 - 1960	The large-scale intervention that reshaped the inherited street layout – construction of the new avenues through the historic road axis and land wall – expansion of the main arterial routes (15m to 50-60m) – parking zones were divided into parcels – expanding coastal roads and widened the existing historic squares (Eminönü, and Beyazıt).	High rank: First development plan for Istanbul.
Building fabric	Variable persistence		The “gecekondu” or shanty buildings in the outer neighbourhoods, especially throughout the land walls. Multi-storey apartment complexes (Modernist and Art Deco styles) in the centre of the Historic Peninsula	Higher rank: increasing domestic immigrants and restored or demolished Ottoman civil architectural buildings for the newcomers
The resulting maps have detected the morphological distinctive of settlements/urban landscape units and the localization of urban elements that tend to have resistance to change: Pre-established and familiar urban elements from Layer A cannot be detected. The historic “mahalle”/neighbourhoods have a high degree of the tendency to resist change during the periods.				
Layer E: layers D + Contemporary spatial data of the Istanbul Historical Peninsula (Fatih municipality)				

Systematic form complexes	Degree of form persistence	Range of Morphological period	Constitutive aspects of historical stratification	Contribution to the inherited cityscape hierarchy (rank)
Ground plan	Short-term persistence	Neo-liberal Policies 1960 – the 2000s	The historical peninsula was divided into regions. The historic street patterns were demolished or reconstructed. Redefined/shaped existing plot widths and depths – re-construction of the seaport to create open spaces.	Mainly high rank: implementation of the Istanbul Floor Master Plan (1964) that leading increases in the building heights and destruction of existing buildings in the historic residential areas (Bilsel, 2019). Most of the conservation areas – were reconstructed under the protection law (no. 5366) in 2005.
Building fabric	Variable persistence		The greater majority of the apartment buildings are in the centre and traditional neighbourhood.	Mainly high rank: the large-scale urban renewal acts: are a new chapter – causing accumulated contemporary architecture and vanishing some of the heritage building stocks – for the urban tissue typology.
The resulting maps have detected the morphological distinctive of units: Urban conservations zones, especially Eminonu and Aksaray coastal zones, shows dramatic changes with the neo-liberal policies.				

5.2 Results in spatiotemporal layering (time and variable embeddings)

5.2.1 Characterisation of the Morphological Regions (Street Age and Street Hierarchy)

Equipped with the analysis in the previous resolution level, the choice of the distinct regions – differentiate one part of the urban area from another and exhibit the inherited patterns and configurations – could be recognizable. Based on Conzen's description of the morphological evolution of cities with a temporal perspective, the research focuses on the two key variables, each of which hosts the state backbone of the morphology of cities corresponding to each morphological unit. Explicitly, we place the street level on the temporal layer as a tangible representation

of time, describing the development of street network hierarchies, offering glimpses about which street type in a specific phase was built.

Characterization of the morphological units is then proposed in the following way: their street ages and street hierarchies demonstrate a higher persistency tendency toward the process of aggregation, exhibited as a constitutional layer between the plots and buildings – so they are considered according to the principle of the historical stratification concept.

Considering the detailed investigation of Conzen's studies on the morphological units, the study assigns two proposed variables, associated with distinct morphological periods, to understand the aggregation process of elements within the urban hierarchy over time. Street hierarchies can be defined mostly systematically as they do not occur typologically without geometry. When specifying the degree of the resolution of the streets, the study considers the following two assumptions: (1) the degree of resolution of streets can vary not only between specific typological clusters; (2) street networks can vary as any typological clusters that contain mutually exclusive types that fit together collectively.

To make use of those purposes, the study first carries out route structure changes, their type properties, and their way of connections. Figure 15 displays the obtained results of different ages of street layers that varied within the current state of the Khan Area in Bursa. The study observes seven distinct types of streets persistent with obtained overlaying results of each map for each period in the current state of street structure.

As shown in Figure 15, the ancient fortification street structure remains, with its tertiary strategic routes that connected to other strategic route formations during the period of 1912 and the 20th century. However, the street layer from 1857, corresponding to the medieval street layout character, displays distinctive behaviour compared with the layers of the 1912 street hierarchy, since the street network does not respond to development stages and often links through loops, end loops, and cul-de-sac street types over time associated with marketplace aggregation. The emergence of secondary strategic routes follows the modernization of the city. However, after the modernization stage of the city, new strategic route patterns are observed at the primary level, where routes connect other parts of the city at each end. As expected, streets approachable to the marketplace reflect the results of transformation within the sites, where connections to the Khan area follow lateral development, roads tangentially connect to the districts with primary strategic routes, and secondary routes connect to local routes with tertiary strategic routes. Indeed, we have confirmed that three types of street distributors are significant historically – primary and secondary distributors from the 20th century period, and tertiary – local

distributors from 1857 and ancient era – are identified within the current state of Bursa city.

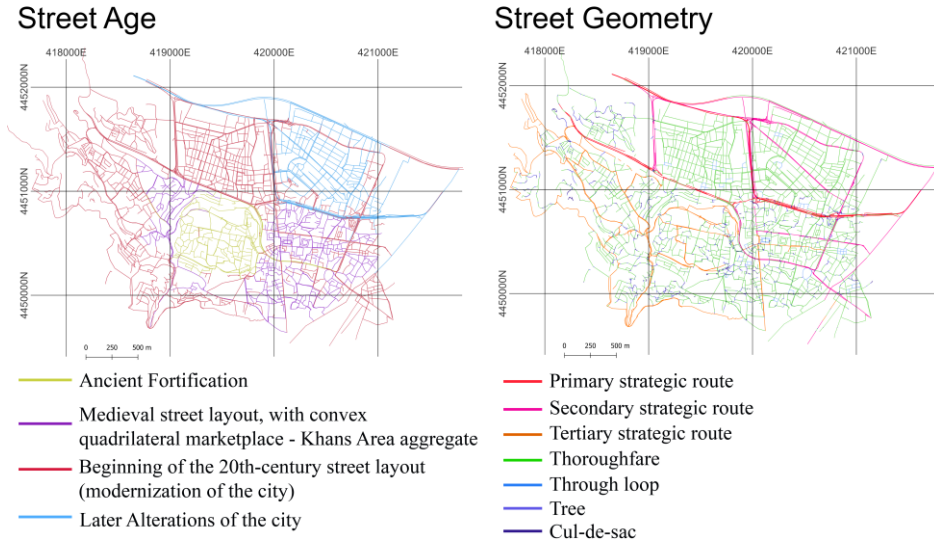


Figure 15. The identification of different street layer ages within the current map of the Khan aggregate which is corresponding to morphological Unit 1 in Bursa has led to the determination of five street types for each period. Street type definitions and classification principles are explained in Section 4.5. Projected coordinates are shown in TUREF / TM30 (EPSG:5254, metres).

As depicted in Figure 16, street layers forming the medieval formation in the Kaleiçi region can be observable in the current state of Edirne city, even with the adaptation or modification of some roads in the Ottoman Era because of the natural disasters that devastated them. The degree of the connection of patterns followed these medieval roots, characterized as secondary strategic roads where routes connected to other parts of the city, evolving to follow a thoroughfare pattern inside a grid-like structure. But the growth of the streets follows Ottoman rules, where the primary and tertiary strategic routes integrated into the medieval structure, which creates typological clusters that varied and diverged at different levels in Edirne city – such as street typology around the Selimiye Mosque Complex with a tertiary thoroughfare and cul-de-sac mixed structure, neighbourhood-level connections with streets (thoroughfare and through loop), or settlement-level connections with roads.

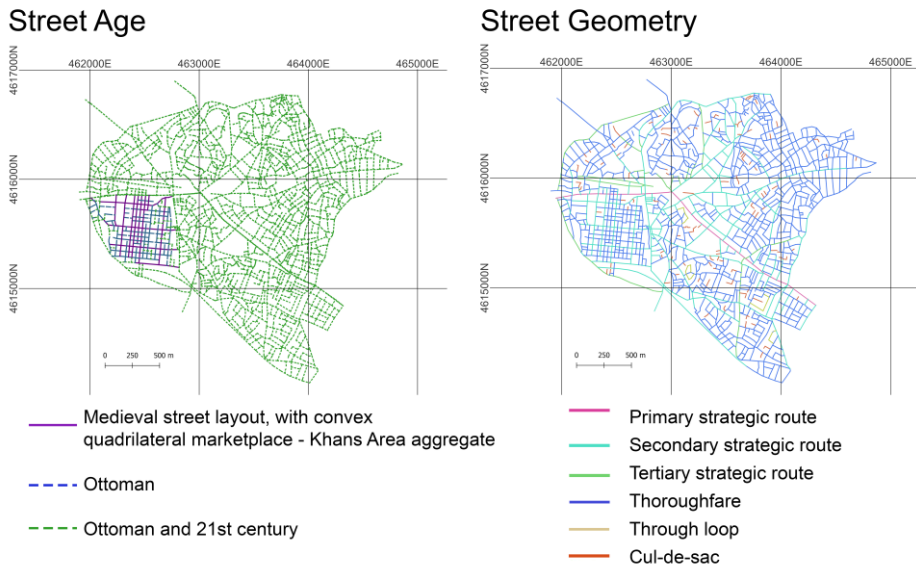


Figure 16. The identification of different street layer ages within the current map of the Edirne Morphological Unit 1 and Unit 2 corresponding to Kaleiçi region and Ottoman sub-neighbourhoods in Edirne has led to the determination of six street types for each period. Street type definitions and classification principles are explained in Section 4.5. Projected coordinates are shown in TUREF / TM27 (EPSG:5253, metres).

Here, rather than rigorously seeking only the identification of the inherited street structures or the effects solely characterizing the urban morphological region, the centrality of the research is to interpret the initial spatial configurations of the units with focus on the urban form elements – streets, blocks, buildings and green spaces – that reflect distinctive persistency or changing characteristics at their corresponding specificity levels. In other words, it is the agglomeration process, various factors, or aggressive transformation processes that promote configurational change, so internal types are not permanent in the case of the morphological units. Therefore, it is credible to adopt measurable amplitudes of physical variables of the morphological region so that the investigation based on quantitative evidence could give accurate correlations to the transformation processes occurring throughout different levels of scale.

5.2.2 Characterisation of Morphological Region (Coverage)

Using the historical stratification method in case of Bursa – spatio-temporal layering – only Morphological Unit 1 resulted in the highest degree of persistency at the lowest levels of scale. The unit covers three regions: Khan Areas and its surroundings (KA), Ancient Fortification (AF),

and Muradiye Social Complex (MK), where (KA) demonstrates morphologically and temporally significant transformation among them within the persistency.

Following the persistency analysis of the land cover types and variety of the age and type of the streets, the characterisation of the morphological unit was applied according to the coverage of the morphological region with the metrics of street lengths (m), block pattern area (m²), and building floor area (m²).

As results are displayed in the Table 4, and the physical variables of the morphological region's land coverage are characterized by quantitative information across different periods. The greater persistency of the street patterns to temporal changes is characterized by continuity holding comparable significance to land coverage. But even though quantitative evidence for street lengths is significant, the main difference is observed in street configurations – distributions of block patterns (1857–1912) and (1912 until today).

The changes in the percentage coverage of blocks and building areas relative to the overall land area are summarised in Table 5. The results from the coverage of block patterns in the 19th century nearly approached land coverage, albeit with significant continuous urban development, as block patterns are less densely built upon – 38.75% in the Khan Area. The results in the block area can be seemingly summarised as two significant trends, showing a significant decrease in the 20th century, diminishing from 95.93% to 84.72%, and then increasing again to 99.03% as observed in current period. These results show clear insights into the devastating influence of the large fires and earthquakes that led to the demolition of certain areas in the Khan region between the 19th–20th century, but the road network structures adhere to the perseverance law compared to development density.

Map, Current	368,326.98	364,739.251	99.03%	172,956.04	46.96%
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The results of spatiotemporal layering of urban patterns in the case of Edirne in Table 6 reveal that, from the maps of Mehmet Selami (1885) to the present, Unit 1 represents consistent persistence at the lowest level of resolution, where this region covers three units: Kaleçi, or the inner castle (KI); the Selimiye Mosque and its complex (SM); and Ottoman neighbourhoods (ON) along the Tunca and Meriç rivers.

The selection of the SM region is mainly based on the layered urban patterns resulting from the transformation of the city of Edirne, which began in the Ottoman era with the construction of the Selimiye Mosque, where urban development differs considerably in this region. Therefore, the distribution of streets plays a significant role in revealing this transformation, as the length of street patterns has markedly shrunk over the years in the current SM dataset. These results show a clear transformation process subject to a very comprehensive restructuring. However, the results of block pattern change show that the increase in the area of blocks is significantly higher than in the period of 1885, where the blocks area extended from 55% to 76% of land coverage, suggesting intensified morphological differentiation among the periods and indicating that the decrease in street length results from block-level developments.

Table 7 indicates that the coverage of block patterns for both periods in the 19th century almost shared the same land coverage, with a small decrease in the percentage from 65.09% to 56.31%; yet there is no valid information about the building patterns then. This could explain the continuity of the urban fabric within the 19th century period, which has been subject only to minor changes within the Selimiye Mosque surroundings. However, within the current state, the percentage of blocks in relation to land coverage is up to 77.66%, reflecting increased variation in ground plans or block layouts, which indicates a trend toward a block-level-based transformation process that could have implications related to particular block pattern unification for the transformation of the region.

This can be evaluated as the contemporary development phase of Edirne, which is characterized by the emergence of high streets toward the Selimiye Mosque, leading to a decrease in the number of blocks from $n = 82$ to $n = 59$. This shift points to the combination of small blocks from the 19th century to create new, larger block patterns within the region.

Table 6. The morphological variation of the SM–Selimiye Mosques region in Unit 1, with the streets, blocks, and buildings, across different time periods.

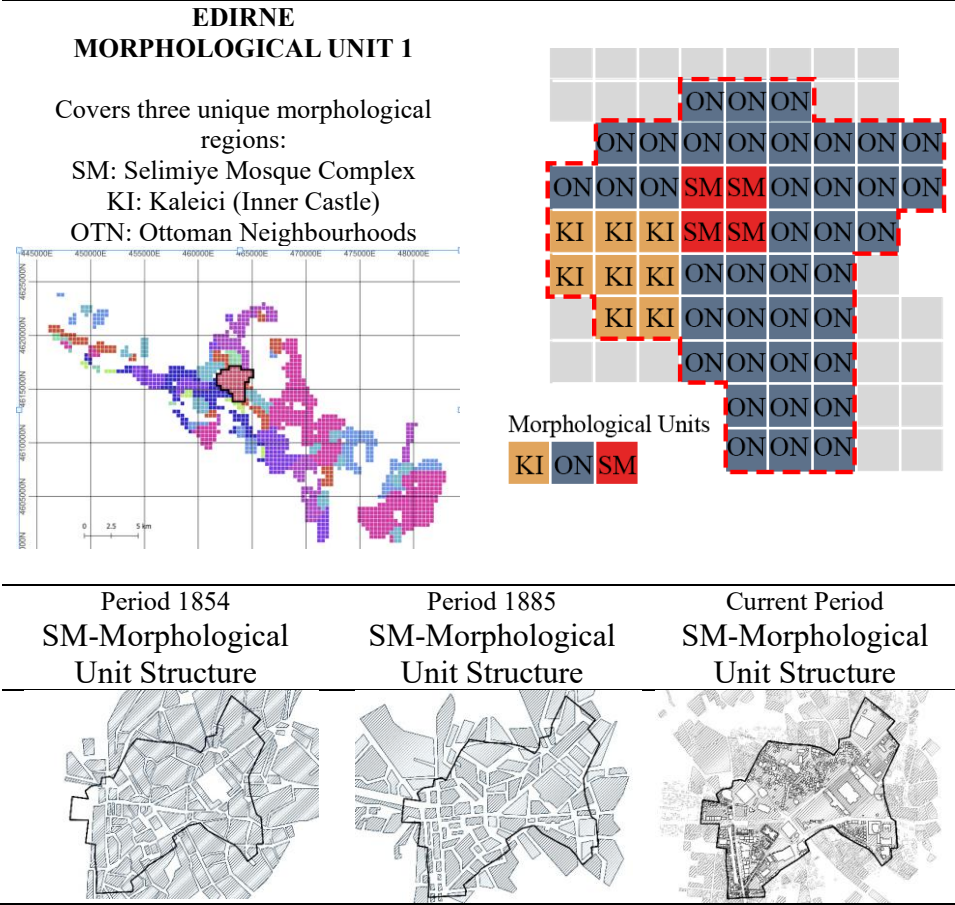


Table 7. Summary of SM-morphological region for Edirne; percentage of blocks area coverage, and buildings area coverage.

Map Period	Total Land Area (m ²)	Total Block Area (m ²)	Block Area Coverage (%)	Total Building Area (m ²)	Building Area Coverage (%)
Map, 1854	433, 641.34	282,242.32	65.09%		
Map, 1885	433, 641.34	244,197.02	56.31%		
Map, Current	433, 641.34	336,783.29	77.66%	173,983.29	40.12%

5.3 Results in aspect and element separation analysis (time and value embeddings) of geometric properties (shape, size, compactness, and proportion)

This section presents the analysis results of the diachronic transformation of geometrical properties of streets, plots, buildings, and green spaces over time, focusing on time and variable embeddings such as shape, size, compactness, and proportion.

5.3.1 Size of streets: Angular segment length (distribution)

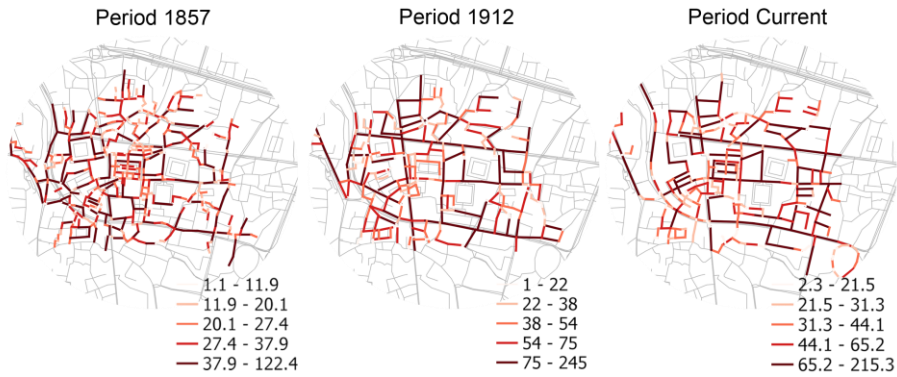
The first set of analyses examines changes or continuity in streets of different sizes, especially the geometric properties of the network, such as segmental diachronic changes across periods. As explained in the methodological chapter 4.5, angular segment length is used as a tool to capture the configurational characteristics of morphological regions in relation to blocks and buildings. The spatial distributions of segment lengths in the Bursa and Edirne city map periods are shown in Figures 17–18, supported by quantitative charts that are able to emphasize the proportions of short or long segments in structuring street-level morphology, and that capture the quantitatively based segment sizes with statistical consistency that emerged over the periods.

In accordance with Figure 17a-18a, street segments from the 1857 period are ranging between 1.1 and 122.4 in length, and the results indicate that longer segment lengths are more frequent and operate as the primary level of the distribution, while shorter segments are found in limited variation, which reflects that they are mostly organized around more bounded areas, such as segments around complex buildings. According to the segmentation results in 1912 period, the length of the street segment values are ranging from 1.2 to 244.6. The analysis indicates that differentiation in segment length sizes is clearly characterized during the modernization era, where the highest segment values range between 75.3 and 244.6, while the longest segment values from the period 1857 fall within the intermediate length range in period 1912. This change reflects the increased transition in primary and secondary street hierarchy that more spatially functions within the configuration of the city.

Compared to this, the size of segments lengths reflects signs of equilibrium in segment sizes sustained its structural role in current Bursa. Overall, in the contemporary settings, physical changes have mostly been accommodated with the transformation of short local streets toward longer arterial routes, but both the persistency from 1857 period and variability from 1912 period remain in significant. This layering analysis and comparison of the statistical properties of segment lengths demonstrate that

Bursa exhibited a palimpsest structure, with increased trends toward diverse types of streets over time and more organised street structure adaptations. A diachronic comparison of the metric length of the segments illustrates that the determination of the road centroids reveals conditions in before and after changes, such as spatial and physical alterations. Results show that the distribution of segment lengths is the basis for interpreting correlations of variables, which leads to revealing configurational persistence or change.

(a) Segment lengths by years, KA (Bursa)



(b) Segment lengths by years, SM (Edirne)

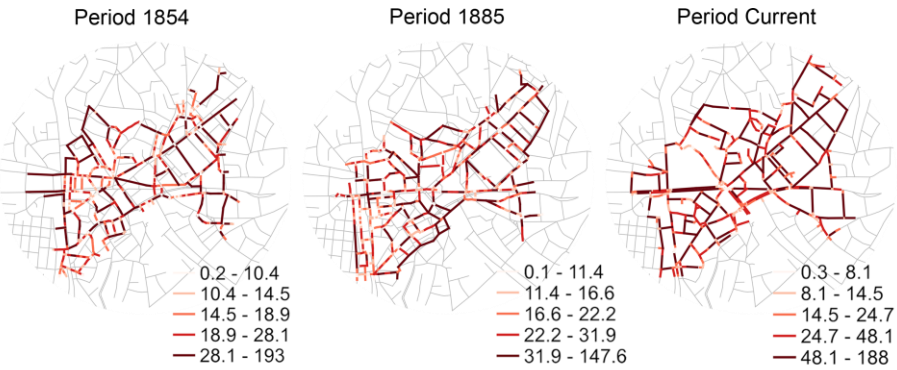
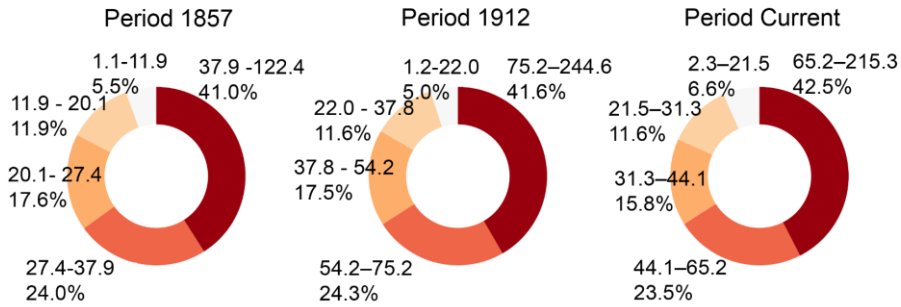


Figure 17. Angular street segment lengths analysis in case of KA (Bursa) (a) and SM (Edirne) (b) for the map periods 1857, 1912, and current.

(a) Segment lengths distributions by years, KA (Bursa)



(b) Segment lengths distributions by years, SM (Edirne)

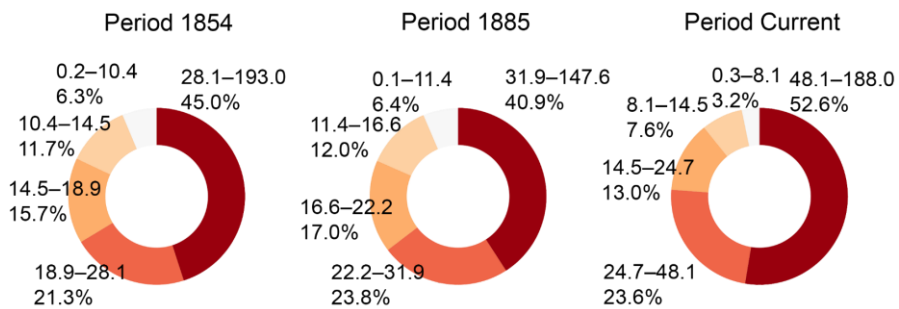


Figure 18. The proportional distributions ranges of the angular segment lengths to the total segment lengths with the corresponding donut charts in case of KA (Bursa) (a) and SM (Edirne) (b) for the map periods 1857, 1912; and current.

The proportion of the size of street segment lengths in the case of Edirne (Figure17b-18b) for the map period of 1854 ranges from 0.2 to 193. The longest lengths accommodated street structures in the case of the SM region, reflecting that this region is more self-organized around the longer segments, where the shorter and intermediate segments generally accommodated the back streets. However, in the period of 1885, there is an obvious shift within the longest segment values (31.9–147.6), reflecting the clear change of the segment size distribution upon aggregation of segments, while it still acts accommodate its continuity. In particular, the intermediate range appears to play a distinctive role in pattern formation, with its persistency being a dependent variable on the transition between the periods. As depicted in the current state, those levels retain their persistency, while there appears to be an increased transition to the longest street segment lengths (48.1–188). The overall transition in the case of Edirne reflects the great persistence and adaptation of the size of segment lengths, and the shortest and intermediate lengths have become adaptive

since the 19th century, demonstrating a more integrated hierarchical street structure.

The results obtained from the spatial distribution of the segment lengths reflect that the palimpsest structure of both morphological regions shows that previous periods persist and subsequent changes add to or modify what exists at a given time. The statistical distribution of the resulting layering of the segment lengths translates the distributional persistency and change to analyse their quantile and range values.

Overall, the results show that for each region, the upper quartiles (Q90 and Q95) display continuity since the 19th century. In summary, there is an overlap of around 100 meters between 1912 and the current period in the case of the KA region, and for Edirne city, only 19th century maps exhibit an overlapping range of around 50 meters; beyond this, there is a significant break in the upper quartile limit in the current period of SM (Edirne).

5.3.2 Proportions of streets: street integration-angular segment analysis

This section reveals the persistency or changes in street integration values that emerge in the historical and map datasets. Analysis of street size, specifically during the modernization of the city and later alteration periods, including the 19th century and current periods, was characterised by a shift in route development towards longer segments, such as primary and secondary roads. This depiction underscores the emerging patterns of long streets, which are broadly stable with the transformation of the historic region in contemporary urban settings, and are incorporated with configurational principles from the early 19th century. As explained in the methodological chapter 4.5, angular integration is used here as an analytical tool to reveal the urban tissue geometry parameter at the block level, consisting of interlocking measures of street segments. The spatial distributions of segment integration are illustrated in Figure 19, as captured in the KA (Bursa) and SM (Edirne) regions, and Figure 20 is reporting descriptive statistics of the quantitative definition of the parameters.

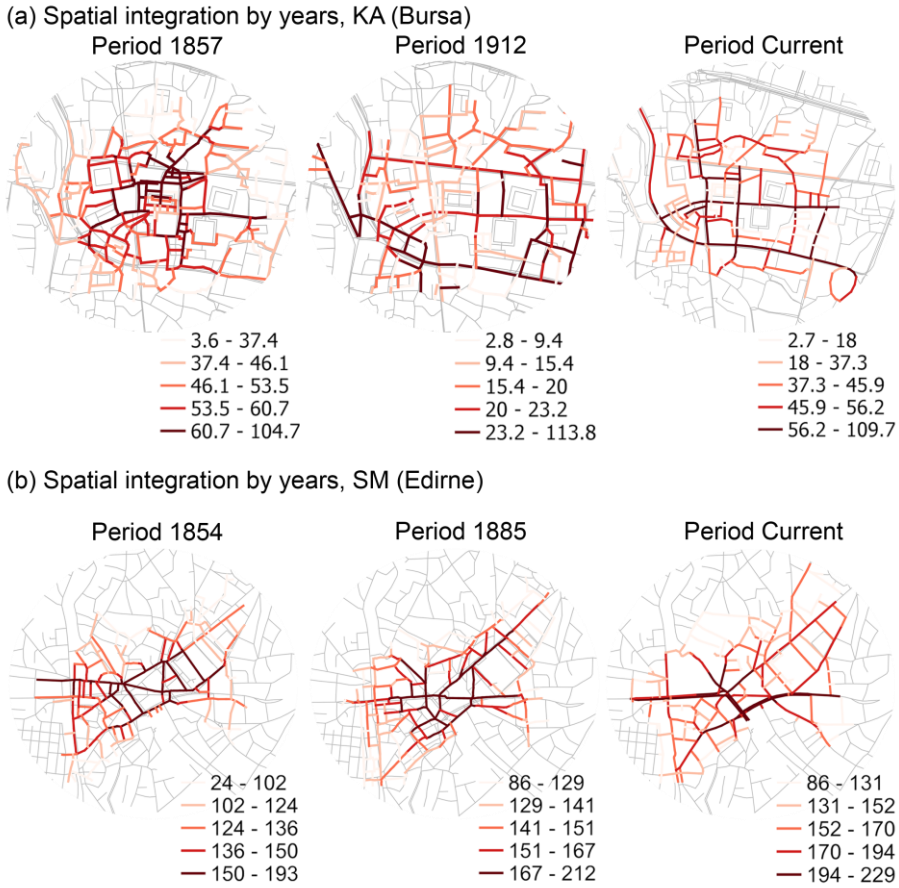


Figure 19. The spatial distribution of street integrations by the map periods for the morphological region KA (Bursa) (a), and SM (Edirne) (b).

In Figure 20a, the results show that in the case of KA (Bursa) for the 1857 period, the angular integrations are a well-integrated structure and have the highest mean integration value, where the distribution is more central and values are clustered around the mean, approximately 30 to 70. The integration system shows likely dense variability (mean $\pm$ SD: 48.0 ± 16.1) and some outliers from the low and higher integration values deposited onto the distribution, being right-skewed, thus having a uniform direction within the centre. Conversely, the distribution is tightly clustered around 0 and 30 with the lowest mean value (18.33) in the period of 1912. The variability (13.96) decreases by increasing the lower integration segments in the entire system, indicating the distribution is less balanced, and also indicating that while structural reorganization appears, a loss of cohesion is emerging in the urban system. Although the urban

transformation was adjusted to create a more organised system, the adaptation of the longer segments with the highest integration values – outliers – results in lower mesh integration density. This structural disruption has been attempted to be controlled by increased mean integration (39.35) in the current period; however, structural discrepancies remain, with greater variability (19.56) to the 1857 period. Moreover, increased variability in integration shows that the urban transformation in the structure significantly affects the urban form characteristics, leading to a more multilayered structure.

The results in Figure 20b show that the distribution of the obtained integration in the current period for SM (Edirne) completely differs from the 1854 and 1885 periods. The measured distribution is much more varied (mean $\pm$ SD: 163.3 $\pm$ 32.4), with a much broader bandwidth, and it shows significant offsets to the right. This suggests that in several segments, there is higher integration, which affects spatial heterogeneity with the highest variety. Even though integration values are more aligned in terms of mean and median (162.8), the distribution shows more discrepancies and is more fragmented compared with periods 1854 and period 1885.

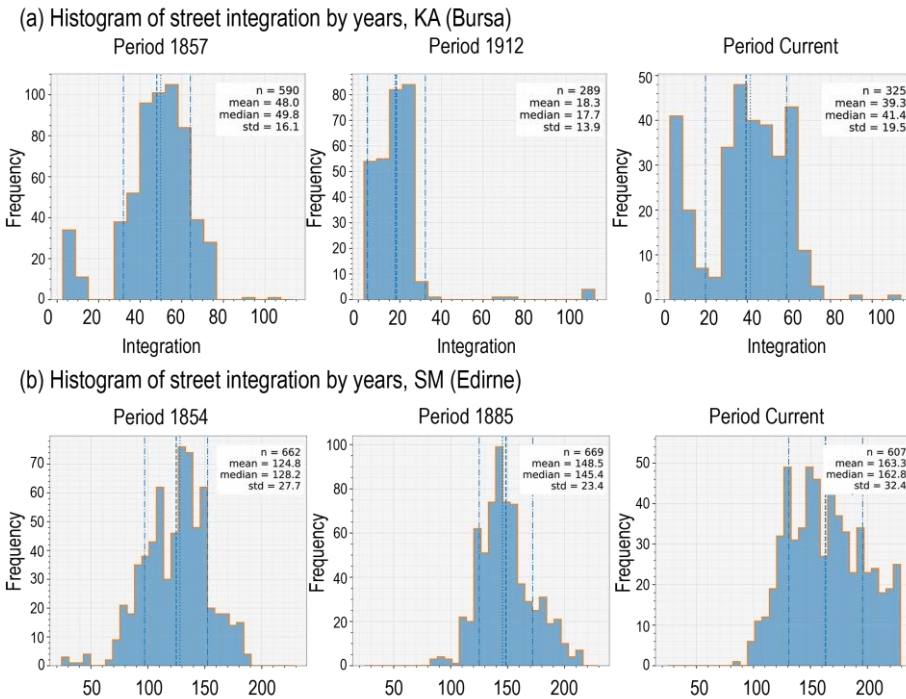


Figure 20. Histogram of statistical distribution of street integrations by the map periods for the morphological region KA (Bursa), and SM (Edirne).

The distribution of integration for the period of 1854 is more consistent, with integration values more closely aligned around the mean and median values. For the period 1885, the distribution is getting smooth right-skewed (mean $\pm$ SD: 148.5 ± 23.4), which indicates a balanced but slightly getting asymmetric pattern, with the higher integration values becoming more frequent.

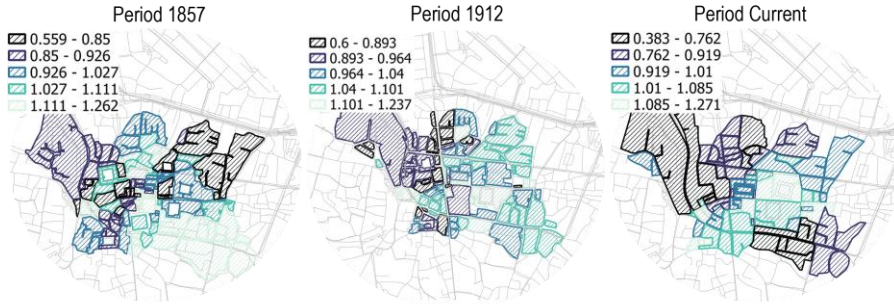
These findings highlight the street integration in the KA region as a palimpsest, highlighting the positive influence of the highest integration values in accelerating urban tissue healing by significantly enhancing the transformation process and transitions of the oldest layers from previous periods.

In contrast, a weak palimpsest structure appears in the case of the SM region, where the integration values reflect continuous expansion and relatively act as transformative across the periods. These findings indicate that transformative growth did not promote the preservation of inherited spatial logic, instead overwriting it, especially with the upper integration values.

5.3.3 Shape of blocks (block elongation)

The spatial and statistical analyses of blocks elongations were performed at the block level to analyse changes in block morphology. The spatial distributions results of block elongation for the KA and SM regions, each displaying varying behaviour over time, are shown in Figure 21.

(a) Block Elongation by years, KA (Bursa)



(b) Block Elongation by years, SM (Edirne)

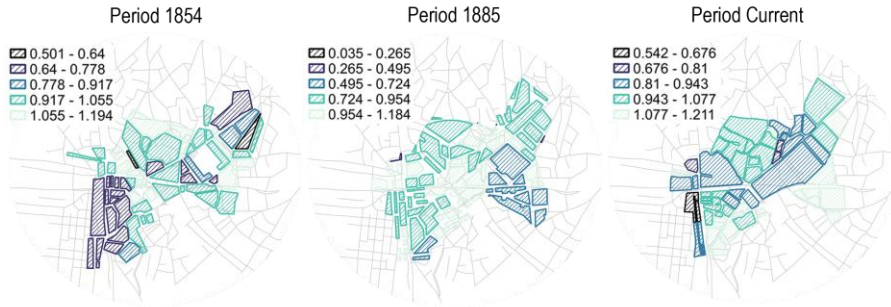
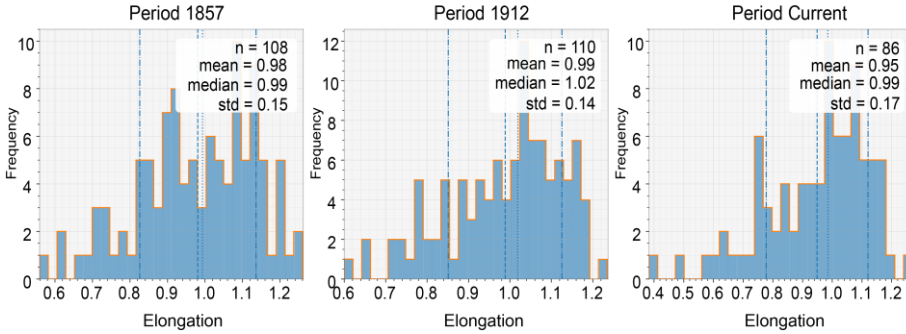


Figure 21. The spatial distributions of block elongation by the map periods for the morphological region KA (Bursa), and SM (Edirne).

The statistical results in Figure 22a show that there are notable morphological changes in the number of blocks counted in the KA region, transforming into more elongated shapes over time, even though mean and median values remain around 1.0, indicating no statistical difference – long-term continuity – between the periods. Furthermore, changes in street integration variation in the KA region seem to have no significant effect on statistical properties either. This might be attributed to the increase in the highest-level segment structure over time, which decreased the number of blocks but did not affect their dimensions. The current state also confirms this, with the highest variability in terms of the widest distributions appearing at both the lowest and highest levels, due to the reuse of older block geometry, with results that are statistically significant.

(a) Histogram of Block Elongation by years, KA (Bursa)



(b) Histogram of Block Elongation by years, SM (Edrine)

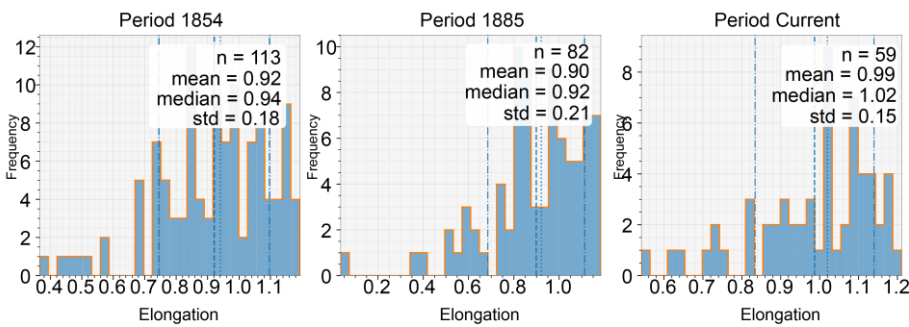


Figure 22. Histogram of statistical distribution of block elongation by the map periods for the morphological region KA (Bursa), and SM (Edirne).

The Edirne (SM) region shows an opposite trend in terms of block elongation variability and dimensions. The results in Figure 22b show that overall block patterns decreased with increasing differentiation over time, especially from the earliest periods, which have lower elongation dimensions with the highest variability, suggesting that the high variability from 1912 accelerates the reuse of previous blocks with the widest low-elongation values, significantly enhancing the palimpsest condition of the region in this period. In contrast, the current period exhibits a clear shift towards higher elongation values by decreasing variability. This can be attributed to the difficulty in preserving irregular layered forms from earlier periods, as interaction with the historical pattern occurs only through geometric correction during the transformation process, while the interaction is continuous with the standardisation of block typologies.

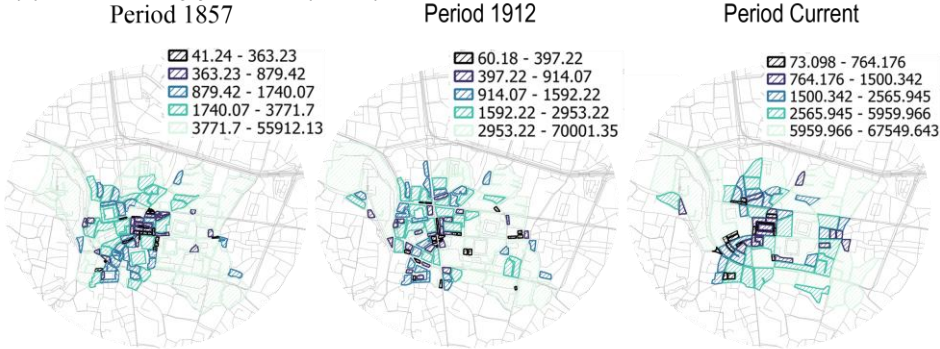
5.3.4 Size of blocks (block area)

The spatial distributions results of block areas for the KA and SM regions, each displaying varying behaviour over time, are shown in Figure 23.

The results in the statistical analysis (Figure 24) of the distributions of blocks areas were strong right skewed due to the higher large values proportions. To address this issue, a logarithmic transformation to blocks area values for each period was applied, which is able to linearize proportional differences in the variations.

In Figure 24a, the findings suggest that there is a substantial overlapped mean area between the period 1857 and 1912 in case of KA (Bursa), compared to a notable increase in the mean area in the current state, which exhibits the presence of the predominantly blocks with highest area ranges influencing an increase in the mean value, even with a decreasing trend in the log-variation. This might be attributed to a significant number of the blocks that fell into the range below log 2.5 for the period 1857 and 1912, and clustered towards the lower value. In addition, several factors, including the presence of some exceptionally larger blocks in the Khan aggregate, influence the variability of the block's shapes at the early stage of the region structure. In the 20th century, variability decreased with the increasing differentiation over time, with more extreme values observed compared to 1857. The results indicate that there is a trend overall in which the frequency of the log transformed block area decreases, with a slightly increasing frequency of the larger blocks. These findings suggest that the shapes of the blocks from the earlier stage were exposed to significant urbanization pressure, acting as physical traces to be replaced over time that advocate tissue transformation, particularly in cases where the patterns are impaired.

(a) Block Area by years, KA (Bursa)



(b) Block Area by years, SM (Edirne)

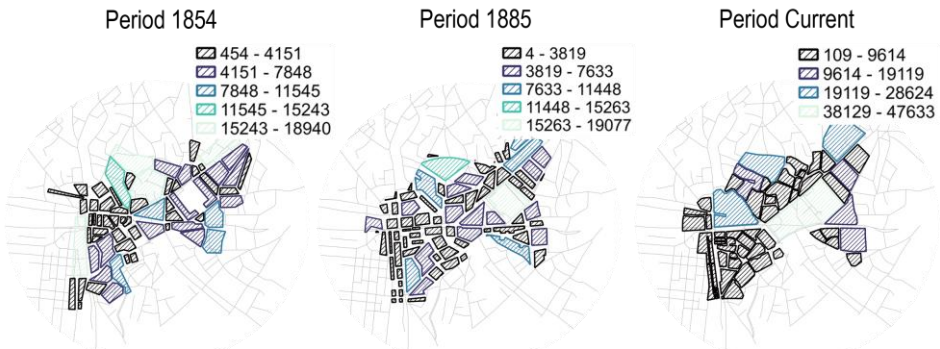
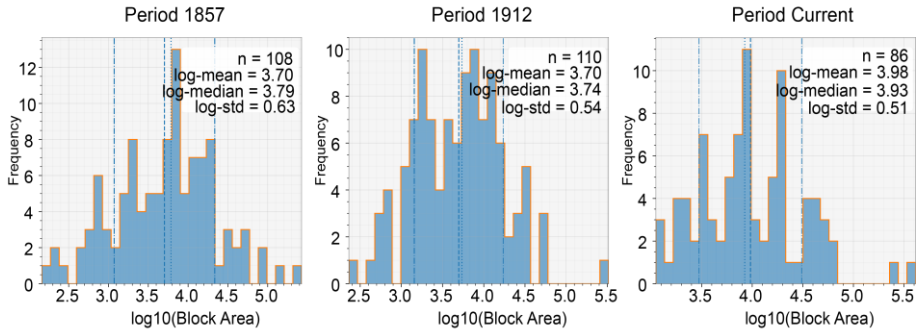


Figure 23. The spatial distributions of block areas by the map periods for the morphological region KA (Bursa), and SM (Edirne).

As shown in Figure 24b, there is a decreased and an increased trend in the log-mean area values over time for the SM (Edirne) region, where the period 1885 has the lowest mean values with the highest variability (mean $\pm$ SD: 3.35 ± 0.56). Compared to the period 1854 and current, there were a greater number of blocks varied in the period 1885, as spatially depicted that they were retention around the Selimiye mosque. This indicates that a balanced structure with different blocks shapes and blocks number differences contributed to the limited dispersion in the scale of blocks. The findings show that the statistical and spatial distributions of the blocks area within the early stage have a significant impact on shaping the blocks structure around the upper block are ranges in the current period, where block sizes remain consistently constrained or densified in 1885, as demonstrated by the lowest variability and moderate log mean area value (mean $\pm$ SD: 3.66 ± 0.43).

(a) Histogram of Block Area by years, KA (Bursa)



(b) Histogram of Block Area by years, SM (Edirne)

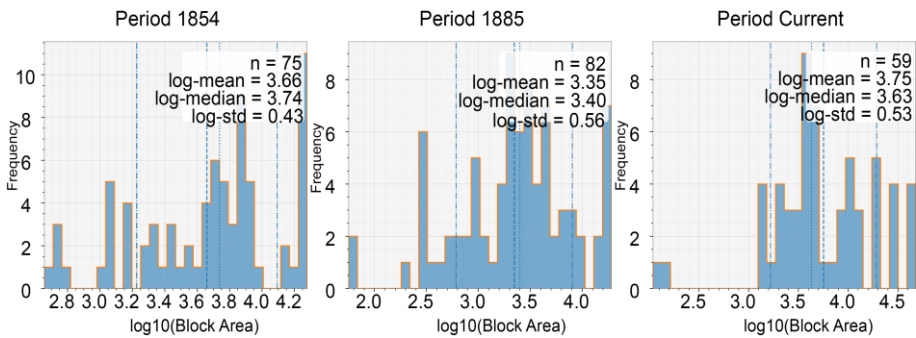


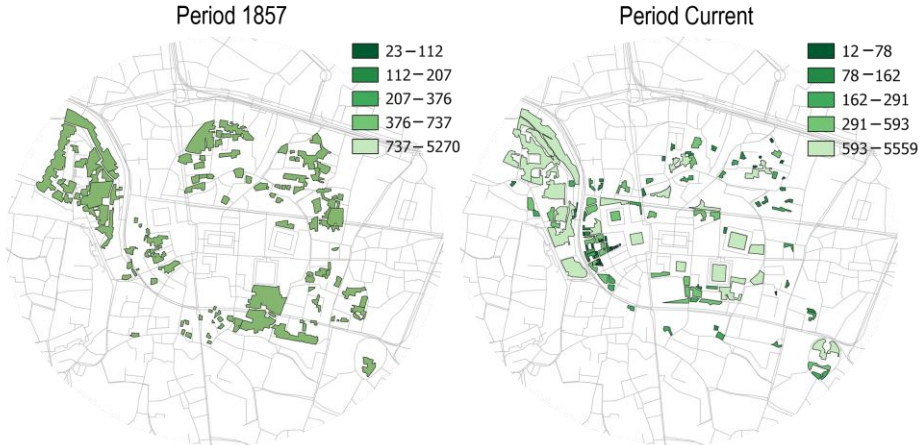
Figure 24. Histogram of statistical distribution of log transformed block area by the map periods for the morphological region KA (Bursa), and SM (Edirne).

5.3.5 Size of Green spaces (Green Area)

The continuous green spaces in many historically stratified cities are most notably located surrounding city walls and are generally contiguous to former physical limitations on urban growth, where a pattern is characterized morphologically as fringe belts. Urban green spaces have changed in terms of their position and size over time within the inner parts of cities or often in historical cores.

The changes in the distributions of green spaces and their statistical properties for the KA region are shown in Figure 25.

(a) Green Areas by years, KA (Bursa)



(b) Histogram of Green Areas by years, KA (Bursa)

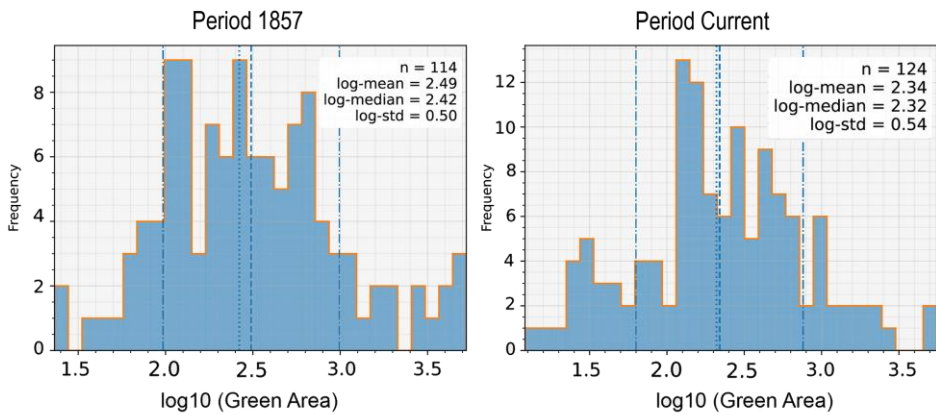


Figure 25. The spatial distributions of green areas and histogram of statistical distribution of log transformed green areas by the map periods of 1857 and current for the morphological region KA (Bursa).

For the period of 1857 in Bursa, a sizeable portion of the green areas was located where urban development had limits for the Khan region. This region is characterised as an inner fringe formation, where small green areas fragmented from there to residential areas. In the current stage, the edges of the urban green areas have become more uniformly sized, indicating that the changes in size are affected by the urban transformation process. In addition, statistical results of the logarithmic transformation of the green areas confirm this reduction in the size of the green areas since 1857, where the mean decreased from 2.49 to 2.34. On the one hand, log-standard deviation in the current state increased, which captures that the size of the green spaces has become proportional more consistent compared

to 1857, which were smaller in size, resulting in more heterogeneous. As observed, green areas surrounding the region are continuous – survival – suggesting persistency on these areas from the phases of change. Moreover, the morphology of the continuous urban green spaces is recognised as a heritage that is embedded in the urban fabric over time.

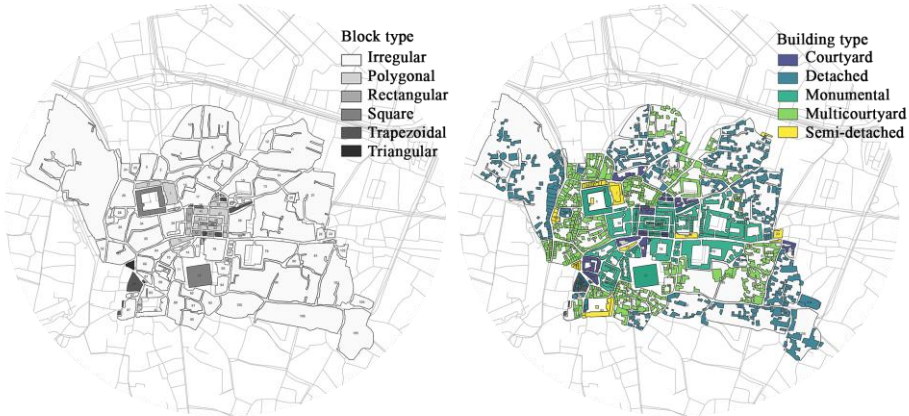
5.4 Results in the levels of abstraction: Specific arrangement (aspects and element separation – time and value embeddings

5.4.1 Building Types and Building Types per Block

The quantitative and qualitative parameters resulting from historical map analyses are illustrated in Figure 26.

The results of the classification of the block types based on their typology and morphological configuration indicate that 107 block typologies were available within the period of 1857 for the KA region, which were formed with respect to their shape and size, compared to the current map, which gives 85 block typologies. The most common typologies obtained from the Khan marketplace region for the two periods are irregular, trapezoidal, polygonal, and rectangular patterns. This can be attributed to the presence of monumental buildings and their complexes that mesh the block geometry toward irregular or trapezoidal patterns due to their complex architectural typologies. There is a substantial reduction in the irregularity of block typologies in the current state, indicating that the typology of the region has lost its organic structure and gained a more regulatory form, which can be attributed to the increase in polygonal, rectangular, and trapezoidal block typologies.

(a) Blocks and Building Types for the period 1857, KA (Bursa)



(b) Blocks and Building Types for the period current, KA (Bursa)

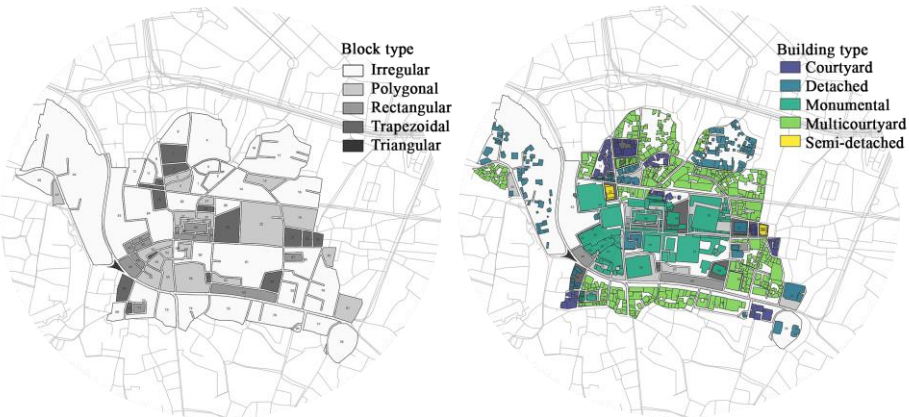


Figure 26. The spatial distribution of the block and building typologies between the 1857 (a) and current (B) for KA (Bursa) region.

The presence of irregular patterns is predominantly localized, except for monumental irregular block patterns, reflecting that they are shaped by multicourt yard or detached configurations within the block patterns, some of which are enclosed with empty corners. Since the 19th century, irregular block patterns demonstrate high frequency (75 in 1857, 33 currently), which indicates higher consistency for this level type; however, the consistency of building types within these blocks reflects different behaviour over time. Therefore, to reveal and identify the tangible patterns of the selected heritage sites, whether hidden, lost, or remaining, each individual building pattern within the blocks is considered.

The results suggest that the purpose of the blocks in heritage sites remains somewhat consistent, but their internal arrangement of buildings does not reflect the same characteristics. This can be attributed to the

diversity and variation of building types within the blocks, which reflects changes in the urban layout of the region. This cannot be observed within the monumental blocks, which reflect an organic diversity of variation over time, where they are typically characterized by courtyard-type building typology. However, most of the surrounding block patterns show typologies shifting from detached types to more mixed and functionally diverse building typologies, especially with an increase in courtyard types and a rise in multicourt yard typologies, particularly on the periphery.

5.5 Results of cluster analysis

5.5.1 Classification by the morphological unit character

This section presents the results obtained in terms of morphological, qualitative, and quantitative analysis for the clustering of the morphological regions. K-means clustering was applied to the categorical labels in street age and street type are converted into numerical values to define the points. Figure 27 displays the total within-cluster sum of squares for different numbers of clusters for the 1106 street segments with 7 street geometry and 3 street age parameters for KA (Bursa), and 296 street segments with 6 street geometry parameters for SM (Edirne). The optimal number of clusters for K-means clustering of street geometry and street age is $k = 4$ for the two morphological regions, as the elbow points indicate where the WCSS does not decrease sharply thereafter with additional clusters.

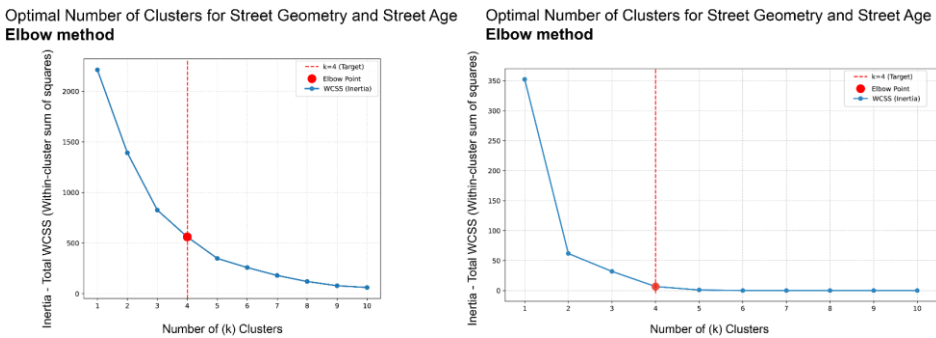


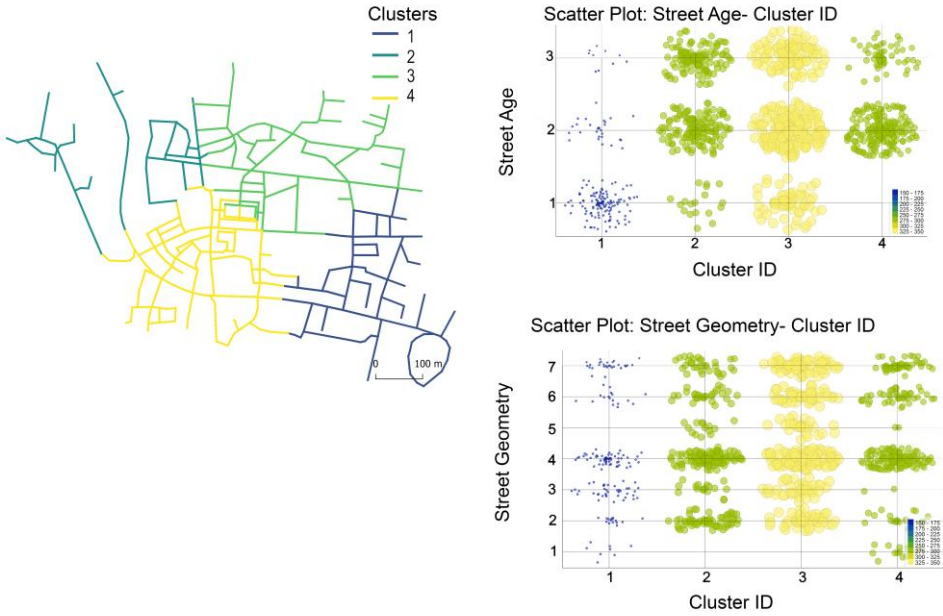
Figure 27. Optimal number of clusters is indicated by the vertical dotted red line at a given level of k for each metric. Metrics for defining optimal clusters were computed with the elbow method for the morphological region KA (Bursa) on the left, and SM (Edirne) on the right.

Figure 28 shows the results of the K-means clustering spatially, and each cluster displays different statistical variation within the regions. Table

8 demonstrates the results of the four clusters according to their quantitative variables - the percentage of distributions - which allow for improved interpretation of pattern relationships from the cluster analysis.

The results reveal that Cluster 3 has the largest cluster size with the 365 number of streets segments and reflect the most diverse distribution of geometry that characterized primarily by thoroughfare, cul-de-sac, tree like patterns with the secondary strategic route. The spatial distribution of the clustered data suggests that these street geometries are representative of the remaining structures from the medieval era (53.1%) and 20th century (30.41%) period and they delineate the surroundings of the marketplace.

**K-means clustering KA (Bursa):
street age, street geometry, and street integration**



**K-means clustering SM (Edirne):
street age, street geometry, and street integration**

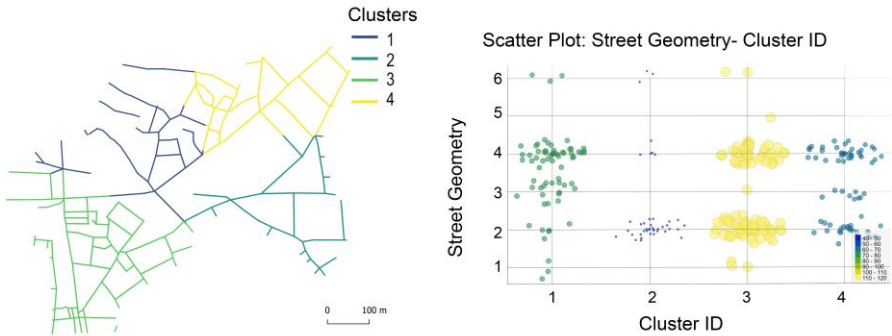


Figure 28. The spatial distribution of the K-means clustering for the KA (Bursa) and SM (Edirne).

Cluster 2 and Cluster 4 have almost the same cluster size but reflect different characteristics, greatly in the street age. On the other hand, Cluster 2 reflects similar proportional characteristics to Cluster 3, displaying combinations of medieval era (47.78%) and 20th century (46.08%) street age patterns, along with predominantly thoroughfare and secondary strategic routes. These similarities exhibit a balance between change and continuity associated with secondary strategic routes, which enhanced the

transition between street the planning practices over time. Cluster 4 demonstrates a stronger alignment with the medieval street era (80.87%) and displays proportionally predominant thoroughfare, three like and cul-de-sac street patterns. Conversely, Cluster 1 has a noticeably smaller size and is predominantly associated with ancient fortifications period (77.78%), indicating a lower degree of persistence of ancient fortification street patterns within KA region, that part of the region is in a far greater transformation process. This difference is driven by predominantly tertiary strategic routes and thoroughfare street geometries.

Table 8. The proportions of the street geometry and street age types were calculated as percentages of the total number of street segments in each cluster for the KA (Bursa) region.

Cluster ID	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Number of Segments (n)= 1106	(n)=171	(n)=293	(n)=365	(n)=277
Street Type (%) 1: Primary strategic route	4.68	0.00	0.00	4.33
Street Type (%) 2: Secondary strategic route	8.77	22.53	13.70	6.86
Street Type (%) 3: Tertiary strategic route	23.39	5.8	11.51	0.72
Street Type (%) 4: Thoroughfare	36.26	45.73	34.52	54.8
Street Type (%) 5: Through loop	0.00	4.78	7.12	0.72
Street Type (%) 6: Three-like	9.94	10.24	13.7	15.52
Street Type (%) 7: Cul-de-sac	16.96	10.92	19.45	16.97
Street Age (%) 1: Ancient Fortification	77.78	6.14	16.44	0.00
Medieval	16.37	47.78	53.15	80.87
Modernization of the city – Begging of the 20 th Century	5.85	46.08	30.41	19.13

In case of SM (Edirne), the results indicate in Figure 28 and Table 9 that Cluster 3 is the largest cluster, maintaining Ottoman and 20th century street geometry with a variety of mostly secondary strategic routes (55.17%) and thoroughfare routes (38.79%). Cluster 1 and Cluster 4 have almost same size, displaying almost similar proportions of the thoroughfare routes and tertiary strategic routes, but they exhibit a distinct proportion of secondary strategic routes in Cluster 4 (35.29%). In contrast, Cluster 2 has the smallest size and is differentiated by dominance of secondary strategic

routes (80.95), which suggests that the modern planning principles are most depicted in this region.

Table 9. The proportions of the street geometries were calculated as percentages of the total number of street segments in each cluster for the SM (Edirne) region.

Cluster ID	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Number of Segments (n)= 296	(n)=70	(n)=42	(n)=116	(n)=68
Street Type (%) 1: Primary strategic route	4.29	0.00	2.59	0.00
Street Type (%) 2: Secondary strategic route	8.57	80.95	55.17	35.29
Street Type (%) 3: Tertiary strategic route	25.71	0.00	0.86	13.24
Street Type (%) 4: Thoroughfare	57.14	11.90	38.79	51.47
Street Type (%) 5: Through loop	0.00	0.00	0.86	0.00
Street Type (%) 6: Cul-de-sac-tree	4.29	7.14	1.72	0.00

5.5.2 Classification by the blocks shape and size

The classification of block shape and size follows the K-means clustering approach to determine the geometric properties of the blocks, and to identify whether block area and block elongation change or persist over time, which could reveal the diversity of the places through the detection of block-level change. As shown by the elbow curve in Figure 29, the optimal number of clusters was observed at $k = 4$ for the two morphological regions, where this level effectively captures the groups of block shape and size that reflect parallel spatio-temporal transformation patterns. The distributions of the clusters for the KA region for each period represent zonal block-level differences, which significant changes in the urban layout.

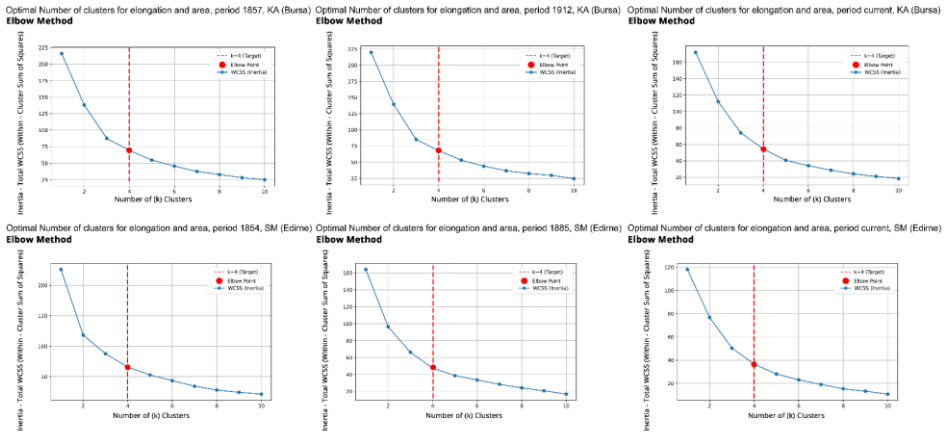


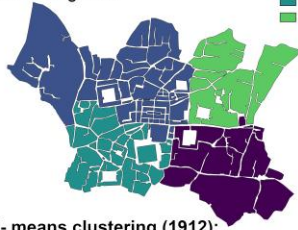
Figure 29. Optimal number of clusters is indicated by the vertical dotted red line at a given level of k for each metric. Metrics for defining optimal clusters were computed with the elbow method for the morphological region KA (Bursa), and SM (Edirne).

The clustering results demonstrated in Figure 30 and Figure 31 display the Ottoman block pattern structure in size and shape for the period of the 1857 KA, while the clusters in 1912 exhibit distinct spatial organization. Cluster 3 is relatively stable in size and shape over time and exhibits distinct block geometry properties that reflect quantitative persistency. More specifically, the median of Cluster 3 is almost the same between the periods, whilst Cluster 1 and Cluster 2 exhibit continuous temporal change, with median values evolving through constant decrease and increase driven by the broader transformation in block size and shape that resulted from the modification of the medieval street patterns, which shrink the block geometries over time.

KA (Bursa)

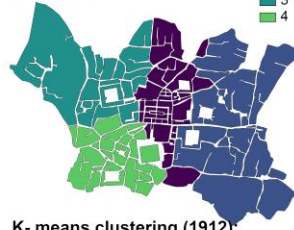
K- means clustering (1857):
block elongation

Clusters
1
2
3
4

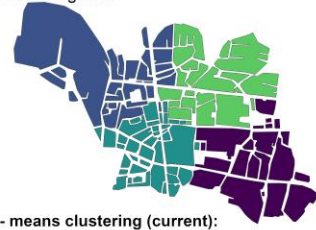


K- means clustering (1857):
block area

Clusters
1
2
3
4



K- means clustering (1912):
block elongation



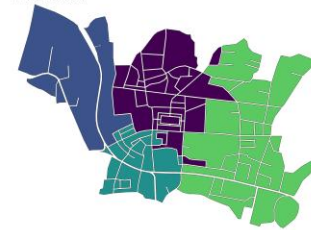
K- means clustering (1912):
block area



K- means clustering (current):
block elongation



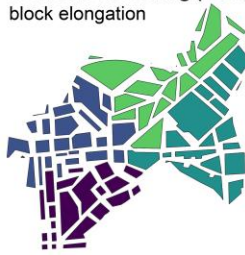
K- means clustering (current):
block area



SM (Edirne)

K- means clustering (1885):
block elongation

Clusters
1
2
3
4



K- means clustering (1885):
block area

Clusters
1
2
3
4



K- means clustering (current):
block elongation

Clusters
1
2
3
4



K- means clustering (current):
block area

Clusters
1
2
3
4

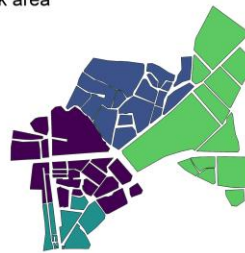


Figure 30. Spatial distributions block elongation and block area by clusters, for the morphological region KA (Bursa), and SM (Edirne).

Block Elongation and Block Area (log) by clusters, KA (Bursa) and SM (Edirne)

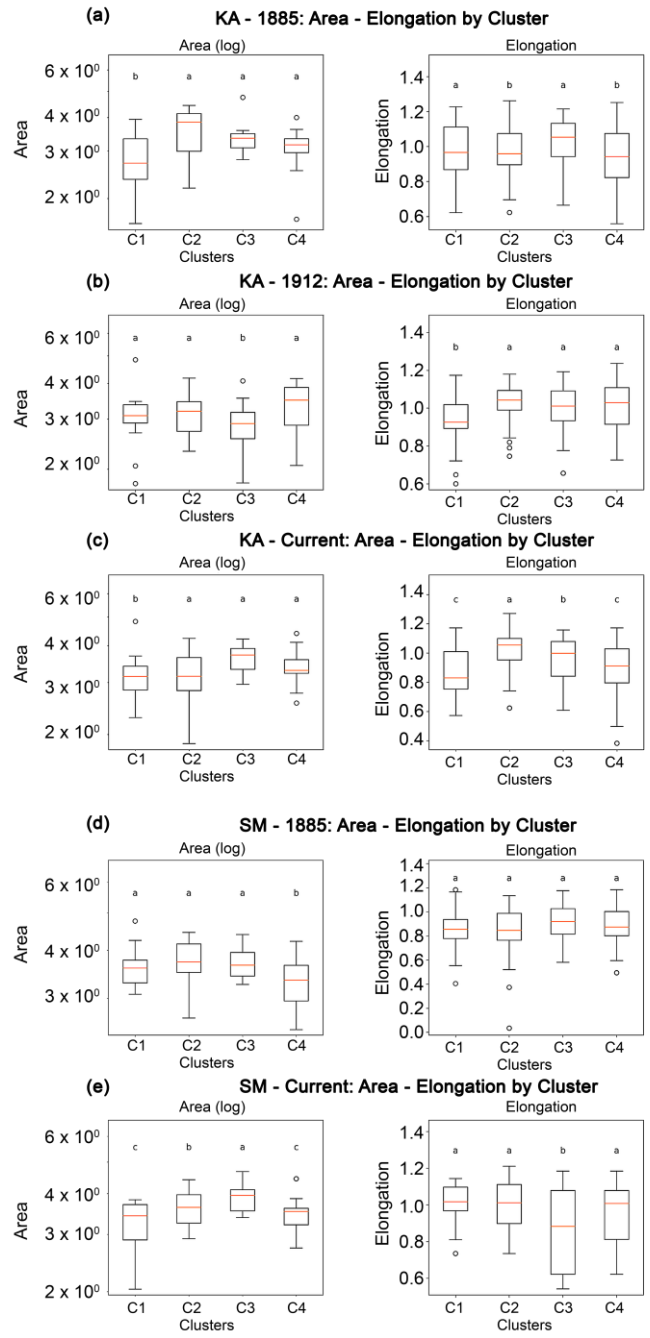


Figure 31. Statistical distribution of block elongation and block area by clusters, for the morphological region KA (Bursa), and SM (Edirne).

Cluster 4 stands out as being a relatively stable in size but show a critical breakpoint around the period 1912, where the shape of the block illustrates a non-linear transition. The clusters observed in the case of SM Edirne for the map periods show that Cluster 1 demonstrates strong spatio-temporal evolution in size and shape; specifically, the area of the blocks exhibits a constant and significant decrease between the periods. While Clusters 1 and 4 also show transformation in size and shape towards soft evolution that tends to be a more compact structure. Cluster 2 only reflects relatively stable elongation and tends toward more oriented changes in size substantially.

Together, these interpretations of the changes in the block parameters provide a quantitative understanding for the changes in block geometries, which primarily relate to increase in the heterogeneity of block geometries that could impact the arrangement of these blocks.

5.5.3 Classification by building types

The classification by building types was utilized to evaluate typological similarities in morphological regions at block level, based on the analysis of their conceptual morphological properties. The classification was acquired using a hierarchical clustering approach that is able to provide high levels of the specificity in the results. The optimal number of clusters was determined as $k=4$, based on Ward hierarchically clustering results.

Figure 32 reports the spatial distribution of clusters building types within the types of block clusters.

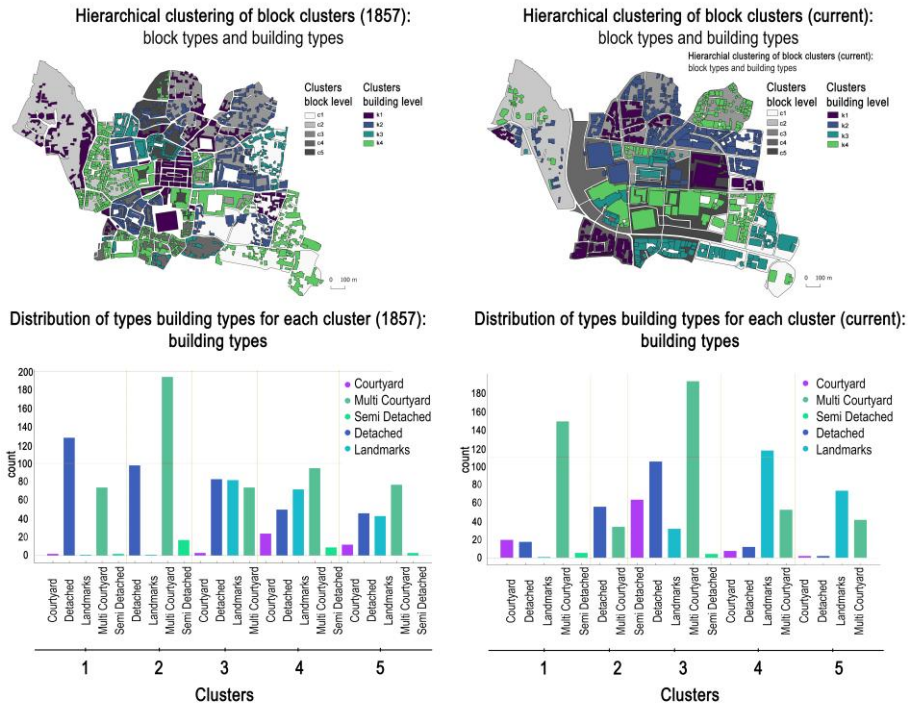


Figure 32. Spatial and statistical distribution of the hierarchical clustering results of the building types for the morphological region KA (Bursa).

Cluster 1 ($n = 207/176$): This cluster can be summed up as the “multi-courtyard” building type group that remains persistent and demonstrates the more prevalent type in the current period. The detached type was more infrequent than the other types, with a significant decrease (from 128 to 16) over time. A noticeable increase in courtyard types took place compared to the other types. There is a shift toward more diverse building types compared to the other clusters.

Cluster 2 ($n = 310/82$): This cluster had the highest proportions of building types historically, while demonstrating a significant decrease in both the number and diversity of building types due to the shrinking of blocks over time. However, multi-courtyard and detached types have preserved their existence.

Cluster 3 ($n=242/363$): This cluster display the greatest diversification of building types, with the emergence of new types like semi detached type. The multi-courtyard type had the highest rate, increasing from the 74 to 176, and is characterised as the most preserved type in this cluster that dominates typology of the cluster. This cluster is the only

cluster that in association with a preserved typology and adaptation with new types.

Cluster 4 (n = 250/181): This cluster displays similar trends over time. Both the number of buildings and the size of the clusters decreased over time, but they differ greatly in maintaining their significance through the presence of multi-courtyard and landmark building types, with a greater strengthening of their typological character in multi-courtyard and landmark buildings over time. This difference from the other clusters is driven in part by the historical significance of this cluster, which is dominated by landmark typologies.

These findings suggest that multi-courtyard typologies are a decisive factor in defining block typologies, with their stability among the clusters significantly enhancing persistence over time. The increased observation of detached and semi-detached types highlights broader changes in block usage over time.

Chapter 6: Empirical testing (falsifiability and testability)

6.1 Testability of the Palimpsest methodological propositions through confirmation with visibility analysis

Testability through visibility and isovist analysis is an assessment of the confirmation results obtained from the measurable information of the built environment at the highest level of the specificity to define and preserve heritage sites. Visibility and visibility graph analysis, and isovist and their field of view calculations, are crucial tools to translate quantitative morphological findings into empirical visibility outcomes of preserved or destroyed heritage elements.

The challenge in perceiving urban space is build upon the variation of shaping elements of the urban environment and the behaviour of isovist through which an observer renders multiple decision. Visibility and permeable visibility analyses must be included in research on urban spatial structures. Hence, spatial analyses allow to specify urban elements to consider or ignore, or whether their restriction influences the spatial configuration in the built environment (O'Sullivan and Turner, 2001); in this way, the alteration of visual permeability can be defined and it can lead to determining the hidden elements in built environment.

The measurement of the level of changes in the disclosure of specific urban elements in different directions can be achieved using tools in visibility analysis. Isovist analysis is used to calculate visible or invisible spaces for an observer, and it also generates different fields of view from

the periphery of space, which could lead to the definition of entire visibility in the built environment.

The method proposed to test the palimpsest approach through the confirmation of visibility and isovist analysis combines different approaches and follows several processing steps to generate different visible fields/isovists from any point where an observer is positioned to perceive patterns in selected urban morphological regions. The method provides a means to select a set of isovists; it has parameters to generate spatial visibility including all elements in the built environment.

Therefore, the method has three configurable parameters or steps, as demonstrated in Figure 33. First, the mapping of the location of each morphological region in relation to the geographic and topographic characteristics of the city as a whole, on which the visibility analysis is applied (a). Second, the immediate surroundings of the morphological region are determined to evaluate all situations that may involve the built environment within the regions (b). Third, the “outline of the spaces” / “nature of the isovist boundaries” are determined to generate isovists in an attempt to obtain perceptual information (tangible data) from any point in space.

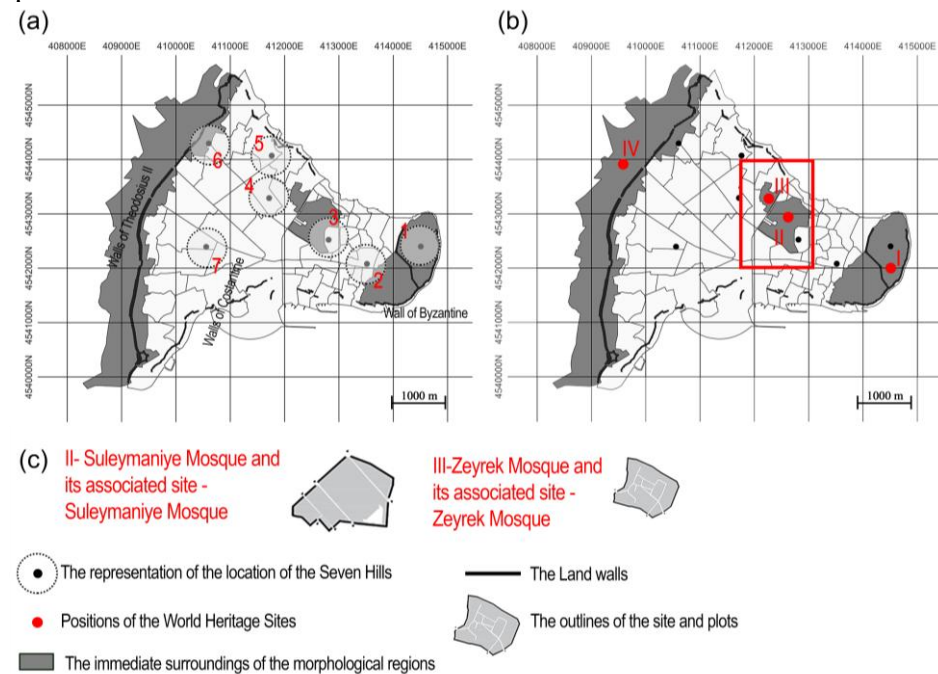


Figure 33. Identification of two morphological regions in Istanbul and their immediate surroundings.

The size and shape of the isovist depend on the geometry of the environment and the distance of the elements from each other, which are set by their configurations. Visibility graph analysis optimizes different isovist measurements using a spatial algorithm that combines them to create clusters of visibility results for built elements and their surroundings in the built environment. More details are outlined in Chapter 2.3.2.

Despite this, the step for the decision of selecting observer points in the morphological region is complex because the observer's field of view can be covered, blocked, or clear. Visible fields or visibility conditions of the surroundings in the morphological regions cognitively define space. To achieve this, points of view from outside the boundaries of regions, covering components of the surroundings as well, are considered. Thus, all viable compositions are determined with regard to visibility conditions within the visible cluster (visual metric depth), visible angles (visual step depth), visible permeabilities (visual integration), the most dramatic or least visible positions, and highly visible (visibility) areas of the morphological region's surroundings.

The selection of perspectives or points where the heritage elements as targeted buildings are visible or not visible simplifies the complexity of the approach. The conditions of the perceived distance, size, and form of the obstacles determine the variety and number of visible rays. Therefore, different viewpoints are generated from the periphery of the morphological regions. The isovist response to the effects of urban elements on visibility condition of the targeted elements and visibility behaviour is demonstrated in Figure 34.

Morphological parameters (characteristics) are defined in the Section 4.3, that direct the function of the urban from elements based on the building blocks, street layout (block geometry) and buildings (preserved or non preserved). These parameters are re operationalized to confirm whereas multiple strata of heritage sites to be preserved or developed in urban systems through:

- Isovist visible areas and field of views (FOV) generated from the multiple observation points.
- Visibility graph analysis to assess quantitative cognitive and perceptual aspects of spaces.

To empirically confirm the patterns derived from morphological quantitative parameters with spatial visibility, testability is ensured by comparing them with historical visibility baselines and current visibility metrics. Due to the lack of historical spatial data that traces the building block patterns, an internal baseline (which has preserved building block patterns) is used for historical visibility within the determined

morphological distinctiveness of areas (Zeyrek Mosque and its surroundings) based on Jacques Pervititch's insurance maps (1922).

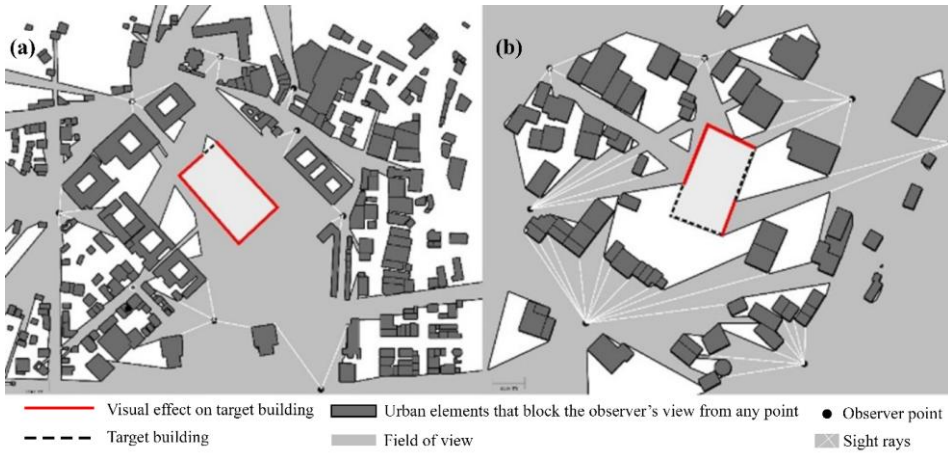


Figure 34. The rays of the isovist reciprocate with the visibility conditions of the surrounding regions and the inside and outside visual permeability of the built environment. The perimeters of the heritage buildings, the Suleymaniye Mosque (a) and the Zeyrek Mosque (b), are targeted as points of interest for the observer, and the isovist behaviours have been presented using 2D analysis for demonstration. Isovist maps generated on the Isovist App 1.7. (McElhinney, 2024) by the Author.

In this context, the determination of the empirical confirmation threshold is critical to ensure the methodological rigor and testability of the palimpsest approach. The quantitative confirmation threshold is defined as: 25% based on general principles of the perception of spatial structures from the literature (Batty, 2001; Lynch, 1964), which suggest that significant and systematic disruptions in visibility must exceed this perceptual threshold to confirm meaningful transformations and validating morphological impacts. Threshold confirmation is determined by a reduction exceeding 25% in the statistical distribution of the mean and standard deviation of spatial visibility metrics, relative to the historical internal baseline and current patterns. This will also contribute to the research by revealing that the concept of the urban palimpsest can be empirically proven through the reuse of abstract patterns from historical layers.

The confirmation of the spatial visibility metrics – visual depth, visual step depth, and visual integration – is corresponding to perceptual dimensions of urban structural spaces as clearly defined by (Cullen, 1961; Lynch, 1964), providing a quantitative basis for detecting significant reductions indicative of morphological changes.

Table 10. summarizes the thresholds for empirical confirmation of spatial visibility metrics as:

Table 10. Threshold confirmation of spatial visibility metrics for the 1922 baseline map and the current map.

Visibility Metrics	Internal (1922) historical baseline (Mean)	Internal (1922) historical baseline (Standard deviation)	Current (Mean)	Percentage of reduction in internal Baseline Mean	Inductive Reasoning (reduction)	Threshold Confirmation
Visibility	0.107	0.089	0.049	53.68%	> 25%	Confirmed
Visual Depth	4.648	2.338	3.595	22.64%	< 25%	Not confirmed (no significant change)
Visual Steps Depth	2.819	0.530	3.872	-37.35%	< 25%	Not confirmed (no significant change)
Visual Integration	5.769	1.911	3.497	39.38%	> 25%	Confirmed

The significant reduction in visibility (53.68%) and visual integration (39.38%) denotes strong empirical evidence of changes in perceptual, empirical, and morphological patterns, proving to a disrupted palimpsest structure (patches) of the historic urban fabric. This indicates that the perceivability of heritage elements has decreased and points to the need to address preservation problems of urban heritage elements. The reduction leads to a reassessment of the affected spatial organization of their buffer zones and their diminishing effect on the intelligibility of built heritage and its visual connectivity to the urban landscape.

The Suleymaniye Mosque and Zeyrek Mosque surroundings (their intersected buffer zone) demonstrate this morphological fragmentation in urban morphology (as already confirmed in Section 5.1.3), reflecting how morphological configuration promotes measurable reductions in the visibility and visual integration of heritage sites.

By generating visibility graph analysis, morphological characteristics are translated into empirical and quantifiable visibility outcomes to reveal the intelligibility problems of built heritage. The Figure 35 shows a graphical comparison of the selected sites based on visibility graph analysis results, with values in local and global measurements plotted in a red-blue colour spectrum. Blue colour reflects minimum area, and red colour reflects maximum area in the visibility graph, with an isovist generated from within those areas.

The results in VGA confirmed significant deviations in the lowest visibility and visual integration scores (blue), which are considered

empirical evidence of morphological transformation, especially where the intersection of buffer zones (Atatürk Boulevard, which reveals the results of the modernisation process of Istanbul) causes the cores of the sites to be not integrated.

This significant transformation in urban form indicates a rupture in the integration of region, meaning that experimental structure of urban fabric is disrupted in the historic environment. This confirmation proves the importance of the correlation between the visibility analysis and visual integration, these connected scores are also affects the entire spatial configuration.

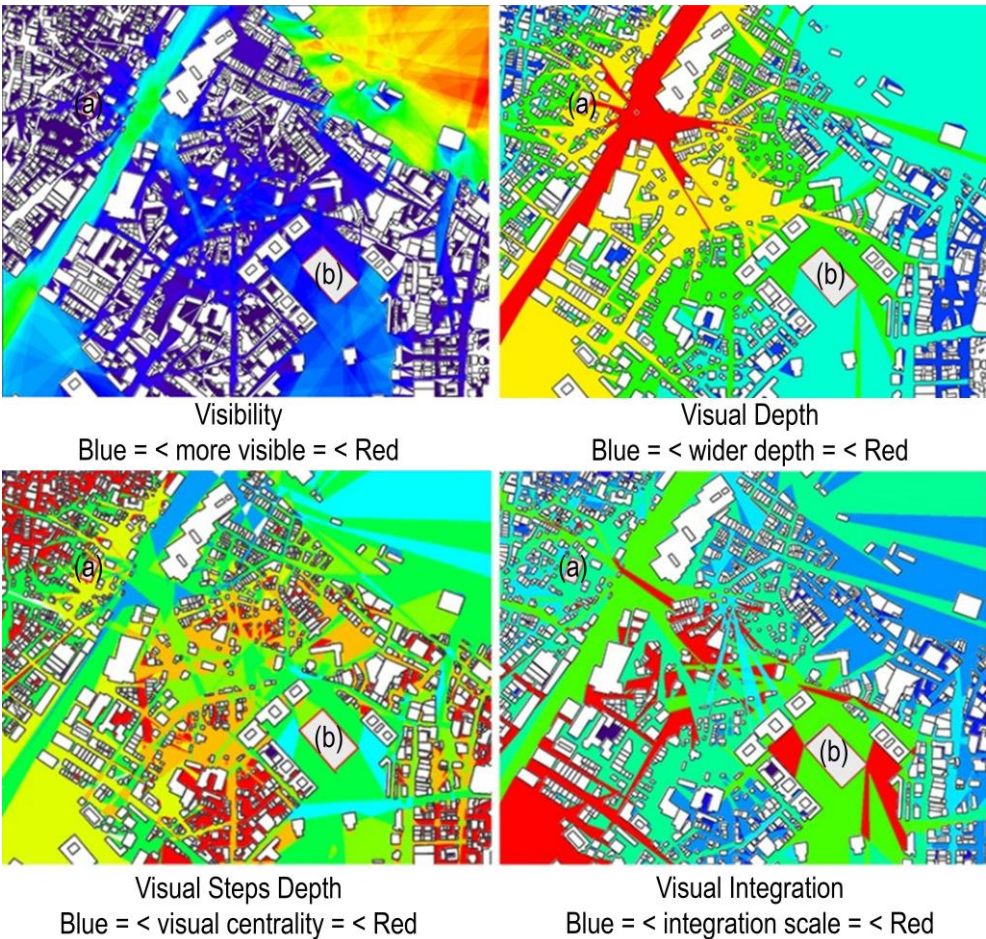


Figure 35. Visibility graph analysis results of selected urban heritage sites. Generated on Isovist App 1.7. (McElhinney, 2024), by Author.

On the other hand, as an outcome of the visibility and visual integration confirmation results, the 22.6% decrease in the visual metric value remains below the determined critical threshold, indicating that the metric perceptual fields of the urban palimpsest remain relatively stable, which is directly related to the preservation of the positions of urban heritage elements.

Similarly, the -37.35% increase in spatial step depth did not meet the established confirmation criterion, suggesting that more complex spatial reconstruction is the primary phenomenon preventing perceptual consistency.

Although the topographic character of the two heritage neighbourhoods located on the third and fourth hills of Istanbul was planned to reveal this perceptual layering, the increased occupation of space and urban spatial layering at the micro-scale disrupt this consistency.

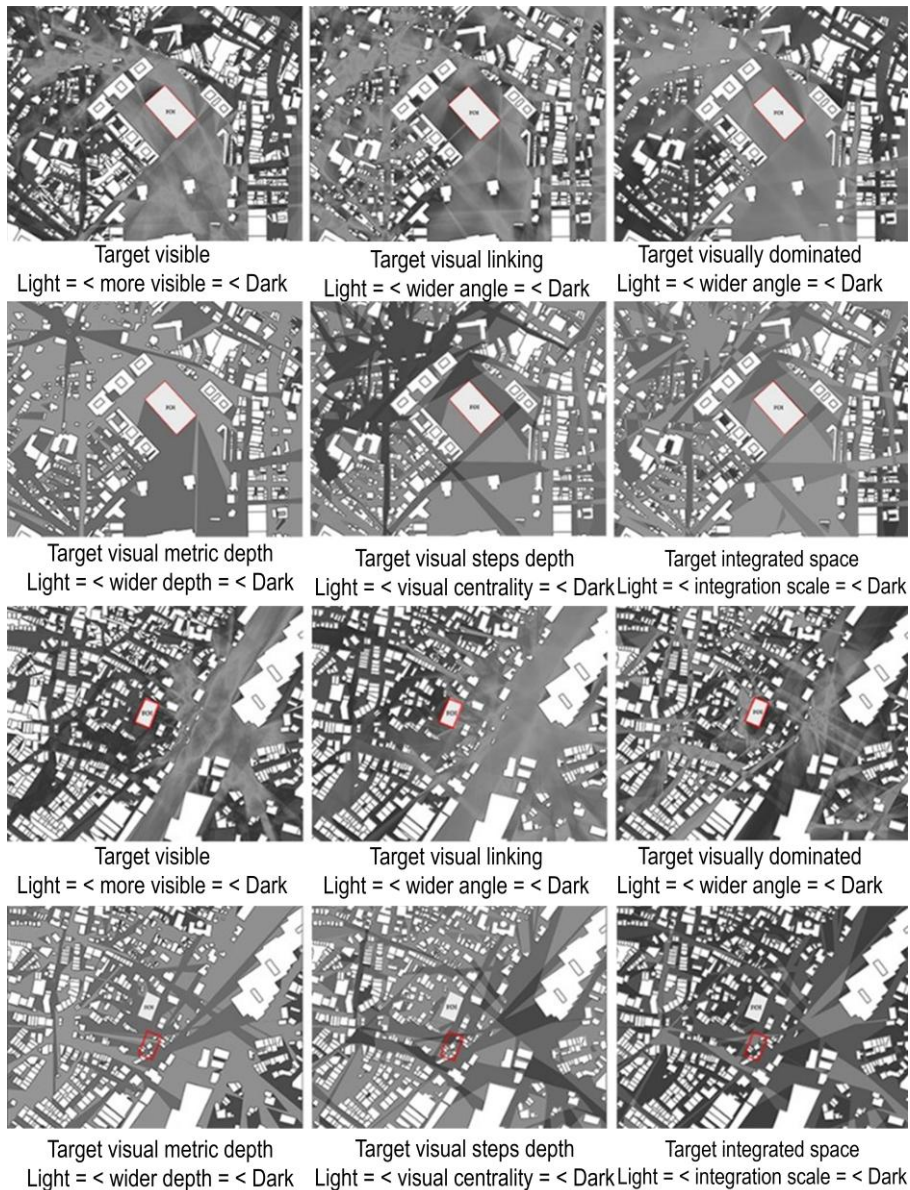


Figure 36. Maps of visual metrics of the Suleymaniye Mosque and Zeyrek mosque. Generated on Isovist App 1.7. (McElhinney, 2024), by Author.

Testability confirmation also ensures the element-based preservation – such as the reduction of the field of view of the Suleymaniye and Zeyrek mosques – through the mapping of spatial visual configurations of heritage sites. This qualitative spatial pattern representation, through the ranking of results based on visibility criteria, navigates the visual spatial configuration that can detect the highest or lowest visual field values within

the elements (objects), supported by the quantitative visual metrics confirmed in this study.

For this purpose, a comprehensive visibility analysis was conducted for the two mosques and their surrounding urban fabric through multiple viewpoints.

The visual metric analysis is applied to present changes in the visual metric distances as determined; grayscale values are selected for the demonstration. Figure 36 shows the results of the visual metric indicators to reveal the legibility of targeted buildings in a quantified way. Note that perceptual indicators in the morphological regions represent three main simulations that include: target visibility, target visual link (depth), and visual dominance (visual openness or visual function), where the spatial metric indicators in relation to integration are illustrated within the three indicators: target visual metric depth, target visual step depth (visual centrality), and target integration with space.

The results highlight that the observed diminished visual metrics are related to changes in tissue that resulted in response to dense and newly constructed urban blocks. In contrast, the metric for the Suleymaniye Mosque is dominated by visual preservation and spatial configuration, reflecting a keeping threshold that does not align with morphological interruption. This observation aligns with changes in the urban fabric being heterogeneous, supporting partial preservation rather than the loss of the entire historicity.

The grayscale values used to produce each graph provide a spectrum of the metric configuration changes for the two morphological regions, where the lighter spectrum indicates higher values, and the darker spectrums indicate lower values. The results indicate that the visual enclosure is mostly diminished around the targeted buildings. The metric spatial dominance, openness, and legibility of Zeyrek Mosque are diminished, where the dark zones dominate due to the short distance between the urban elements surrounding the mosque. This can be attributed to a quantitative decrease in visibility and issues in controlling its immediate surrounding settings.

6.2 Testability of the Palimpsest methodological proposition through the qualitative and quantitative analysis within the Pittsburgh (PA, US)

The proposed Palimpsest methodology is tested in Pittsburgh (PA, US), which is not one of the main research case study sites, but is used to demonstrate how the methodology works in a different context.

Figure 37 shows that palimpsest methodological propositions follow three steps: temporal layering (1), spatio-temporal layering (2), and element separation analysis (3). The resulting quantitative analysis shows that there was significant spatial differentiation between 1921 and the current period at different scales - street, block, buildings, and greenery, as demonstrated in Figure 38.

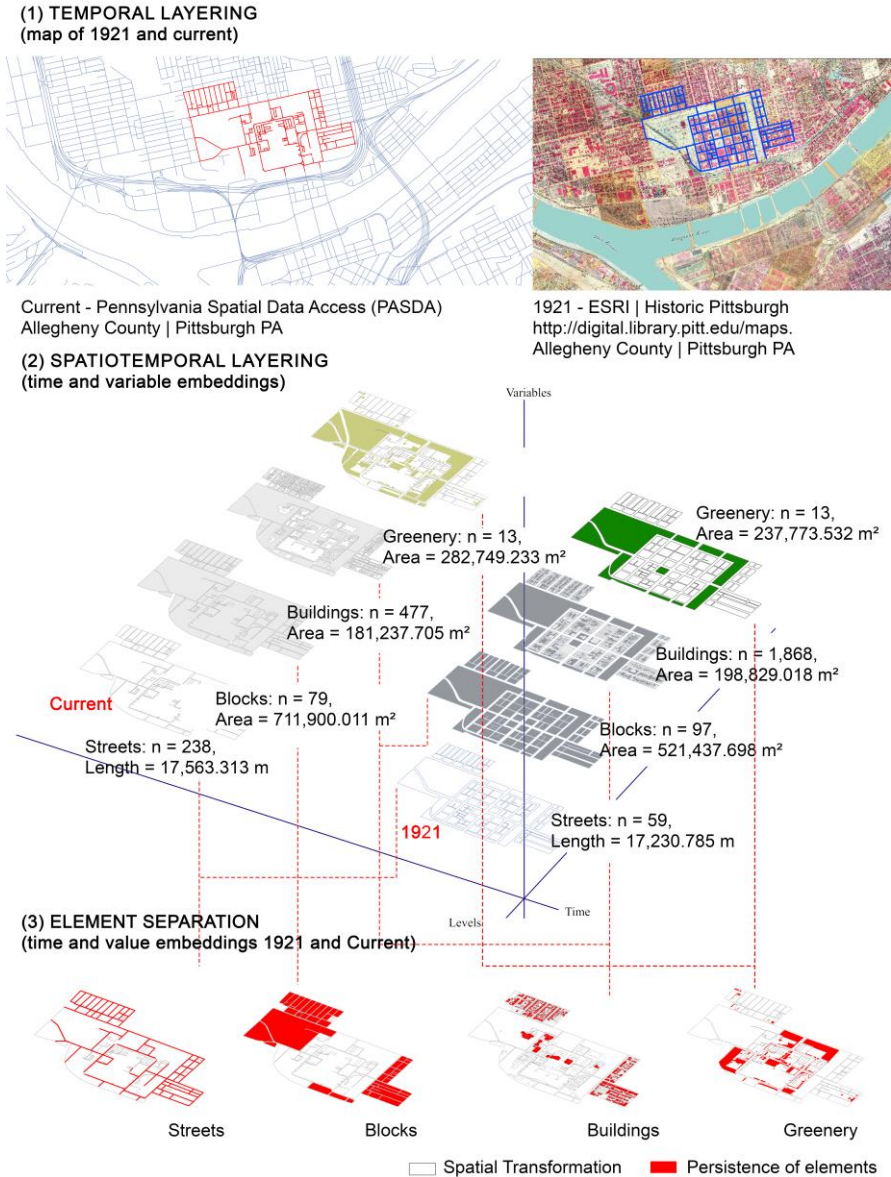


Figure 37. Three step methodological proposition for the investigation of the palimpsest methodology in case of the Pittsburgh, USA, Allegheny County.

The statistical analysis revealed that one of the main morphological changes taking place decreased in $\log_{10}$ transformed mean (1921/current: 2.26/1.75) and median (1921/current: 2.21/1.76) street lengths. This can be attributed to the significant reduction in street lengths, where the Mann-Whitney U test indicates ($p < 0.001$). This street transformation at the street level is attached to the blocks, with changes in shape in response to the emergence of new urban patterns since 1921. As depicted in the spatial analysis, the smallest blocks, which were located at the centre of the area, were substantial transformed and experienced significant alterations; others, the largest blocks from 1921, have remained relatively preserved.

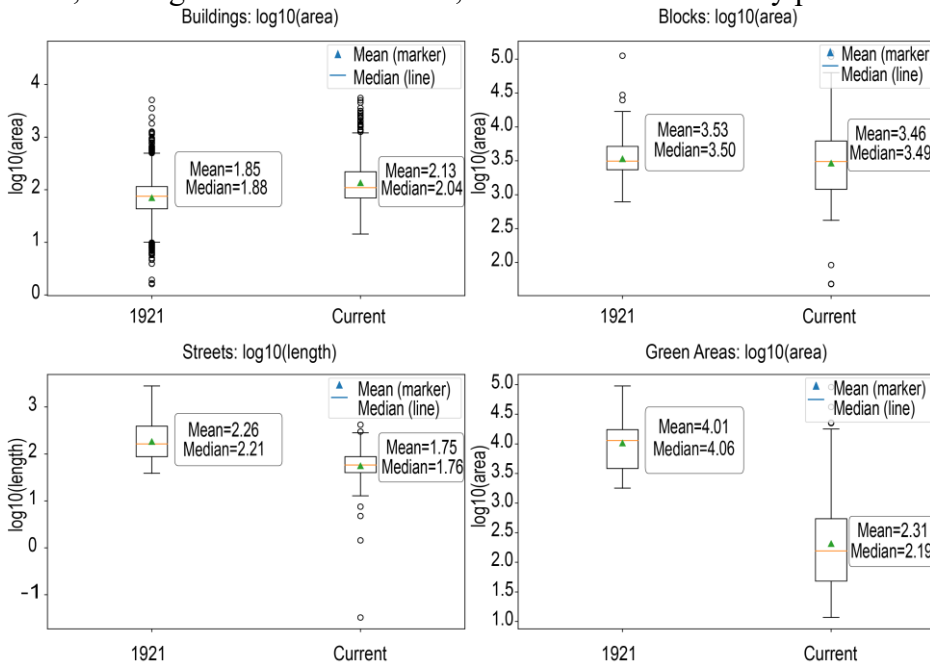


Figure 38. Distributions of the size values of the streets, blocks, buildings and green spaces for the period of the 1921 and current.

Although the spatial analysis indicates the significant transformation, the Mann-Whitney U test statistical analysis of the $\log_{10}$ transformed block area indicate that there are no significant differences between period ($U = 3941$, $p = 0.75$). On the other hand, while the boundaries of the blocks are scope of the changes, the internal arrangement of the blocks is also transformed spatially. The buildings within the transformed blocks have been demolished to create superblocks. These changes are also depicted in the descriptive statistical analysis, where the box plots in Figure a (c) show that mean $\log_{10}$ (area) value (2.13) in current is much higher than the mean $\log_{10}$ are in 1912 (1.85), and the standard

deviation of the current building areas is much larger, showing greater variability in building size. This can be attributed to the Mann-Whitney U test, which indicates that there is a meaningful difference exists between the periods ($U = 297,727$, $p < 0.001$), confirming a significant increase in median building area in the current period.

The results also indicate that mean (1921/current:4.01/2.31) and median (1921/current:4.06/2.19) of the $\log_{10}$ transformed green areas decreased between the periods. The Mann-Whitney U test confirms that there are a statistically significant loss and fragmentation in size of green areas ($p < 0.001$).

6.3 Integration of Green spaces as a measurement of change: Testability of the Palimpsest methodological proposition through the qualitative and quantitative analysis within Central European city examples

In this section, the palimpsest methodological proposition is tested in the urban green spaces and their integration values over time. The position (location) of the green spaces is focus as the measurement of the change and their relationship with the integration. While cities are transformed their components is also affected by changes, especially quality and quantity of green spaces are neglecting when the new urban planning decisions applied. In light of this issue, the palimpsest method will apply in the green space level to analyse continuity of changes in urban fabric over time by space syntax global integration analysis. The investigation is focus on the three central European cities, Bratislava (Slovakia), NoviSad (Serbia), and Sopron (Hungary), which have experienced distinctive very high patterns of historical integration and patterns of the evolution at different levels of urban form. Particularly, development of the cities follows the Fringe Belt like conception that have experienced phases of formation. These formations are more depictive on urban green spaces evolution that ate historically functioned different levels of fringe belts.

The main methodological step taken in for the case studies is to using the cartographic maps and their vectoral transformation and their spatial and temporal alignment with the contemporary data sources in GIS environment. Following the identification of the geographical location of the urban green spaces and quantification of the road network data is obtained form the OpenStreetMap (OSM) for the space syntax integration analysis. The contemporary vector datasets for the identitarian process were extracted from available source in the Copernicus Land monitoring Service, Urban Atlas 2018. To integrate the different urban green spaces

with different geographical parameters for the different period, spatial development phases and types of fringe belts are determined. Based on this criterion types of the urban green spaces are identified. Spatial integration analysis is obtained in QGIS with the help of the Space syntax Toolkit plugin (DepthmapX software).

The overlapping of the two different types of layers (points and lines) focusing on the spatial embeddedness of urban green spaces for the statistical analysis to test the association between form and change. To do this, the centroid of the polygonal-shaped urban green spaces was calculated and assigned as a point layer. Finally, the calculation of the n-nearest neighbouring attributes is applied to the point of the urban green spaces according to the shortest direct connection to the integration, which allowed interpretation and comparison of certain positions (fringe types) that are more or less integrated into the built environment.

The result for the Bratislava case in Figure 39, the ancient fortification stage and inner fringe belt period of Bratislava is related as a result of a major pause in urban growth. These fringes represent the first green belt shaped by the presence of green spaces surrounding the city centre during the interwar periods. In the 20th century, in the city plan, these green belts caused the formation of an early Suburbs that the city's historical urban area and surrounds the green space belt extending outward from today's city centre (intermediate fringe belt).

This intermediate fringe shows clear differences from the physical characteristics in terms of the layout of building blocks and street patterns. Although this fringe has been shaped mostly by green spaces associated with the patterns of more regularly planned streets and building blocks, and the natural landscape patterns designated for these parcels, the boundaries – as in almost every major city – are defined by connections at the regional level via major roads or at the neighbourhood level via streets.

Due to the nature of the city plan, many interconnected origin pairs and destinations develop along the periphery of the intermediate fringe, forming routes that connect all other parts of the city through the settlement areas of the inner and intermediate fringes. In this context, the degree to which urban green spaces are connected to these routes – at the neighbourhood and local level – plays an important role in explaining the direction of urban development and the transformation of the city.

Differences within the syntax structure of the streets and the way they are connected to each other reveal the configurational structure of the built form. For that matter, applied space syntax analysis reveals different intersection angles and different intersection degrees and types, due to differences in the fringe periods. Therefore, urban green spaces in different

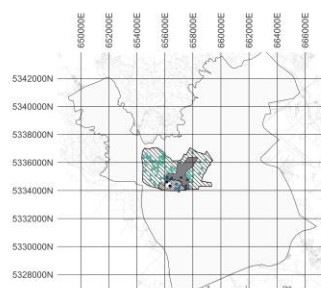
fringes contain different configurational properties according to the intersections.

Even though the graphical representation of the integration provides a profile of many attitudes and the hierarchy of relationships between regions, quantitative attributes can only provide insights into the role of urban green spaces in the direction of development.

In the case of Novi Sad, Figure 39, the major factor in the formation of the inner fringe belt is the resilience of the land use type and the fluctuation of urbanization over time. This is particularly related to the resilience of the built-up area. In the case of land use types, green spaces are a significant component that marks the limits of urban growth during the inner fringe belt period. When the urbanization period pursued its outward spread from the inner fringe belt, associated with the new routes, it resulted in the limits of the next phase of development (intermediate fringe), generally shaped by a new planning perspective. The outcome in the landscape of the intermediate fringe belt is often characterized by land uses that include more regularly planned green spaces deeply integrated within the urban fabric. However, in the case of Novi Sad, this is more about survival with significant planning implementations.

In the case of Sopron city, Figure 39, the fringe belt development mostly reflects medieval city development, in which the inner core has survived for centuries. In response, the inner fringe belt came into being at the edge of the historic core. It is intelligible as a response to the first expansion of the city border, resulting in the formation of this fringe belt, as the burgeoning of green spaces at the urban core periphery for public purposes is associated with the fluctuation of urban land use development. Pressure for development toward the outer part of the inner fringe zone is a reflection on planning practice in relation to green fringe belt development, which has led to fragmented green areas, notably the growth of built-up areas.

Bratislava - 20th century



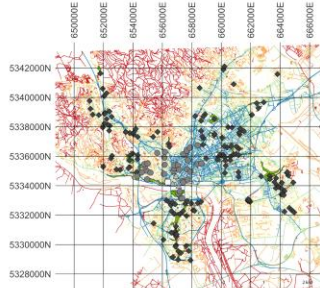
Urban Green Spaces

- Ancient fortification green space
- Inner fringe green space
- Green spaces outside fringe belts
- Intermediate fringe green space

Fringe Belts

- Ancient Fortification
- ▨ Inner Fringe Belt
- ▨ Early Suburbs
- ▨ Intermediate Fringe Belt
- Later Development

Bratislava - Current



Urban Green Spaces

- Ancient Fortification Green Space
- ▨ Inner fringe green space
- ▨ Green spaces outside fringe belts
- ▨ Intermediate fringe green space

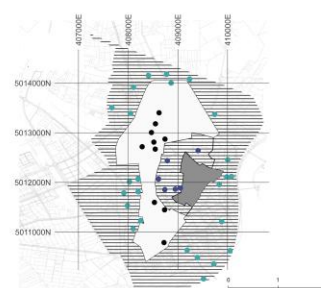
Integration

- 4 – 7996
- 7996 – 9820
- 9820 – 11,285
- 11,285 – 13,038
- 13,038 – 17,816

Urban Green Patterns

- Green Urban Areas

Novi Sad - 20th century



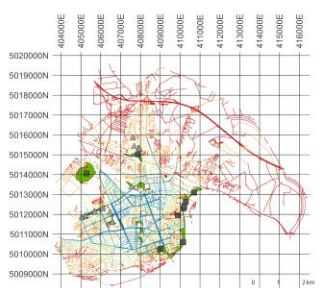
Urban Green Spaces

- Inner fringe green spaces
- Green spaces outside fringe belts
- Intermediate fringe green spaces

Fringe Belts

- Old Town
- ▨ Inner Fringe Belt
- ▨ Early Suburbs
- ▨ Intermediate Fringe Belt
- Later Development

Novi Sad - Current



Urban Green Spaces

- Inner fringe green space
- ▨ Green spaces outside fringe belts
- ▨ Intermediate fringe green spaces

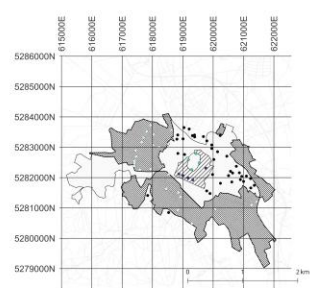
Integration

- 4 – 5189
- 5189 – 6021
- 6021 – 6689
- 6689 – 7495
- 7495 – 9956

Urban Green Patterns

- Green Urban Areas

Sopron - 20th century



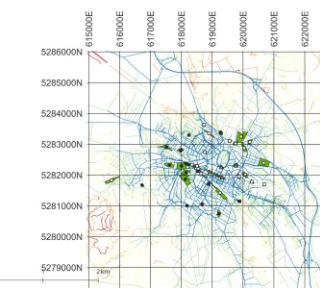
Urban Green Spaces

- Old town Green Space
- Inner fringe green space
- Green spaces outside fringe belts
- Intermediate green space

Fringe Belts

- Old Town
- ▨ Inner Fringe Belt
- ▨ Early Suburbs
- ▨ Intermediate Fringe Belt
- Later Development

Sopron - Current



Urban Green Spaces

- ▨ Inner fringe green space
- ▨ Green spaces outside fringe belts
- ▨ Intermediate fringe green space

Integration

- 3 - 2829
- 2829 - 3234
- 3234 - 3583
- 3583 - 3969
- 3969 - 4836

Urban Green Patterns

- Green Urban Spaces

Figure 39. Spatial distributions of urban green spaces and their fringe belt formation for the map period of 20th century and current. Bratislava and Sopron are mapped in ETRS89 / UTM zone 33N, while Novi Sad is mapped in WGS 84 / UTM zone 34N.

Box-plot analysis in Figure 40(a) illustrates the complementary outputs of the space syntax map. The output map of Bratislava reveals that urban green spaces in the ancient fortification have very high median integration values, reflecting that these green spaces are the most integrated at the 20th century. However, their mean and median integration values have substantially declined in the current state, which indicates that they have lost historical spatial centrality and significance. These results highlight that the type of these green spaces is not stable in urban fabric of the most preserved areas, indicating that planning decisions for green spaces have not been significantly considered in the integration of the urban structure.

Inner fringe green spaces historically have high median values with very wide integration values, suggesting heterogeneity in spatial accessibility. In the current phase, they are losing their median integration role and have a narrower distribution, which indicates that they have altered from structural connectors to more localized green spaces and shifted as transitional green spaces between the ancient fortification and later alteration of the city. However, they remain their ecological contribution to the city, although in very different direction.

Green spaces located other than those within the urban fringe belt have historically highest mean and median integration values, which suggests strong integration variations with higher values. Although their influential role in historical integration is prominent, in current state they show a greater predominance of lower integration values that affect the reduction in upper integration values. These results highlight that their structural dominance is fragmented and that they have lost their significance, with relatively reduced stability during the formation of the current urban fabric.

Green spaces in the intermediate fringe belt show moderate median integration historically, which reflects their functions as elements of urban expansion. In current phase, there appear low integration outliers and increased dispersion between the values. These results reflect that peripheral expansion has resulted in these green spaces to primarily serve for local users and to be likely low integrated within the entire spatial integration.

Box plot analysis shows that in Novi Sad, Figure 40(b), there appears to be a relationship between the distribution of green spaces and the integration levels with modern urban planning principles. While, the inner fringe green spaces had the highest median integration and the highest variation in integration in the 20th century, they have substantially lost their integration role and their variability in current phases. These results reveal

fragmentation of green spaces within this fringe belt formation, but they still preserve their functionally, possibly due to remnants of earlier urbanization acts, which partially resulted in discontinuous green corridors and the planning resilience of green spaces in the historic urban fabric.

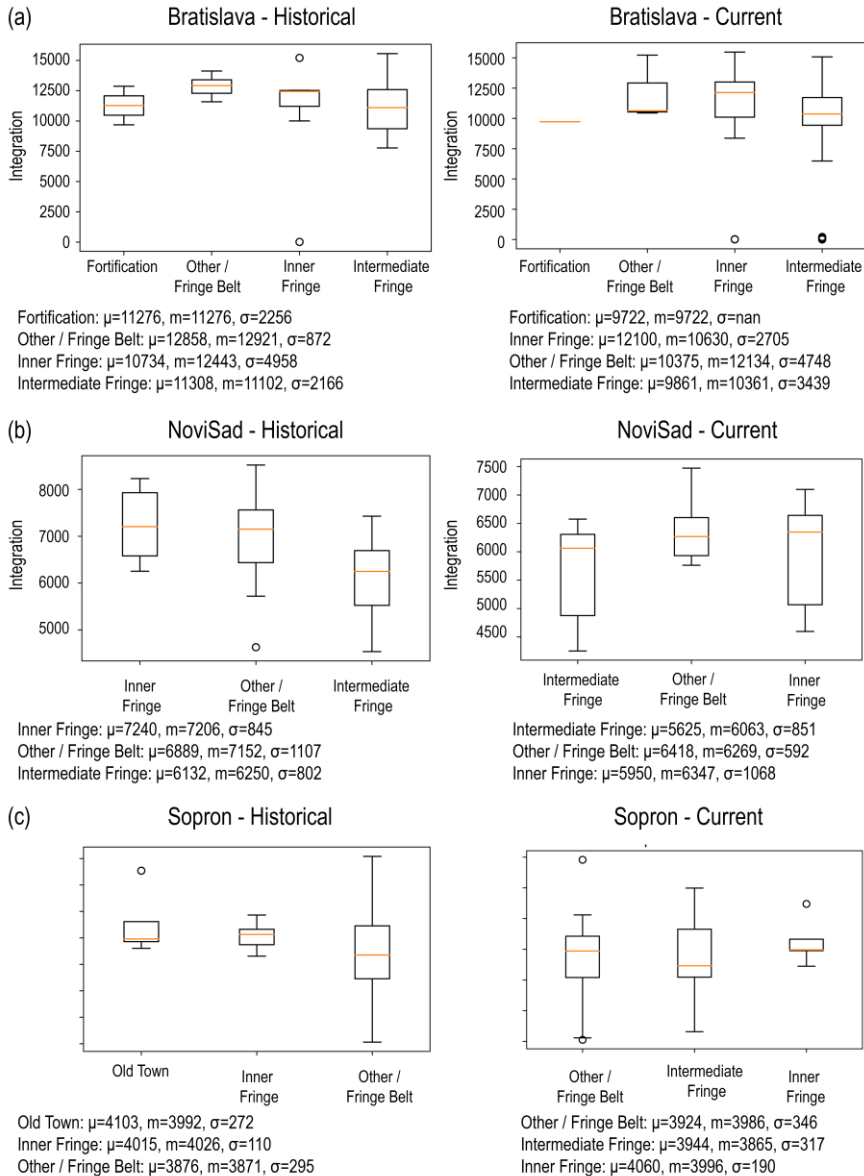


Figure 40. Statical distributions of urban green spaces and their fringe belt formation for the map period of 20th century and current.

Nevertheless, the results also reveal that greens spaces other than those within the urban fringe belts exhibited the highest mean and median integration values historically. These green spaces are spatially embedded into transition areas in current state, which is depicted in the reduction of both their median and mean integration values, and an increasing in clustering around the lower integration values. The results highlight that integration is varying in resolution, which suggests fragmentation toward more suburban development.

On the other hand, the urban green spaces in the intermediate fringe belt show the lowest mean and median values in the current state, reflecting greater fragmentation. The results reveal that spatial disconnect in green spaces is more apparent. This can be attribute to less connected green spaces and low functional integration in the expansion areas are influenced by urban planning intervention and significant changes in the direction of development.

In the case of Sopron city, Figure 40(c), the fringe belt development mostly reflects medieval city development, in which the inner core has survived for centuries. In response, the inner fringe belt came into being at the edge of the historic core. It is intelligible as a response to the first expansion of the city border, resulting in the formation of this fringe belt, as the burgeoning of green spaces at the urban core periphery for public purposes is associated with the fluctuation of urban land use development. Pressure for development toward the outer part of the inner fringe zone is a reflection on planning practice in relation to green fringe belt development, which has led to fragmented green areas, notably the growth of built-up areas.

We also noted, based on the global integration analysis of the Sopron city case Figure 40(c), that the urban fabric has been historically preserved where the integration of urban green spaces is consistent. The variability of the parks is limited in the inner fringe belt; these areas are more connected with moderate median integration value to the historical urban structure. This suggests a highly consistent, distinct, and historically preserved zone, with restrictions in urban form and fixed development boundaries.

In contrast, the parks in the intermediate fringe are located surrounded by the inner core; this indeed confirms the integration transition with moderate median. However, in the outer intermediate fringe recorded very wider dispersion in integration pattern of green spaces. This suggests that urbanization is more prominent, and green spaces are more dispersed, leading to their connectivity variability.

6.4 Empirical testing of palimpsest methodological proposition through artificial intelligence, deep learning and urban morphology

This chapter will demonstrate the result of the empirical testing of the palimpsest method through the methodological link between the urban morphology, deep learning and artificial intelligence in case of the Istanbul, historical peninsula, to identify patterns a Convolutional Neural Networks (CNNs) based (automatic segmentation using OpenCV and NumPy in Python) on both historical and contemporary map sources, their types of patterns will be investigated through the human based urban morphological analysis, and artificial intelligence. The testability of falsifiability of the findings will be evaluated by artificial intelligence.

Specific regions or units have been already identified in the Section 5.1.3 that demonstrate significant historical stratification, or regions are demonstrate significant changes in the contemporary setting (Layer E formation) in Istanbul. Four world heritage sites as covered; 1. Sultanahmet Archaeological Conservation Park (SA); 2. Suleymaniye Mosque and its associated site (SC); 3. Zeyrek Mosque (Pantokrator Church) and its associated site (Z); and 4. Istanbul Land Walls Conservation Site (LW), were delineated and used as guide to determine and identify tissue based information for the identification of the inherited patterns in the most significant change zone. The identification process follows principle of compositional hierarchy; the elements and their relationships within a hierarchy, that could be able to make urban tissue analysis in change zone, which is defined as a zone in urban conservation area that covering the Hobyar, Tahtakale, and Rüstempaşa neighborhoods – Eminönü coastal zone (E). Accordingly, urban tissue analysis is specified as: identification of the streets and routes; and then identification of blocks and parcel series geometric features; and lastly plots and buildings were identified in qualitative and quantitative ways – such as blocks and plots dimensions, and blocks and plot types.

6.4.1 The results of the urban tissue analysis based on qualitative and quantitative identification of the streets, blocks, plots and buildings

The identification of the street types has been characterized by the analysis of the geometrical and topological properties of routes or streets for each selected heritage sites. Accordingly, the types have been determined as: primarily strategic route, secondary strategic route, territorial strategic route, thoroughfare; through loop; tree-like, cul-de-sac, and end-loops.

The angular connection of those streets and routes have revealed types of blocks, resulted in the identification of the block boundaries with their distinct morphometric characteristics – such as block areas and block

shapes. Accordingly, types of blocks have been identified as: rectangular, polygonal, triangular, trapezoidal, polygonal-shaped or irregular-shaped. Each block has been characterized by different plots, and their combination has been characterised by building patterns (typology). The plots patterns have been identified as narrow and shallow, , narrow and deep, wide and deep, and wide and shallow. The building patterns that have give the block typology have been characterised as: courtyard, multi-courtyard, detached, semi-detached, and landmark.

The extracted leading types or unique types for the zones of the Sultanahmet Mosque and Hagia Sophia (SA – Sm, and SA - Hs), the Suleymaniye Mosque and its surrounding zone for (SC), the Zeyrek Mosque and the settlement tissue covering the mosque for (Z), and the Tekfur Palace of the Land Walls (LW – Tp) are indicated in Table 11.

Table 11. The results of the leading types of urban tissues and their pattern types.

Tissue type	Code	Street types	Plot types	Block types	Building types
Sultanahmet Mosque and Hagia Sofia	SA - Sm and SA-Hs	Primarily strategic route; Thoroughfare; Through Loop; Tree-like / Cul-de-sac	Wide and Deep; Narrow and Deep; Wide and Shallow	Irregular; Polygonal; Square; Rectangular; Trapezoidal; Triangular	Landmark; Courtyard; Multicourtyard
Suleymaniye Mosque	SC	Thoroughfare; Tree-like; End-loops	Wide and Deep; Narrow and Deep; Wide and Shallow	Irregular; Polygonal; Square; Rectangular	Landmark; Courtyard; Multicourtyard
Zeyrek Mosque	Z	Through Loop; Tree-like; End-loops	Narrow and Deep; Wide and Deep	Irregular; Trapezoidal	Landmark; Courtyard; Multicourtyard; Detached
Tekfur Palace	LW-Tp	Primarily strategic route; Thoroughfare; Through Loop; Tree-like; End-loops	Narrow and Deep; Wide and Shallow	Irregular; Trapezoidal; Triangular; Rectangular; Polygonal	Landmark; Courtyard; Multicourtyard; Detached
Hobyar; Tahtakale; Rustempasa Neighbourhoods (Eminonu Coastal Zone)	E	Primarily strategic route; Thoroughfare; Through Loop; End loop	Narrow and Shallow; Wide and Deep	Irregular; Polygonal; Trapezoidal	Landmark; Courtyard; Multicourtyard

The results reveal that seven unique route and street types has been appeared as: primarily strategic route (SA; LW; E), , through loops (SA; Z;

E), thoroughfare (SC; LW; E), tree-like (SC, LW), cul-de-sac (SA, SC, Z, LW), and end loop (SA).

The results also indicate that heritage blocks are generally surrounded by courtyard-type complex buildings. This is in some way in harmony with the courtyard-type typologies around it. Especially the typologies (SC), (Z) and (E), and the typology of the built environment around them, are mostly courtyard type or multiple courtyard type. The building patterns attributed in blocks have been characterized as detached type, without forming a certain shape. Those typologies are only found in the tissue zones (Z, and LW–Tp). This makes the formalization of a pattern language logic in the case of the historical peninsula from those areas, typologically based, logical. On the other hand, SA-Sm and SA-Hs case vary with contemporary and historical patterns, which promises the distinctions of new patterns (additions).

Based on these results, patterns have been identified at the contemporary setting the (E) case for the street, block, plots and buildings level and have been also indicated in Table 11.

After that, pattern recognition process has been applied within the highest levels of specificity for the E case (change zone). The recognition for this resolution is covered with the block-level separation. The maps used for this area corresponding the period of 20th century.

Several steps have been followed for the pattern recognition. As a first step, blocks have been counted for each period and for identification of types, demonstrate the results both spatially (Figure 41) and temporally (Table 12). After that, patterns recognition logic has been formulated to define the stability of a block type over time based on the trend score.

Calculation of the Trend Score (TS) is formulised as:

$$= \frac{(1940 - 1906)/1906 + (2025 - 1940)/1940}{2}$$

Table 12. Types of blocks in (E) and their counts for the periods of 20th century and actual, and their trend scores.

Block types	1906 (n=117)	1940-41 (n=112)	2025 (n=63)	Trend Score (TS): 1940- 1906	Trend Score (TS): 2025- 1940	Trend Score (TS)
Irregular	28	30	8	0.0714	-0.7333	-0,331
Polygonal	27	32	35	0.1852	0.0938	0,139
Rectangular	16	3	6	-0.8125	1	0,094
Square	2	0	0	-1	0	-0,5

Triangular	1	2	0	1	-1	0
Trapezoidal	43	45	14	0.0465	-0.6889	-0,321



Figure 41. Spatially identified types of blocks in (E) for the periods of 20th century and actual (above), and their trend scores (below).

The results indicate that irregular, polygonal, rectangular, and trapezoidal pattern types can be recognizable, while each of them shows increased or decreased trends over time. The positive trend is only identified within the polygonal type. Rectangular type demonstrates significant decline between the periods of 1940 and 1906 but can be found in the contemporary setting. Irregular and triangular types have declined

trend values around - 0.3, but they remain. There is no long-term persistency for the square and triangular block typologies.

This identification process is also to be taught to artificial intelligence to determine where the change in urban structure is significant over time and to identify own urban tissue types. This kind of structure guide to AI-based pattern identification (no human in the process) to identify types based on their spatial and historical characteristics. This approach contributes to palimpsest method to accurately test the results both obtained from the quantitative and qualitative way (textual knowledge) about the morphological and historical characteristics of settlements. That information will be given to AI as inputs.

But it is noted that, AI could be established logic thinking, if the inputs are clearly defined by the human logic with the strong unsupervised learning methods, and if the hierarchical logic that is considered for the pattern recognition is systematically conceptualized.

6.4.2 Pattern identification at the highest levels of specificity – Deep learning and Artificial intelligence assessment

To initiate the pattern identification process at the highest levels of specificity, Automatic Semantic Segmentation (ASS) analysis using the Python and OpenCV (cv2) environment was applied to both historical maps and contemporary map sources. The used Python code for automatic segmentation based on CNN is provided in Appendix 3.

These map sources were converted into machine-readable vector format, which help the transformation of the unstructured map data to structured data. Structured data makes easy the identification process of the urban tissue types by AI. AI have perfect understanding of map features from this cleaned data sources. The 18th and 19th centuries maps were used to detect where spatial change is significant at the lowest levels of resolution. The scale of these maps is very high, so it just gives the opportunity to detect changes at the street and block level.

The maps used for the pattern identification analysis cover the periods of the 20th century because their scale represents more details about the urban morphology, and the CNN model is not struggling to capture the pattern structures.

The obtained semantic maps are fed into the AI, GPT-4o environment, and three distinct prompts were developed for the interpretation of the maps that represent spatial geometry by segments.

The role of the AI is the reasoning agent for the pattern recognition. GPT-4o AI model was used, because of its technology allows to read the multimodal inputs such as visual and linguistic data types and to generate

integrated reasoning over those data from various types rather than for autonomous pattern extraction.

Table 13-14 demonstrate the semantically segmented historical and contemporary maps generated through CNN-based image processing in Python. Those maps were used as input to the AI, supported with structured textual descriptions that contained information about the human based identification of the urban tissue.

The interaction with AI followed a prompt-based strategy which is designed to guide identification within predefined morphological criteria. Prompts were formulated to restrict the analysis to spatial and structural characteristics. The exact wording of prompts is used is provided in Appendix 4.

Table 13. The changes zones are highlighted with red boxes based on the AI identification. The area for the investigation at higher level of specificity, which corresponds to the urban conservation zone, is highlighted with a blue box which demonstrates most significant change zone. Source: Historical base maps were obtained from Salt Research, Map Archive: François Kauffer, Plan de la ville de Constantinople et de ses faubourgs tant en Europe qu'en Asie (1786), Identifier: APLKA01; and Ekrem Hakkı Ayverdi, 19. yüzyılda İstanbul'u gösteren haritalar (1875–1882), courtesy of IFEA. Used with permission from Salt Research. Segmentation, overlay analysis, and change-zone identification were produced by the author. Google Satellite imagery, 2025, was used as the contemporary reference.

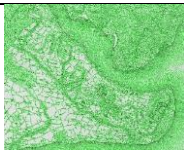
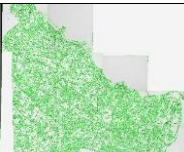
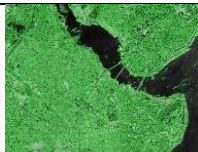
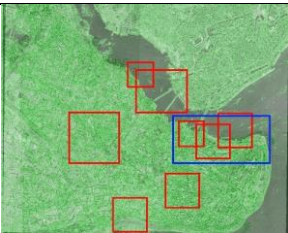
Segmented Maps			Overlay map highlighting the most significant change zones
François Kauffer (1786) Scale: 1:2000	Ekrem Hakkı Ayverdi (1875–1882) Scale: 1:2000	Google Satellite (2025)	
			

Table 14. CNN outputs of segmentation results of 20th century maps for the pattern recognition process. Source: Historical base maps were obtained from Salt Research, Map Archive, courtesy of IFEA: Charles Edward Goad, Plan d’assurance de Constantinople. Vol. I – Stamboul, Nos. 4, 5, 6, 8, and 9, Identifiers: APLGDSTAM04, APLGDSTAM05, APLGDSTAM06, APLGDSTAM08, and APLGDSTAM09; and Jacques Pervititch’s Eminönü insurance/real-estate plans. Used with permission from Salt Research. CNN-based segmentation outputs were produced by the author. Google Satellite imagery, 2025, was used as the contemporary reference.

Segmented Maps		
Charles Edouard Goad’s Istanbul Insurance Maps – 1906 Scale: 1:600	Jacques Pervititch’s insurance maps - 1940-41 Scale: 1:500	Google Satellite (2025)
		

The first prompt was directly asked GPT-4o to determine any changed zones at the lowest resolution level based on the spatial geometry of the streets and blocks from the overlay of the maps of different time periods. The scales of those map periods are extensive and CNN able to segmentize the zones across the historical peninsula. An obvious aim is to increase the AI ability to detect where the added, removed, or modified street networks appeared.

The findings confirm that AI reason-based determination of the tissue zones result (as shown in Table 13) typically parallels the urban tissue typologies of the world heritage sites (remain) and urban conservation zones (changed or modified). The results also indicate that the need for AI and machine learning tools to develop a historical stratification model, which depends on the readability of the urban morphology that forms the basis for the pattern recognitions and typological comparison of the settlements.

Second prompt were requested AI to define its own types at the highest levels of resolution based on the output of the CNN model of the segmentation results of the 20th century maps (as shown in Table 14) and input of textual knowledge (results in the Section 6.4.1) about the

morphological characteristics of tissue zones given to AI for accurate identification.

The matching results of human and AI-based identification of the urban patterns are shown in Table 15. The results revealed that AI was able to reason (identify) pattern types both spatially and temporally and demonstrated perfect agreement with the human-based identification, with only some minor differences within the streets and plots typologies. AI and human perfectly agree for the type of buildings identification since they used almost the same vocabulary for this level of identification across all tissue zones. But artificial intelligence needs more deepened knowledge about the identification of the street patterns and plot patterns.

Table 15. The matching results of human and AI-based identification of the urban patterns over time for the tissue zone of Hobyar, Tahtakale and Rustempasa - Eminonu costal - (E). Matching results is determined according to how AI well captured urban patterns recognition compared with human knowledge. If AI identified types nearly match the human, the score is Perfect; if AI shows almost same knowledge, score is Strong; if AI and human assessment is less overlap, score is Partial; and if there is no overlapping result, score is Never.

Map-Period	Observed Street types (Human)	Observed Street types (AI)	Matching Result
Charles Edouard Goad's Istanbul Insurance Maps - 1906	Thoroughfare; Through-loop; Cul-de-sacs / Dead Ends	Primarily strategic route; Secondary strategic route; Thoroughfare; Cul-de-sacs / end Loops	Partial
Jacques Pervititch's insurance maps - 1940-41	Primarily strategic route; Secondary strategic route; Thoroughfare; Cul-de-sacs / Dead Ends	Primarily strategic route; Secondary strategic route; Thoroughfare; Cul-de-sacs / Dead Ends	Perfect
Map of Municipality - 2024	Primarily strategic route; Thoroughfare; Through Loop; End loop	Primarily strategic route; Secondary strategic route; Thoroughfare; Cul-de-sacs / Dead Ends	Partial
Map-Period	Observed Plot types (Human)	Observed Plot types (AI)	Matching Result
Charles Edouard Goad's Istanbul Insurance Maps - 1906	Narrow and Deep; Narrow and Shallow	Wide and Sahllow; Narrow and Deep	Partial
Jacques Pervititch's insurance maps - 1940-41	Narrow and Deep; Narrow and Shallow; Wide and Shallow	Narrow and Deep; Wide and Shallow	Strong
Map of Municipality - 2024	Narrow and Shallow; Wide and Deep	Narrow and Deep (Dominant); Narrow and Shallow (Some); Wide and Deep; Wide and Shallow (Limited)	Partial
Map-Period	Observed Block types (Human)	Observed Block types (AI)	Matching Result
Charles Edouard Goad's Istanbul Insurance Maps - 1906	Irregular; Square; Trapezoidal; Polygonal; Rectangular; Triangular	Irregular; Rectangular; Triangular	Partial

Jacques Pervititch's insurance maps - 1940-41		Irregular; Square; Trapezoidal; Triangular	Polygonal; Rectangular;	Irregular; Rectangular; Triangular; Polygonal	Strong
Map of Municipality - 2024		Irregular; Trapezoidal	Polygonal;	Irregular; Polygonal; Rectangular; Trapezoidal; Triangular	Perfect
Map-Period		Observed (Human)	Building types	Observed Building types (AI)	Matching Result
Charles Edouard Goad's Istanbul Insurance Maps - 1906		Landmark; Multicourtyard; Detached	Courtyard;	Landmark; Multicourtyard; Detached	Perfect
Jacques Pervititch's insurance maps - 1940-41		Landmark; Multicourtyard; Detached	Courtyard;	Landmark; Multicourtyard; Detached; Semi-Detached	Perfect
Map of Municipality - 2024		Landmark; Multicourtyard	Courtyard;	Landmark; Multicourtyard; Detached; Semi-Detached	Perfect

Final prompt was asked to AI to create decision logic based on obtained tissue typologies that identifies which patterns from the 20th century persist over time. This process enables pattern recognition analysis systematically. Figure 42 shows comparative decision logic between humans and AI.

In Table 12, the stability of a block type have been already defined over time by using a Trend Score model. Based on human logic, polygonal blocks represent the most stable type; on the other hand, rectangular typology exhibits medium partial stability. Conversely, block types – irregular, square, triangular, and trapezoidal – follow low persistency, with a trend of zero in the case of the square and triangular types. However, AI results show almost the same results with a different interpretation. AI indicates that the polygonal type not only has an increased (upward) trend but also contributes to the direction of the development.

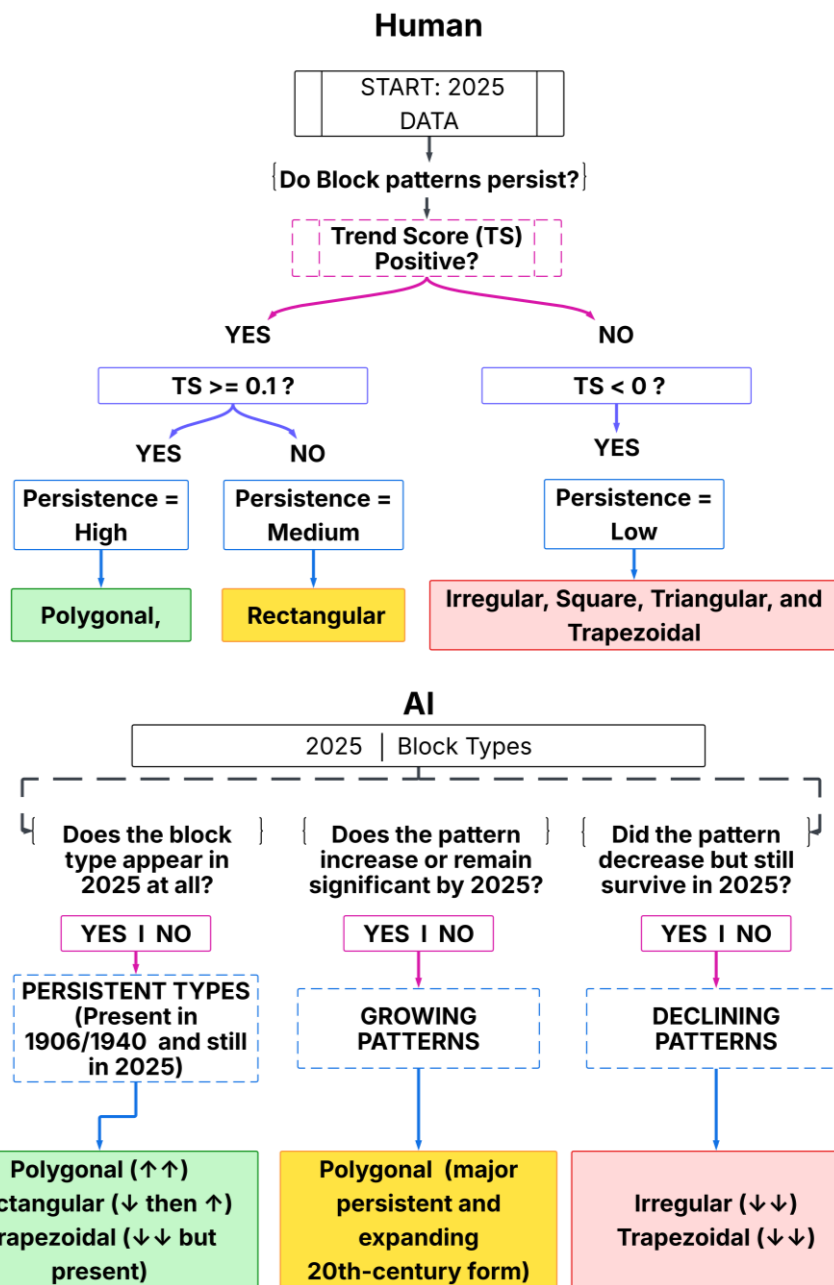


Figure 42. A comparative decision logic of the pattern recognition between the human and AI.

Chapter 7: Discussion and Conclusion

7.1 Findings and Limitations

In this dissertation, a comprehensive and a novel method was developed to investigate historically layered cities through morphological, qualitative, and quantitative analysis. It combines the historico-geographical approach with remote sensing approach through a longitudinal study. It also combines the Caniggian typomorphological approach with the configurational approach and the nascent application of deep learning in urban morphology. In this way, the method brings current technological advancements into research that integrates artificial intelligence with urban morphology.

In this study, a methodological contribution was developed by extending the qualitative and quantitative investigation of urban form through GIS and statistical analysis. This was done to obtain comprehensive information about the transformation process. The spatiotemporal layering process combines the advantages of both descriptive and analytical frameworks and demonstrates the reliability of measurable components of urban form. This enables the analysis of geometric characteristics embedded within a period, thereby increasing our understanding of the distribution of variables over time and the dynamics of urban transformation. Furthermore, the incorporation of numerical variables from different elements and temporal dimensions reveals that changes in one element are not separate but interlocking.

The method was based on the temporal and spatio-temporal layering of different map sources (cartographic, earth and vectoral data) and their preprocessing in GIS environments. The key strength contribution lies in this method is its innovative solution for preprocessing historical maps. It employs Automatic Semantic Segmentation based on Convolutional Neural Networks for the historical stratification model. The OpenCV and NumPy libraries in Python were leveraged to optimize the map data and correct pixel distortion.

Descriptive and analytical approaches to urban morphology form the core of this method. They were used to quantify patterns at different levels of scale, including land cover, morphological unit, streets, blocks, buildings and green spaces. These patterns were examined within different time periods and different geographical context and were qualitatively described. Supervised learning was used for the recognition and classification of patterns. The outputs of the quantitative morphological analysis were obtained through statistical analysis, revealing measurable

variables – area, lengths, elongation, and integration – at different levels of scales.

The main body of the method describes the formation and transformation processes of places by examining the persistence or change of patterns in structural and numerical parameters. K-means and hierarchical clustering methods were used to simplify these parameters. This enables the identification of correlations between changes in topological parameters and transformation process. But, it also proved that changes in numerical parameters within a particular level are not always related to transformation process.

The results validated the potential of computational tools that perform quantitative analysis – descriptive statistics and inferential statistics – to identify urban patterns as human do. The findings proved that the proposed method showcases a robust and reproducible framework for examining urban patterns. It also provides a reliable means to model historical stratification process in different cities by quantify and automating urban morphology through supervised (deep learning) and unsupervised technique (clustering).

Furthermore, the empirical testing of the palimpsest methodological propositions validated that artificial intelligence technology significantly improves the identification and recognition of patterns at different scales, both within a certain period and across periods. Another key advantage of AI in this method is its ability to discriminate patterns that exhibit persistence or change based on a human generated prompt strategy derived from the core structure of the method.

I believe that the proposed method, based on the interaction between urban morphology, deep learning, and artificial intelligence, could contribute to a more comprehensive knowledge on urban morphology. It could also provide a new direction for other studies, especially in attempt to develop robust alternatives for examining the formation and transformation processes of cities.

Nevertheless, some methodological issues needed to be addressed. First, the cartographic maps used for the case studies contained limited information on urban morphological properties. Most of them has scanning related distortion, which made the georeferencing process and detection of block divisions and buildings difficult. Second, there was a lack of sufficient reference points for determining Ground Control Points (GCPs) and accurately aligning the spatial features of cartographic maps with the desired coordinate systems.

To address these issues, textual data from cities (unstructured data) may need to be integrated into the analysis of different aspects of cities. A

similar approach is proposed by Reades et al. (2025). Therefore, the robustness of the palimpsest method should be evaluated through further exploration. This could involve using recent advancements in computational tools and leveraging the artificial intelligence technology to integrate textual data from cities. Such an approach could help address problems related to the temporal understanding of the cities by combining structured spatial data with unstructured urban data.

Land monitoring services have received limited attention in urban morphology as well. Existing research often describes patterns of land cover and changes in urban growth, but most studies tend to less integrate this level of resolution to interpret morphological structural, formation, or transformational processes at higher levels (Antoni et al., 2019; Batty and Xie, 1994; White and Engelen, 1993). The method in this dissertation offers a multi-level, multi temporal, and interdisciplinary approach. It evaluates the relationship between changes in and persistence of land cover types to determine urban morphological specificity – the morphological unit. It could also reveal the relationship between the degree of historical stratification and morphological unit differentiation.

A gap was noted in the theoretical discussions in the literature review. There is a need to strengthen current spatial analysis methods in urban morphology, such as cellular automata and fractal methods. These could be used as complementary methods to enhance the observation, simulation and analysis of the urban form and quantifications of the changing patterns.

Despite the progress made in this study, the approach has some methodological and algorithmic limitations, particularly when CNN models are applied at the scale of an entire city and during the prompt generation process. Algorithms can generate meaningful and accurate results if fed by domain knowledge grounded in human expertise. Unpredictability in data sources may affect the accuracy and reliability of the results.

I have suggested that even researchers who do not have knowledge of new technological tools should begin to ask how these tools can be adopted to existing approaches. They should also consider how to use them wisely and purposefully.

A further goal is to create a comprehensive deep learning model based on Conventional neural networks. The model will integrate a U-Net architecture with a ResNet50 backbone using Python. It will be able to detect and analyse urban patterns at multiple scales using high resolution arial imagery. By leveraging artificial intelligence, the model will identify

different urban tissue types and distinguish between them based on prompts generated through urban morphological analysis.

7.2 Scientific Thesis and New Contributions

Thesis statement 1. The palimpsest method effectively analysed historical stratification in cities, revealing urban patterns that traditional approaches could not fully identify.

I demonstrated that the proposed palimpsest method contributed to analysing the historical stratification process of different cities, because it revealed urban patterns, whether persistent or changed across different spatial and temporal layers, for the different case studies that traditional qualitative and quantitative approaches in urban morphology alone could not fully identify.

Thesis statement 2. Quantitative analysis with computational tools can identify urban patterns.

I pointed out the potential capability of quantitative analysis with computational tools for the identification of urban patterns - as descriptive approaches within the urban morphology do.

Thesis statement 3. Correlation between topological parameter changes is related to the transformation process, but numerical parameter changes within a level are not always related.

I revealed that the correlation between the changes in the topological parameters is related to the transformation process, but I also revealed that changes in the numerical parameters within a level are not always related to the transformation process.

Thesis statement 4. Qualitative, quantitative, and statistical analysis can describe historical morphological characteristics, but translating quantitative findings into perceived space dimensions is limited. Isovist and visibility analysis are suggested to simulate historical places and validate architectural heritage elements.

I demonstrated that the combination of the qualitative, quantitative and statistical analysis can describe and identify the historical morphological characteristics, but they remain limited in translating quantitative morphological findings (changes or persistency) in two-dimensional spaces into the perceived space dimension. Therefore, I suggested isovist and visibility analysis as empirical testing of the proposed method to simulate the historical places based on an observer's experience in different time

settings and to validate the geometry of the spaces and foundation of the architectural heritage elements.

Thesis statement 5. Empirical testing shows the palimpsest method, combined with deep learning and AI, outperforms other methods for identifying and recognizing elements across different scales and periods.

I also demonstrated that the empirical testing of the palimpsest method with deep learning and artificial intelligence technology significantly outperforms for the identification and recognition process of elements at different levels scales within a certain period or across the periods.

Thesis statement 6. AI technology was used to read large data sets, proving the palimpsest method to discriminate patterns of persistence and change based on human prompts.

I proved the palimpsest method/technique reported in literature by reading the large data sets with AI technology to discriminate patterns that exhibit persistence and change based on the prompts generated by humans.

7.3 Possible Directions for Further Research

The avenue of further research based on the objectives presented in this methodological dissertation is wide. One direction could further study the different interrelated aspects of the urban form, such as details of the built environment that are the transformation of the natural features through deliberate application of human energy to suit human needs and purposes, while other could focus on the aspects of the built environment that defined by the flows of energy and resources related to the temporal dimensions. Starting with the multi-level and multi-scale direction of the palimpsest technique and proposed modular method, further research should interconnect different theories of urban form as the branches of a tree and support each other at many points with the direction of the Kevin Lynch's and Karl Kropf's ideas (Kropf, 2017, p. 20).

The analysis carried out in this dissertation in urban morphology should extend its focus towards to the substance out of built environment is made, which is the natural environment change. Therefore, further research should focus on the question of the exact context of the formation of towns. The question of metabolic processes such as hydrological cycles, geology, topography, flora, fauna, and climate, that have developed around the built environment could reveal the ecological layers that may contribute to ecological restoration, or flood modelling. Such inclusion of natural infrastructure data could open a potential pathway of research linking

morphological persistence with complex characteristics of built environment, which would strengthen the practical implications of the palimpsest methodology for sustainable and climate resilient urban development.

Chapter 8. Summary

The main aims of the palimpsest method in this study was to investigate the spatiotemporal characteristics of historically stratified cities at different levels of resolution and different levels of specificity. The CLC based land cover maps captured the persistency of regions, defined as land cover types within a cell, through a persistency score. The score of $p=4$ was assigned based on the frequency of land cover types within regions. It demonstrates the highest persistency threshold within certain spatial units. Areas below this score could not be assigned as morphological unit.

Furthermore, the determination of morphological units based on this scoring system facilitates integration with the historico-geographical approach. It enables the analysis of morphological units' differentiation according to Conzen's historical stratification principle. This allows the delimitation of persistent or changed zones in urban form beyond qualitative investigations.

The findings reveal that morphological unit formation is hierarchical and that the transformation of its fabric is gradual. This transformation varies according to the different quantitative and qualitative attributes of each element. Previous studies reported that there is part to whole and part to part relationship in the emergence of urban fabric. These relationships extend from buildings to blocks, blocks to streets, and street to urban tissue (morphological regions). Changes in one pattern can promote the differentiation of another pattern and cause it to gain new characteristics.

Therefore, the preservation of the basic backbone of cities is highly relevant. This backbone corresponds to the structure of the street network or street configuration and its relationships within the hierarchical structure. Appendix 5 provides summary statistics in a table. It presents the distinct patterns of shape, size, and integration persistency ranges. These are defined as value intervals that overlap across periods in the KA and SM regions.

The statistical results suggest that, in Bursa, the predominant bulk of street integration is 25-45. This corresponds to the mid-integration range and shows strong persistency across the three periods through overlapping values. Lower integration values of 5-25 have remained from 1857 and

1912, dominant into the current period. However, their spatial presence is weak but continuous.

In case of Edirne, there is a clear overlapping range towards to higher integration values that display a more stable street integration. Street integration ranges between approximately 120-160 reflect very strong persistency that remains in all periods. The observed low integration values from 1854 are largely absent in the contemporary setting.

The range differences are evident in the results of the clustering analysis. The differences in street age and street type in clusters where the landmarks are located show statistically similar patterns compared to the surrounding region, but they also display a more diverse distribution of patterns. This confirms that the street network hierarchy is influenced by modernist planning practices, while the historic core has maintained its organic structure due to the preservation of the monuments' layout, reflecting the persistence of the city's basic layout and plans. Streets around the heritage surroundings are designated to have a high level of correlation to the subsystems, enhancing the configurational properties of the heritage sites.

There seem to be primary reasons in the street integration ranges in two cities difference is statistically significant that Bursa is the oldest capital city and street systems are shaped around the marketplace that local streets can not match the routes directly. The central mosques create larger open spaces, and in turn effect the street network's integration threshold, as depicted in the SM case the higher integration is structured around the Selimiye mosque which is structure dominated the characteristics of the morphological region.

Block area and block elongation distributions show strong morphological continuity across the periods, with persistency range in shape and size values are evident in both morphological regions. The medium size of the blocks was preserved their ranges in all three periods for the two morphological regions. The strong persistency ranges in block area in KA (3.6 – 4.2) and SM (3.51 – 3.67) that constantly constituted dominate distributions of size of the blocks, that reflect preservation of the morphological structure in the central part of those regions. These findings add to the correlation between the persistency in street integration with the preservation of the block structure is evident.

Moreover, the spatial continuity of the green areas across the periods for the case of KA differ significantly but the level of scale remains remarkable stable. The finds suggest that while transformation process occurs the environmental functions of the urban green areas are preserved in the spatial configuration of the city.

The findings from the empirical testing of this approach in different cities, presented in Sections 6.2 and 6.3, confirm that the preservation of street integration is crucial for achieving a palimpsest structure of spaces. At the same time, the transformation of the urban fabric continues through correlations between elements at upper levels.

The robustness of the method was evaluated in case of the Istanbul Historical Peninsula. The results confirm that increases and decreases in visibility metrics provide strong empirical evidence of changes in urban tissue. These changes occurred in response to changes in the spatial configuration of the buildings. The diminishing effects on the observer's experimental spaces also affect the intelligibility of built heritage.

The findings highlight that blocks, plots, and building patterns found in each selected tissue zone play a critical role in the recognition of types and the maintenance of leading patterns in a city. AI successfully captured the objects from the map through CNN-model-based semantic segmentation analysis.

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List of Publications related to thesis

- Sarihan, E.**, 2021. Visibility Model of Tangible Heritage. Visualization of the Urban Heritage Environment with Spatial Analysis Methods. *Heritage* 4, 2163–2182. <https://doi.org/10.3390/heritage4030122>
- Sarihan E.**, 2022. The Concept of the Urban Palimpsest. The Urban Fabric Transformations in Inherited City image. W: XXIX International Seminar on Urban Form. ISUF 2022 Urban Redevelopment and Revitalisation. A Multidisciplinary Perspective. 6th June – 11th September 2022, Łódź–Kraków, Kantarek A.A. (Ed.), Hanzl M. (Ed.), Figlus T. (Ed.), Musiaka Ł. (Ed.), Lodz University of Technology Conference Proceedings No. 2554, Lodz University of Technology Press, Lodz 2023, p. 1424-1437, ISBN 978-83-67934-03-9, <https://doi.org/10.34658/9788367934039.114>
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Appendix

Appendix 1.

Identification of the gaps in most existing literature

Reference	Method(s) Used	Descriptive (Qualitative)	Analytical (Quantitative)
Al-Doski et al. (2013)	Image classification methods, remote		+
Alexander (1977)	Pattern language	+	+
Alexander (1979)	Pattern language	+	+
Bartie (2011)	Visibility modelling and GIS		+
Batty (2001)	Isovist analysis		+
Batty (2009)	Network analysis		+
Batty (2013)	Network analysis	+	+
Batty and Longley (1994)	Fractal analysis		+
Benedikt (1979)	Isovist analysis		+
Caniggia (1963, 1979)	Typological approach	+	+
Conzen (1960, 1988)	Historico-geographical approach- Town plan analysis	+	+
Cullen (1961)	Aesthetics townscape analysis	+	
Di Gregorio (2005)	Land cover classification		+
Dibble et al. (2015)	Urban morphometrics		+
Herold et al. (2002)	Landscape metrics		+
Hillier (2014), Hillier and Hanson (1984)	Space syntax analysis	+	+

Reference	Method(s) Used	Descriptive (Qualitative)	Analytical (Quantitative)
Huang et al. (2007)	Spatial metrics and remote sensing		+
Kropf (1993, 2009, 2014, 2017a, 2017b)	Typo-morphological approach: Combination of the typological and	+	+
Lopes et al. (2019)	Co-visibility analysis		+
Lovra (2016, 2018)	Integrated method of urban morphology	+	+
Lu & Weng (2007)	Image classification methods		+
Lynch (1964, 1972)	City image and perceptual urban analysis	+	+
Marshall (2004), Marshall and Gong (2005)	Street networks and street patterns analysis		+
Moudon (1997)	Typo-morphological approach: Combination of the typological and	+	+
Muratori (1960)	Typological approach	+	+
Ogburn (2006)	Visibility analysis		+
Oliveira (2013, 2016)	Integration of different morphological approaches	+	+
O'Sullivan and Turner (2001)	Visibility analysis		+
Rossi (1984)	Urban and architectural analysis	+	
Schirmer and Axhausen (2016)	Multiscale classification of urban		+
Schmidt (2017)	Land cover classification		+
Scrase (1989)	Burgage plots and townscape analysis		+
Slater (1981, 1989)	Burgage patterns analysis	+	+
Strappa (2018)	Typological and morphological analysis for architectural and urban design method	+	
Venerandi et al. (2017)	Urban morphometrics		+
Vialard (2013)	Blocks based typological and morphological analysis		+

Reference	Method(s) Used	Descriptive (Qualitative)	Analytical (Quantitative)
Whitehand (2012, 2009, 2010, 2019)	Historical geographical approach	+	+

Appendix 2.

Permission Correspondence for Historical Maps: permission for the use of the following historical map materials was requested and obtained from Salt Research.

Historical map materials covered by the permission:

“Bursa şehri harita mufassalası”

Identifier: APLMUHBUR001

Link: <https://archives.saltresearch.org/handle/123456789/12204>

Salt Research, Map Archive

“Bursa şehrinin harita-i manzûmesi (Mikyas 1:8000) / Plan officiel de la ville Brousse / Official city map of Brousse (Bursa)”

Identifier: APLKIT001

Link: <https://archives.saltresearch.org/handle/123456789/111021>

Salt Research, Map Archive

Charles Edward Goad, “Plan d'assurance de Constantinople. Vol. I - Stamboul. No: 4.”

Identifier: APLGDSTAM04

Link: <https://archives.saltresearch.org/handle/123456789/118013>

Salt Research, Map Archive, courtesy of IFEA

Charles Edward Goad, “Plan d'assurance de Constantinople. Vol. I - Stamboul. No: 5.”

Identifier: APLGDSTAM05

Link: <https://archives.saltresearch.org/handle/123456789/119995>

Salt Research, Map Archive, courtesy of IFEA

Charles Edward Goad, “Plan d'assurance de Constantinople. Vol. I - Stamboul. No: 6.”

Identifier: APLGDSTAM06

Link: <https://archives.saltresearch.org/handle/123456789/124831>

Salt Research, Map Archive, courtesy of IFEA

Charles Edward Goad, “Plan d'assurance de Constantinople. Vol. I - Stamboul. No: 8.”

Identifier: APLGDSTAM08

Link: <https://archives.saltresearch.org/handle/123456789/107058>

Salt Research, Map Archive, courtesy of IFEA

Charles Edward Goad, “Plan d'assurance de Constantinople. Vol. I - Stamboul. No: 9.”

Identifier: APLGDSTAM09

Link: <https://archives.saltresearch.org/handle/123456789/111076>

Salt Research, Map Archive, courtesy of IFEA

Jacques Pervititch, Eminönü sigorta/gayrimenkul planları

Link: <https://archives.saltresearch.org/handle/123456789/1838>

Salt Research, Map Archive, courtesy of IFEA

Ekrem Hakkı Ayverdi, 19. yüzyılda İstanbul’u gösteren haritalar

Link: <https://archives.saltresearch.org/handle/123456789/1811>

Salt Research, Map Archive, courtesy of IFEA

François Kauffer, “Plan de la ville de Constantinople et de ses faubourgs tant en Europe qu’en Asie levé géométriquement en 1776 par Fr. Kauffer, vérifié et augmenté en 1786”

Identifier: APLKA01

Link: <https://archives.saltresearch.org/handle/123456789/116051>

Salt Research, Map Archive

Appendix 3.

This code presents the CNN based automatic segmentation procedure used for extraction of streets and blocks and to overlay the segmented maps in the Jupyter notebook environment.

```
import cv2
import numpy as np
# Load historical or contemporary map image
image = cv2.imread(imagemap_path)
# Convert to grayscale
```

```

gray = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)
# Edge detection to identify streets
edges = cv2.Canny(gray, threshold1=50, threshold2=150)
# Contour detection to identify urban blocks and buildings
contours, _ = cv2.findContours(
    edges,
    cv2.RETR_TREE,
    cv2.CHAIN_APPROX_SIMPLE
)
# Create segmentation mask
segmentation_mask = np.zeros_like(gray)
cv2.drawContours(segmentation_mask, contours, -1, 255, 1)
# Overlay segmentation on original image
overlay = image.copy()
overlay[segmentation_mask == 255] = [255, 0, 0] # red overlay

```

Appendix 4.

Prompt 1: Please identify any change zones according to the segmented images provided, highlight them with red boxes. The segmented street networks and contours of urban block structure are highlighted in green for the periods 1768, 1875-1882, 2025 and their overlay. Please consider overlay comparisons of these maps across the time periods and show a zone that demonstrate significant changes using blue box highlights. You must only consider the textual description provided in txt file, which has information on the criteria followed for identifying the urban tissue zones. You must not perform any external knowledge. You must just focus on the prompt directives.

Prompt 2. Please identify your own street, block, and building types based on the segmented images provided for the periods of 1906, 1940, and 2025. Please consider the textual description provided in txt file, which contains information for the determination of the types of street, block and building. Please match your results with the results of human assessment. Please give scores according to the following: if your identified types nearly match the human, use score is Perfect; if you find almost same knowledge, use Strong; if you and human assessment is less overlap, use Partial; and if there is no overlapping result, use is Never. You must not perform any external knowledge. You must just focus on the prompt directives.

Prompt 3. Please create your own decision logic to identify which urban blocks patterns from 20th century persist across the map periods. Follow the information provided in the XML file, which contains the counts of each block type for the map periods of the 20th century and current. Decide trends of persistency by asking yes or no questions. You must not perform any external knowledge. You must just focus on the prompt directives.

Appendix 5.

The statistical summary of the integration, area, elongation measurements and their persistency scale for the KA and SM regions.

Street Integration						
Morphological Region: KA (Bursa)						
Period	n	mean	median	Std	Strong range	Persistency
1857	590	48.0	49.8	16.1	30 – 65	
1912	289	18.3	17.7	13.9	5 – 30	
Current	325	39.3	41.4	19.5	25 – 60	
Morphological Region: SM (Edime)						
Period	n	mean	median	Std	Strong range	Persistency
1854	662	124.8	128.2	27.7	95 – 155	
1885	669	148.5	145.5	23.4	120 – 175	
Current	607	163.3	162.8	32.4	130 – 190	
Block Area (log ₁₀)						
Morphological Region: KA (Bursa)						
Period	n	mean	median	Std	Strong range	Persistency
1857	108	3.70	3.79	0.63	3.4 – 4.2	
1912	110	3.70	3.74	0.54	3.4 – 4.2	
Current	86	3.98	3.93	0.51	3.6 – 4.4	
Morphological Region: SM (Edime)						
Period	n	mean	median	Std	Strong range	Persistency
1854	75	3.66	3.74	0.43	3.34 – 3.90	
1885	82	3.35	3.40	0.56	2.99 – 3.67	
Current	59	3.74	3.63	0.53	3.51 – 4.08	
Block Elongation						
Morphological Region: KA (Bursa)						

Period	n	mean	median	Std	Strong range	Persistency
1857	108	0.98	0.99	0.15	0.85 – 1.10	
1912	110	0.99	1.02	0.14	0.9 – 1.10	
Current	86	0.95	0.99	0.17	0.85 – 1.10	
Morphological Region: SM (Edirne)						
Period	n	mean	median	Std	Strong range	Persistency
1854	75	0.93	0.95	0.15	0.84 – 1.04	
1885	82	0.90	0.92	0.21	0.81 – 1.05	
Current	59	0.99	1.02	0.15	0.91 – 1.10	
Green Areas (log ₁₀)						
Morphological Region: KA (Bursa)						
Period	n	mean	median	Std	Strong range	Persistency
1857	114	2.49	2.42	0.50	2.0 – 2.8	
Current	124	2.34	2.32	0.54	2.0 – 2.7	

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Table 13. The changes zones are highlighted with red boxes based on the AI identification. The area for the investigation at higher level of specificity, which corresponds to the urban conservation zone, is highlighted with a blue box which demonstrates most significant change zone. Source: Historical base maps were obtained from Salt Research, Map Archive: François Kauffer, Plan de la ville de Constantinople et de ses faubourgs tant en Europe qu'en Asie (1786), Identifier: APLKA01; and Ekrem Hakkı Ayverdi, 19. yüzyılda İstanbul'u gösteren haritalar (1875–1882), courtesy of IFEA. Used with permission from Salt Research. Segmentation, overlay analysis, and change-zone identification were produced by the author. Google Satellite imagery, 2025, was used as the contemporary reference. 135

Table 14. CNN outputs of segmentation results of 20th century maps for the pattern recognition process. Source: Historical base maps were obtained from Salt Research, Map Archive, courtesy of IFEA: Charles Edward Goad, Plan d'assurance de Constantinople. Vol. I – Stamboul, Nos. 4, 5, 6, 8, and 9, Identifiers: APLGDSTAM04, APLGDSTAM05, APLGDSTAM06, APLGDSTAM08, and APLGDSTAM09; and Jacques Pervititch's Eminönü insurance/real-estate plans. Used with permission from Salt Research. CNN-based segmentation outputs were produced by the author. Google Satellite imagery, 2025, was used as the contemporary reference. 136

Table 15. The matching results of human and AI-based identification of the urban patterns over time for the tissue zone of Hobyar, Tahtakale and Rustempasa - Eminonu costal - (E). Matching results is determined according to how AI well captured urban patterns recognition compared with human knowledge. If AI identified types nearly match the human, the score is Perfect; if AI shows almost same knowledge, score is Strong; if AI and human assessment is less overlap, score is Partial; and if there is no overlapping result, score is Never. 137

List of Abbreviations

AI	Artificial Intelligence
CA	Cellular Automata
CLC	CORINE Land Cover
CNN	Convolutional Neural Network

FOI	Field of Interest
GCP	Ground Control Points
ISUF	International Seminar on Urban Form
OBIA	Object Based Image analysis
U-Net	U-Shaped Convolutional Neural Network
VGA	Visibility Graph Analysis