

FOR AN URBAN HISTORY OF MILAN, ITALY:
THE ROLE OF GISCIENCE

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FOR AN URBAN HISTORY OF MILAN, ITALY:
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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iv
LIST OF TABLES	viii
LIST OF FIGURES	ix
ABSTRACT	xi
INTRODUCTION	1
SIGNIFICANCE	6
MILAN THROUGH THE CENTURIES	
I. A Brief History of Milan	9
II. Shaping Milan’s Urban History	11
CHAPTER	
I. Studying Urban History through Historical Maps	15
Objectives	15
Methodology	17
Results	25
Discussion	28
II. Layering the Toponymic Tapestry of the City	41
Objectives	41
Methodology	45
Results	49
III. Positional Accuracy, Positional Uncertainty, and Feature Change Detection in Historical Maps: Results of an Experiment	73
Objectives	73
Methodology	80

Results.....	83
CONCLUSIONS.....	100
First Chapter Achievements.....	100
Second Chapter Achievements	101
Third Chapter Achievements	103
The Role of Scale.....	104
Future Directions	106
REFERENCE LIST	109

LIST OF TABLES

Table	Page
1. Probability of urban change for the periods under study.	38
2. Comparison between relative RMSE (historical maps vs. historical maps) and absolute RMSE (historical maps vs. 2005 map)	38
3. Time periods for Object Age and Object Name Age	61
4. Number and percent of street segments by Object Age and Object Name Age	64
5. Mean length (m) of street segments by Object Age and Object Name Age	65
6. The algorithm.....	93
7. Distance measurement categories: combined level of inaccuracy and uncertainty.....	94
8. Probability of change and combined levels of inaccuracy and uncertainty	94
9. Results of the Kruskal–Wallis test.....	99
10. Spatio-Temporal matrix	108

LIST OF FIGURES

Figure	Page
1. Milan is ideally placed as Italy's gateway to Europe.....	13
2. Location of historical walls and gates superimposed on a 2005 map of Milan.....	14
3. The 1737 Cairolo map (Biblioteca Trivulziana, Milano)	30
4. The 1820 Cagnoni map (Biblioteca Trivulziana, Milano)	31
5. The 1884 Bassani map (Comune di Milano, Milano)	32
6. Control points and distortion grids of the historical maps under study (maps not to scale)	33
7. Neighborhood generalization and building amalgamation (map digitizing process).....	34
8. Historical map overlays and feature change (green: unchanged zones; red: changed zones).....	34
9. Feature-change detection (left) and creation of the urban-change probabilities surface (right). The example is that of changes occurring between 1737 and 1820, draped on the 2005 map	35
10. Distortion grid and displacement surface of the historical maps relative to the 2005 reference map.....	36
11. Derivation of the final urban-change map; the example shown is for the 1737–1820 time interval.	37
12. Surfaces representing the final temporal probabilities of change for the time period under study	37
13. Percentage of cells falling into the categories of high and moderate probability of change. In light grey are comparisons between historical maps and the 2005 map; in dark grey are comparisons between historical maps.	39
14. Spatial patterns of high probabilities of urban change, 1737–2005.	40
15. Milan's historical zones (left) and <i>Sestieri</i> , or districts (right)..	61

16. Number of Object Age (left) and Object Name Age (right) street segments by zone	62
17. Location and percent occurrence of street segments by Object Age (top) and Object Name Age (bottom).	63
18. The Roman layer.	66
19. The Medieval layer.	67
20. The Early Modern and Austrian-Napoleonic layers.	68
21. The Post-Unification layer.	69
22. The Twentieth Century layer.	70
23. Polar bar charts representing the occurrence of street segments categorized by Object Age (left) and Object Name Age (right) by <i>Sestieri</i>	71
24. Neighborhood analysis: location of significant clusters of street segments categorized by Object Age (left) and Object Name Age (right).	72
25. Fischer's uncertainty model.	87
26. The 2005 CTR map (detail).	88
27. The 1884 Bassani map (Biblioteca Trivulziana, Milano).	89
28. Area under study	90
29. Visual representation of the methodology workflow	91
30. Flowchart representing the algorithm.	92
31. Contour map showing the combined levels of positional inaccuracy and positional uncertainty for the 1884 map.	95
32. Combined effects of positional inaccuracy and positional uncertainty on probabilities of urban change for the three grids: 1) original (centered), 2) vertically shifted and 3) diagonally shifted.	96
33. Reliability of results: original (centered) grid and derived grids (vertical or horizontal shifts)	97
34. Descriptive statistics, frequency histogram and box plot of the three grids: original (centered), vertically shifted, and horizontally shifted.	98

ABSTRACT

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SUPERVISING PROFESSOR: ALBERTO GIORDANO

The objective of this dissertation is to investigate the history of the city of Milan, Italy, employing Geographic Information Science (GIScience). Using historical maps and ancillary data, the spatiality of historical events that interested the city is analyzed, interpreted and explained by means of new geospatial technologies used to both corroborate and at the same time confute previous believes upon the history of the city. The body of this dissertation is divided into three main chapters that analyze the urban history of the city under different scales both temporal and spatial.

First I use an analytical methodology on historical maps to detect the changes that have occurred on the urban fabric at a city-wide scale over a period of four centuries. Once detected, these are shown to be related with the major events that characterized the social and urban history of the city.

In the second chapter the main historical layers that comprise the formation of Milan are revealed. Compared with the analysis of the first chapter, here I increase the spatial scale (neighborhood/street-wide scale) as well as deepen the temporal scale up to two millennia. A hybrid approach trying to bridge qualitative and quantitative methods is used to analyze the toponymic pattern of the downtown streetscape. Furthermore a cluster analysis is conducted to inquire into the more local identities that are part of the daily experience of the space.

In the third and final chapter I deal with the identification, classification and visualization of cases of positional accuracy and uncertainty in historical Landscape Pattern Analysis (LPA). Employing a sample of a map analyzed in the first chapter, my goal is to detect spurious changes in the context of a feature change map analysis, showing these are connected with the map generalization process operated by the map maker and how this process can affect the map reliability.

I finally conclude with important remarks on scale dependency of geographical events and how GIScience can be fruitfully used to discover the multiple spatial and temporal layers of the history of the city.

INTRODUCTION

The empirical approach in urban geography is about the description, analysis and interpretation of processes taking place in the city. The theoretical approach, on the other hand, examines how these same processes relate to the townscape as concerns the construction of cultural and spatial forms (Aitken, Mitchell, and Staeheli 2005). If urban geographers are to understand the contemporary urban space and also map its future (Aitken, Mitchell, and Staeheli 2005), I would argue that the same should be said for past urban environments.

“Cities are culture and geography’s largest artifact” (Vance 1990, 4), and every city contains traces of past landscapes entangled in the contemporary spatial framing (Hayden 1994). A key step in understanding urban areas is to analyze the physical and cultural remains that tend to persist in townscapes. This process of historical sedimentation is particularly relevant in cities that have been settled for a long time. In these cities, the layering of physical and cultural remains that tend to persist in townscapes reflects an intertwined and often irregular mix of historical periods (Conzen 1988). However, these cultural remains are sometimes not preserved, especially when development and redevelopment occur (Hayden 1994). Narrating the spatial history of a place is not easy for a variety of reasons, including a lack of documentary sources; hence, one of the biggest challenges for researchers is to fill historical lacunae by logical inferences and educated guesses (Vance 1990). Continuous growth and development unavoidably create functional dynamisms in the morphological aspect of a city (Vance 1990). Interestingly, the geographical component of the

townscape, besides providing the spatial framing, influences the content of social relations as well. This derives from the fact that a city is the product of human beings, a socio-geographical process, therefore both cause and effect of these social relations (Backaus and Murungi 2002).

Although subdividing the continuity of time in discrete moments might hinder explanations (Vance 1990), it is also undeniable that cities, as spatial process, have expanded and developed over time in phases that can be followed and analyzed by spatio-temporal cross-sections (Denecke 1988). With this in mind, focusing the attention on timely-based socio-morphological adaptations of a city, one can begin inferring upon the dynamism of urban forces (Vance 1990).

Following the traditional descriptive approach which saw a city as a whole complex geographical object, regionalism decomposed this complexity into smaller units preparing the ground for the analytical approach which further fragmented them, enabling the study of the phenomena from a different and more detailed perspective. The analytical approach can then be integrated by an historical perspective (Denecke 1988).

This research aims to investigate the history of the city of Milan (Italy) using an analytical approach and at different geographical scales and temporal granularities, as well as considering its social and historical aspects. Geographic Information Science (GIScience) and geospatial technologies will be used to study the evolution of urban spatial forms focusing on the relationships existing between forms and the processes that have created them.

In the last two decades, the tools and methods of GIScience have been applied quite extensively to historical and historical geography research. An emerging trend in historical geography (Holdsworth 2002), Historical GIS (HGIS) has attracted the attention of a variety of scholars emphasizing a variety of applications (Kienast 1993; Knowles 2000; Dragicevic, Marceau, and Marois 2001; Gregory and others 2002; Bender and others 2005; Gregory and Ell

2006 and 2007; Hillier and Knowles 2008). The term “Historical GIS” has been used to describe both the construction of historical spatial data warehouses, such as the Great Britain Historical GIS project (Gregory and others 2002) and the corresponding, currently under way US project (National Historical Geographic Information System 2004), as well as more analytical studies of the type I am undertaking here, whose goal is to examine the spatiality of historical events using the principles, methods and tools of GIScience (Pearson 2001; Berardo and Mawby 2003; Smith, Clement, and Wise 2003; Pearson 2004 and 2005; Giordano and Nolan 2007; Hillier and Knowles 2008).

In the specific context of urban applications (Siebert 2000), the main purpose of HGIS is to visualize and interpret the spatial history of a city. To the visual display of the results of the analysis—maps, charts, and tabular data—the researcher should follow with an interpretation to reveal and explain the presence of spatial patterns (see also Okabe 2006 for particular application of GIScience in social sciences). This is both a quantitative and qualitative process: the true contribution of GIScience is the quantification of information about the physical characteristics of the features under study and the revelation of spatial patterns emerging from the analysis. The interpretation of the results of the analysis, however, can only be approached with the tools of the historical geographer and the political geographer.

This dissertation aims to tackle three sets of research questions, which together explore the role GIScience can play in advancing historical geography and urban history.

- How can analytical cartography and GIScience be applied to historical maps in order to discover the relationship existing between the changes that have occurred in the urban fabric and the historical events of the city?

The goal of chapter one is to demonstrate how a spatial analytical methodology employed on historical maps, can reveal the intimate connection between the changes that

have occurred in downtown Milan over the course of centuries and its political history, seen through the study of the cartographic production of the city.

- What can the study of the current streetscape toponyms reveal about the struggles and takeovers of the city? Can the semantic approach in reading street names reveal particular politics of power and say something about the “historical layers” that have concurred to the formation of the city?

While the analysis conducted in chapter one concerns a city-wide scale in space and nearly four centuries in time (from the 18th century to date), chapter two takes a different approach in both spatial and temporal scale. Spatial scales range from the neighborhood to the street, while the temporal span ranges from the Roman period to the 20th century. The space-time relationship is analyzed taking into consideration the toponymic patterns of the streetscape of the city, reading the urban environment as a text and trying to understand a city and its iconography as a product of human expression (Gross’ semiotic discourse 1990).

- What can be inferred about the accuracy of historical maps and its close connection with uncertainty? How reliable are the outcomes extracted by their analysis? How could the process of accuracy/uncertainty assessment be formalized and visualized to gain a better understand of map reliability for drawing more accurate conclusion about feature change detection?

The issue of geographic data quality is one of the main concerns in GIScience applications; this is particularly true in the cases of historical geodatabases. The third and final chapter proposes a method to estimate the positional accuracy and uncertainty of historical maps by mean of script automation and geovisualization techniques. Built on the methodology employed in the first part of the dissertation, a sample of the initial dataset is analyzed to determine the location of spurious changes due to the cartographic misalignment of maps. The

scale of this part of the study is much larger than the one previously employed (few meters on the ground) while the temporal span is slightly longer than a century.

As a final remark, the final chapter of this dissertation will discuss the issue of scale dependency in geographic analysis, as well as examining the strengths and weakness of GIScience when dealing with historical applications.

SIGNIFICANCE

The purpose of this dissertation is to show how Geographical Information Science can play an important role when employed for humanistic research (Pratt 1989). As a product of the quantitative revolution, GIScience might not at first sight appear to meet the requirements of human science and its qualitative aspects (Philo, Mitchell, and More 1998); however, its ability to unearth spatial patterns and their dynamics can represent a valuable tool for analyzing and increasing the human experience and how this experience relates to the landscape (Jiang 2003).

One of the main topics of this dissertation is to address the scale dependency of geographic phenomena and how GIScience can help provide insight into it, specifically as concerns historical-related issues. As stated by Jantz and Goetz (2005), relationships established among physical features vary when analyzed at different scales (what in literature is termed the Modifiable Area Unit Problem – MAUP – Openshaw 1983). In particular, not only the scale affects the findings in physical patterns, but also, and more interestingly, the socio-political aspect can assume different connotations according to the geographical extent to which the analyzed phenomenon is taken into consideration.

Macro and micro scale analysis in urban settings have been conducted for different purposes: while the former attempts to model local changes at the neighborhood level (Bockstael 1996), the use of the latter is more focused on detecting broader urban-scale factors and patterns (Johnston and Barra 2000; Tucci, Giordano, and Ronza 2010). This study can provide insight on the many possibilities for employing geospatial technologies for historical

research. It offers constructive suggestions regarding analytical techniques as well as visual tools and historical interpretations of spatial related results at different scales.

Apart from the non-specificity of this study (its methodology may be applied to any urban setting) one of its key factor is the application of geovisualization techniques for the achievement of an insightful “visual thinking” about the data extracted, “a method for seeing the unseen” (McCormick, DeFanti, and Brown 1987, 3). From an historical research point of view, the outcomes of this study can be compared with the findings of local scholarship, to see if there are any similarity and/or relevant differences. Furthermore, spatial analysis and geovisualization techniques can unearth changes that have not been recorded by local studies of urban history (in the case of Milan, Pellegrino 1984, 1985, 1986, 1987, 1988, 1991, is the most comprehensive example), which tends to focus on the more central and architecturally prestigious parts of a city. Historical feature change detection can also be used to detect broader patterns of urban change that might have been remained hidden and not analyzed in the official historiography. In the case of Milan, visual histories and architectural textbooks often tend to focus on the history of a limited number of highly visible landmarks in the built environment, tracing the “spirit of place” of modern Milan back to the post-Unification era (from the 1860s to the 1920s) and to the interwar (1920s and 1930s) and postwar periods (from 1950s on). By contrast, this research will show that the impact of changes dating back to the Austrian and Napoleonic periods (from the 1750s to the 1850s) is more substantial and more widely diffused than those three.

The large scale analysis discussed in the third chapter completes and integrates the small scale analysis of the previous two, and is a specific contribution to GIScience in the sense that the algorithm developed can be used as a tool for testing the reliability of feature change methodologies.

The importance of the toponymic analysis of the streetscape in urban setting echoes Tuan's reflections (1991), in which he notes how the construction of a place is not only represented by the mere transformation of the physical space, but is also comprised of historical and social events which, large or small, accumulate throughout the course of time. In this context, geography in general, and GIScience and Historical GIS in particular, can contribute to discovering in their entirety and complexity the interplay of conflicting ideologies and the various spatial narratives inscribed in a place.

When treated as embedded text, toponyms and their spatial arrangement reveal the history of a place. Offering an approach different from more traditional studies based on largely qualitative methods, a quantitative analysis of street names can be used for corroborating or confuting previous long-held beliefs on the spatial history of a city.

Besides contributing to the current scholarship on the politics of naming, the added value of the Milan's case study is its temporal span (from Roman times to the present), which is much wider than that of similar studies found in the literature. Furthermore, this study can also show the potential of our approach in the broader context of cultural preservation in urban settings. Gross (1990)—writing before the age the Internet—has noted how the increasing use of new technologies and media, and the relative information overload that their use can provoke, has caused signs from the past to retain less and less power in conveying their messages, thus converting urban environments into 'anti-memory' places. Combined with traditional historical analysis, GIScience and the Historical GIS approach can be of great benefit to the historian and cultural preservationist, by unearthing previously hidden historical urban features as well as offering useful geovisualizations to display and popularize the history embedded in the cityscape.

MILAN THROUGH THE CENTURIES

A Brief History of Milan

Geography has played an important role in the history of Milan. Located in the middle of the *Pianura Padana* (the plain formed by the *Po* River) in northern Italy, Milan sits on the most important roads connecting northern Europe with the Italian peninsula and the Mediterranean basin (see Figure 1).

Location likely also gave the city its name: *Mediolanum*, the Latin name for Milan, may have been derived from the words *medius* (middle) and *planum* (plane; Pellegrini 1990, 109–10). Following the Roman conquest of western Europe, Milan's nodal location within the Roman road network made of the city an important political and administrative centre of the Late Empire (286–402 CE). During the medieval period, Milan was at the centre of the European “city belt” that was the backbone of the continent's economy (Dowd 1961; Rokkan and Urwin 1983) and stretched from the Flemish harbours to Tuscan merchant cities such as Florence and Siena. Later, when the Italian peninsula lost its centrality to Europe's seagoing empires, Milan established itself as Italy's gateway to the world's new economic and cultural centers, playing a key role in the cultural and economic modernization of the country.

Like those of many other European cities, the current urban form of Milan is the result of several historical periods layered on each other. Founded by the Celts at the beginning of the fourth century BCE, the village of *Metlaun* was conquered by the Romans in 222 BCE and turned into a military camp, which subsequently expanded into a Roman city. Following the standard scheme for urban planning adopted by the Romans, the city walls were built in a square,

bounding nearly 80 ha of land crossed by two main roads, the *Decumanus Maximus* (from south-west to north-east) and the *Cardo Maximus* (from south-east to north-west), that passed into and out of the city via four gateways (*porte*) complete with watchtowers; two additional gates were added later in the Roman period (see Figure 2).

After a brief period of decline following the fall of the Western Roman Empire in 476 CE and the Barbarian invasions of the sixth century (Calza 1999), Milan re-emerged as the most prominent of the northern Italian city-states in the medieval period. During this period the city became progressively larger, expanding in a series of concentric rings built around the Roman urban core. An accurate reconstruction of the gradual transition from the Late Roman period to the medieval city is made difficult by the common practice of recycling construction materials for the rebuilding process, which largely obliterated the previous urban fabric. In addition, a major breakdown marked the city's urban history in 1162 when, after months of siege by the troops of Frederick I, emperor of the Holy Roman Empire, Milan was partially destroyed. In 1167, following the city's rebuilding by its inhabitants, a new ring wall surrounded by a ditch filled with water (the *Navigli* canal) was added. Still a small town by European standards (Figure 2, middle ring), with a total surface area inside the walls of 260 ha (Castellano 1999), medieval Milan was nonetheless the largest and most populated Italian city of the time. After the city fell under Spanish rule in the first half of the sixteenth century, a new ring of bastioned walls was erected to encompass the *borghi* (boroughs) that had grown up along the connecting roads. Contrary to the tendency of locating new walls next to older ones, Governor Don Ferrante Gonzaga built the new bastioned wall at a distance from where the old one had stood (Adorini 1999).

Although they had exhausted their defensive function and by the mid-eighteenth century had been transformed into a pedestrian walkway (Della Torre 1999), the Spanish

Bastions marked the city's administrative boundaries until 1873, when urban expansion driven by railways and industrialization finally broke through the historical city (Figure 2, external ring).

Shaping Milan's Urban History

Traces of the hegemonic discourses produced by Milan's power elites can be found on the city's streetscape and its toponyms, and have originated a complex tapestry in which different past and conflicting ideologies co-exist. During the centuries that followed the end of the Roman Empire, for instance, the effects of a weak centralized power can be seen in Milan's slow and unplanned urban growth, characterized by a proliferation of new convoluted street segments built on the urban structure left behind by the Romans and contained within the Medieval wall ring.

The rise of Milan as the cutting edge of Italy's modernization under the 'enlightened' Austrian Emperors during the second half of the 18th century is epitomized by the so-called *Cusani* reform (1786), generally referred to as the starting point of the modern, state-sanctioned toponym assignation process. By Joseph II's orders, street names began to appear on street corners and the first, primitive numeration system was developed: starting from the Royal Palace (number 1) and proceeding outward toward the periphery of the city, each building was numbered progressively in a spiraled manner. The obvious inefficiency of this method was soon disclosed—how, for example, were new buildings to be numbered?—and a less problematic way to assign numbers was introduced in 1860, when a decision was made to proceed street-by-street with even and odd numbers on different sides of the street (Buzzi and Buzzi 2005). (This is the system still in use in the country, with the notable exception of Venice.) In the following decades, due to an increase in street use by a growing population employing horse carriages and other forms of transportation, a more efficient network design became a major concern for city planners: new urbanization projects, layered on top of the medieval city, were proposed

which included new orthogonal streets based on wider and longer street segments. Until the late 19th century, the bulk of the street network was still concentrated inside the Medieval wall ring, and it is only at this time, with the first town-planning scheme (the *Beruto* plan), that a new urbanism (American Planning Association 2006) takes place throughout the city (Lapini 2004).

The *Beruto* plan of 1884 is the first in Milan explicitly drafted with the objective of rationally and sustainably designing the city and its street network. The main plan was based on a decentralized urban growth model, which had started in the 1870s with the placement of factories outside the city core in an area called *Corpi Santi*, connected to the city by a network of wide avenues (Morandi 1992). The most interesting part of the first version of the plan was how Beruto designed the city blocks. These were supposed to be larger (200-400 meters each side) than the existing ones and were to serve as multifunctional entities capable of accommodating residential, productive, and commercial activities (Morandi 1992). Contrary to this initial idea, however, in the final version of the plan the city blocks remained smaller and monofunctional. The street network grew denser, with a minimum street width of 14 meters and a total road surface, built by both the city government and private individuals, of 3.8 million square meters at the end of the century (Morandi 1992).

In the 20th century, Milan expanded dramatically, but the object of this study - the central core area - did not change substantially from a morphological point of view. Toponymic changes did occur and will be examined in the second chapter.

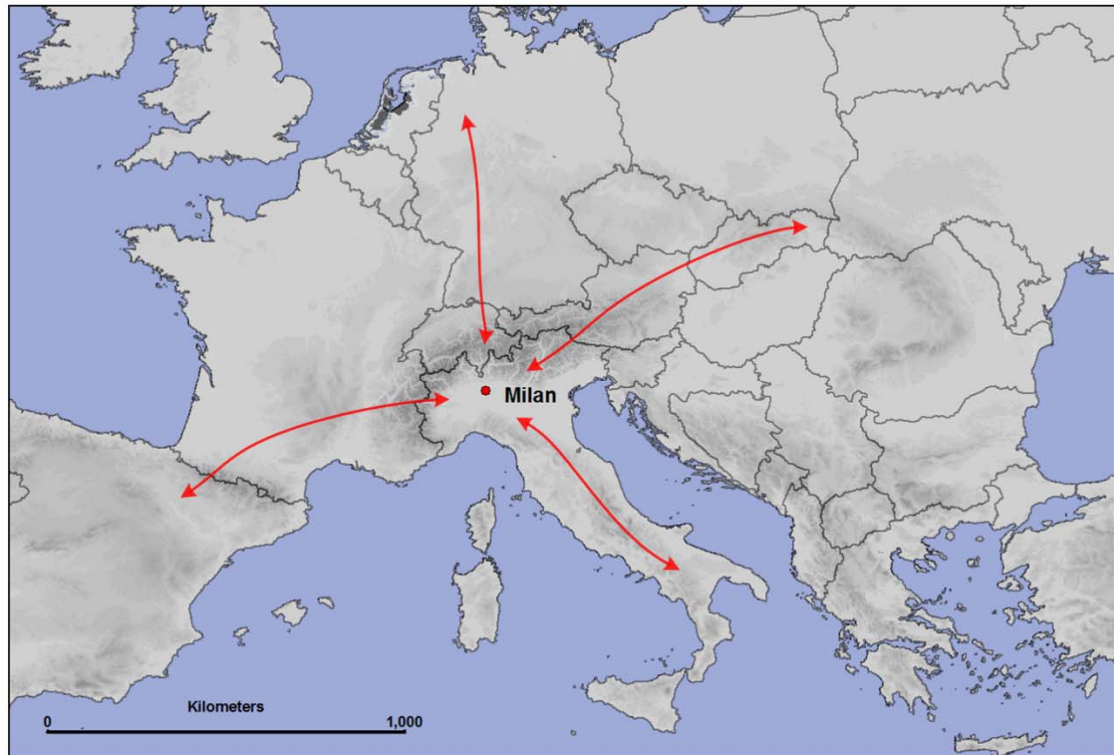


Figure 1. Milan is ideally placed as Italy's gateway to Europe.

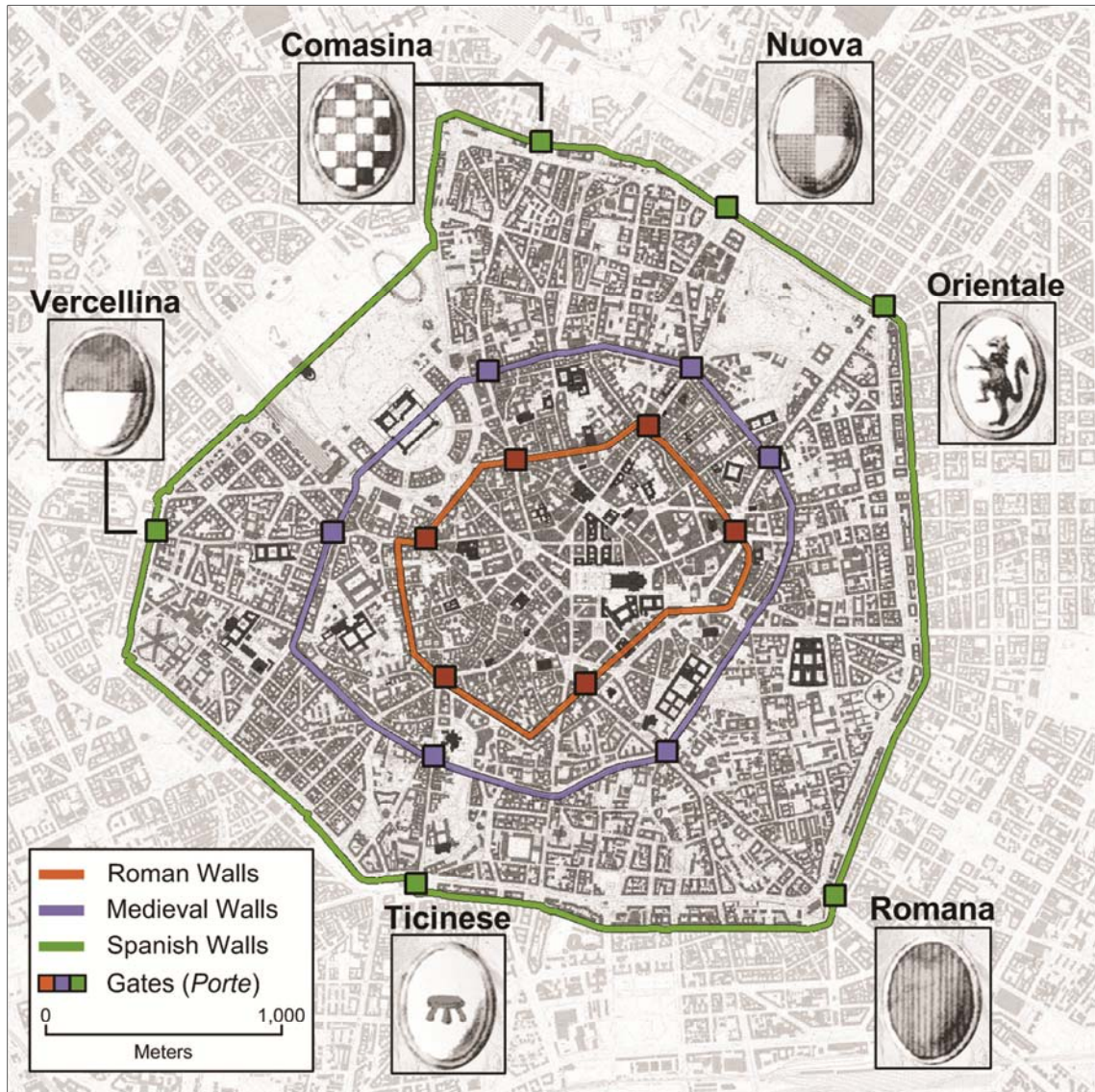


Figure 2. Location of historical walls and gates superimposed on a 2005 map of Milan.

CHAPTER I

STUDYING URBAN HISTORY THROUGH HISTORICAL MAPS

Objectives

For centuries, maps have successfully shown how graphic abstractions can be used to understand the world (MacEachren and Kraak 2001). As J.B. Harley (2001) has argued, maps perform this role within a social and historical context: maps have been used not only to represent the landscape but also as a form of art, as instruments of power and sovereignty, and as propaganda (Wood and Fels 1992, 2008). The map “replaces rather than represents territory” (Casti 2005, 12). Based on this premise, I thought it would be interesting to explore the extent to which changes in the form and structure of a city, as represented in a set of historical maps – in this case, maps of Milan, Italy – reflect major events in the history of that city. While Harley and his followers have used mainly qualitative methods to make their arguments, in this chapter I propose a quantitative methodology that employs geovisualization and spatial analysis techniques and tools to answer the research question. Such a methodology relies on the availability of positionally accurate maps, an issue I will discuss below.

In urban cartography, and in cartography in general, the last three centuries have seen both an increasing focus on positional accuracy and the rise of the thematic map: the power of the two combined is demonstrated by John Snow’s 1855 cholera map of London, to cite just one example. By contrast, during the Middle Ages, at least in Western Europe, most urban historical maps appear to have had no specific function beyond the mere representation, often stylized and archetypal, of geographical features. Cartographic works across Europe show the standard

characteristics of Ptolemaic maps (Miller 1998): only the most important civil and religious buildings are prominently represented; no street network is depicted; distances and directions are only proportionally accurate. Although concerned with representing urban features in their correct topological relationship, medieval bird's-eye maps are hardly accurate from a positional point of view. This was a conscious choice on the part of the cartographers, in the sense that positional accuracy was not of primary importance (Wright 1925, cited in Woodward 1987, 288) in the social and historical context in which the medieval map-maker operated. The reason, P.D.A. Harvey argues, is that "in the Middle Ages, the normal way of setting out and recording topographical relationships was in writing, so in place of maps we have written descriptions: itineraries, urban surveys, field terriers, and so on" (1987, 464).

Starting at least in the eighteenth century – in response to changed social, economic, and political conditions and taking advantage of technological innovations – carefully and precisely recording the location of features on the ground became a primary objective of the cartographer's work. As a consequence, the positional accuracy of urban maps, as well as other types of maps, increased (see, e.g., the history of cadastral maps as narrated in Kain and Baigent 1992). This shift presents an opportunity for geographic information scientists, who can apply the quantitative tools and methodologies of geographic information science (GIScience) to the study of historical maps.

GIScience adds one important dimension to the study of urban historical cartography: the evaluation of the positional accuracy of the location of features, the search for spatial patterns, and the comparison of maps across time can contribute to a better understanding of the map itself and of the context in which it was produced. Of course, in order to do this type of analysis the researcher must be reasonably confident in the accuracy – thematic as well as positional – of the maps he or she is using. It is for this reason that, in my analysis of urban

changes in Milan, I have deliberately excluded maps predating the eighteenth century. Although such maps do exist, a comparison of pre-eighteenth-century historical maps using the quantitative methodology introduced here would not, in my opinion, lead to reliable results.

Previous research has shown the usefulness of spatial analysis tools in depicting accuracy and uncertainty in historical maps (Oetter and others 2004; Hessler 2006; Livieratos 2006; Pontius and Lippitt 2006), but this is not the focus of the present chapter. Rather, I use an inductive approach and geovisualization techniques to discover how historical events have left their mark on the urban form of Milan. The role of geovisualization in particular should be stressed. As noted by Alan MacEachren and Brewer, “maps help to provide the contextual reference information to allow interdisciplinary idea sharing” (2004, 21); thus, they can also play a role as highly interactive exploratory tools (MacEachren and Kraak 1997) to reveal spatiotemporal patterns and to help researchers test existing hypotheses and formulate new ones. In my work, I used GeoVISTA Studio to discover urban changes whose full extent emerged only through the use of geovisualization techniques and concepts.

Using GIScience to help understand the history and historical geography of a place is probably the most ambitious objective of the historical GIS approach (Kienast 1993; Knowles 2000; Dragicevic and others 2001; Gregory and others 2002; Bender and others 2005; Gregory and Ell 2006, 2007, Hillier and Knowles 2008). In this conceptual framework, I believe that a quantitative perspective is capable of enhancing and complementing the prevalently qualitative approaches to the study of historical maps of which Harley was the most prominent proponent.

Methodology

To illustrate the most recent changes in the urban history of Milan, I have chosen three maps. The 1737 Cairolo map (Figure 3) captures the city at the eve of the first wave of urban modernization under the “enlightened” rule of the Austrian empress Maria Theresa (1740–80)

and her son, Joseph II (1780–90); the 1820 Cagnoni map (Figure 4) reflects changes introduced during the second half of the eighteenth century, corresponding to the years of Napoleonic rule (1796–1814) and the early Restoration period; the 1884 Bassani map (Figure 5) map shows the city's layout after the first wave of post-Unification restructuring, to which the new Duomo square and the Galleria Vittorio Emanuele II belong.

The historical maps were compared with one another other and with the 2005 regional map (the Carta Tecnica Regionale, or CTR – the official Italian large-scale map subdivision). The analysis is limited to the city centre, an area bounded by the medieval walls before they were modified. This part of Milan has been continuously inhabited since medieval times and includes the original Celtic and Roman settlements. The 1884–2005 period includes the second wave of the post-Unification restructuring (following the 1884–1889 Beruto plan), the inter-war renewals under the Fascist regime, and the rebuilding of the city after the destructions of World War II. The three historical maps chosen for the analysis are well known to urban historians in Milan and are representative of the historical periods under study. As already mentioned (and as will be demonstrated in the Results section), the three maps are also positionally accurate, within the capabilities of the technology of the time.

The methodology is based on a comparison between historical and contemporary maps, conducted in order to detect and visualize changes that occurred in Milan during the last two-and-a-half centuries. The methodology used to compare the maps includes five steps:

- 1) Georeferencing the historical maps and generating distortion grids.
- 2) Digitizing and then rasterizing the georeferenced historical maps.
- 3) Reclassifying the raster images obtained in step 2 and generating a surface of urban change probabilities.

4) Calibrating the urban change probabilities surface with the historical maps' distortion surfaces (created using the distortion grids generated in step 1).

5) Calculating absolute (historical maps vs. 2005 map) and relative (historical maps vs. one another) urban change maps.

The final results after applying the methodology outlined above and described in the next section is a series of maps (see Figure 12) depicting areas in the city where urban change is most likely to have occurred between the mid-eighteenth century and the present time. More specifically, the five steps listed above include the following:

- 1) The first task in a historical map comparison analysis is usually to overlay one map on another in order to assign geographical coordinates to a map with unknown spatial coordinates (the historical map) using a georeferenced map of known higher accuracy as reference. A commonly used overlay procedure involves identifying control points (CPs) in both the georeferenced map and the map with unknown spatial coordinates. Control points are features (e.g., corners of buildings, street intersections) on the ground that are clearly recognizable on both maps. This procedure has become standard in historical cartography studies, dating back at least to Eduard Imhoff's seminal 1939 work (cited in Ravenhill and Gilg 1974, 48), and in recent decades it has been used, with slight variations, in several studies addressing the accuracy of historical maps at a variety of scales (Andrews 1974; Stone and Gemmell 1977; Murphy 1979; Hsu 1978; Yerci 1989; Strang 1998; Pearson 2001, 2004, 2005). For this study, I located approximately 50 CPs for each historical map. The Georeferencing tool in ArcMap 9.2 was used to rectify the maps and then calculate their root mean squared error (RMSE) value. Following Giordano and Nolan (2007), I employed the nearest-neighbor resampling method to georeference the historical maps. Figure 6 shows the CPs used in the study and how

different parts of the maps were distorted when the overlay process was conducted.

The resulting distortion grids, generated using Map Analyst, use compressed or enlarged meshes to visualize the local deformation and rotation of the historical maps (Jenny, Weber, and Hurni 2007). The grids provide insights into which parts of the historical maps are more positionally accurate and which are more distorted. This information was subsequently used in step 4 to create distortion surfaces.

- 2) In this step, I overlaid the historical maps for pair-wise comparison. To do so, I digitized the 1737, 1820, and 1884 maps and then converted the resulting vector layers to a raster format. The resolution of the cell in the raster layers is 5 m, a value I believe is appropriate considering the scale and positional accuracy of the maps involved and the objectives of the study. Note that instead of digitizing single buildings, I performed a neighborhood generalization, constructing polygons around the main street axes (Li and others 2004) and using a building amalgam simplification (Regnauld and Revell 2007). This procedure resulted in the merging of all buildings belonging to a common complex (see Figure 7). By generalizing the buildings to the block level, I was able to investigate the main trends of three centuries of urban changes in Milan. This generalization is consistent with the scale of the analysis – the city or its historical neighborhoods, rather than single buildings – and my objectives. Had I looked at changes in the location of individual buildings, the resulting picture would have been blurred by hundreds or thousands of small changes, due for the most part to the relative positional accuracy of the three maps (see step 3 below). Thus, the result is a representation that is zonal (i.e., by block or historical neighborhood) rather than by building. In the third chapter of this dissertation, however, I will get into more details regarding changes at the building

scale by employing a more accurate digitization while analyzing a smaller area, therefore able to inquire at much larger scale.

- 3) After the initial data processing was completed, maps were overlaid in chronological order (1737 with 1820, 1820 with 1884, and 1884 with 2005), with the objective of detecting changes between time periods in the history of the city of Milan. Previous research has shown that the process of storing historical information in a digital format can be extremely problematic, principally because of the multifaceted nature of uncertainty in either the conceptual modeling (i.e., how phenomena are observed and mentally organized) or the physical modeling (i.e., the extraction of useful information) that follows the conceptual stage (Plewe 2002, 2003). This chapter as well as the third deal with both types of uncertainty. In order to detect changes between time periods, I applied a dichotomous subdivision in which each cell was coded as either building (B) or no building (N). This allowed me to keep track of which cells did not change their value over time (B stays B from an earlier to a later map, or N stays N) and which did change (B becomes N, or vice versa). Figure 8 shows the chronological overlay of the historical maps and the resulting feature-change detection (extreme right). In the figure, unchanged zones are shown in green and changed zones in red. For the rest of the analysis, however, I chose to employ a probabilistic representation of the results shown in Figure 8, based on the consideration that the historical maps are likely not as positionally accurate as the 2005 map and also because of the likely deformation of the medium (paper) in which the historical maps were created (this factor is of particular consideration for the oldest maps, 1737 and 1820). These two factors make the digital representation of the location of urban features intrinsically uncertain; this uncertainty is caused both by the imprecise measurement of

the phenomenon (conceptual modeling) and by the erroneous conversion of into a digital format (physical modeling; Schneider 2001). Statistical simulations and analytical error propagation concerning data uncertainty, and in particular positional accuracy, have been the focus of many researchers (Hunter and Goodchild 1997; Florinsky 1998; Schneider 2000). From the opposite point of view (i.e., analyzing what can be considered certain), it is reasonable to assume that positional uncertainty increases as one moves away from the location of a feature on a map, assuming that the cartographer tried to represent features in their correct geometrical form (the same concept underpins the “epsilon band” in the representation of the positional accuracy of a line). Given these considerations, rather than showing the transition between B and N as a sharp boundary, as is in Figure 8, I conceptualized it as a continuously variable quantity ranging from its more likely location to less likely ones (see Figure 9). The resulting urban-change probabilities surface was generated using a local polynomial interpolator. This method produces surfaces that take into consideration local variations within the map by employing a subset of CPs that fits local trends:

$$\sum_{i=1}^n w_i (Z(x_i, y_i) - \mu_0(x_i, y_i))^2 \quad (1)$$

The interpolation is based on a moving window centred at $\mu_0(x, y)$, where n is the number of points within the window, and w_i is the weight:

$$w_i = e^{\left(-\frac{3d_{i0}}{a}\right)} \quad (2)$$

where d_{i0} is the distance between the point and the center of the window, a is the parameter that controls the distance decay, Z is the datum at the location i , and $\mu_0(x_i, y_i)$ is the value of the polynomial. The algorithm was implemented in the ArcGIS GeoStatistical Analyst extension. The interpolator was applied to a sample (20%) of the cells generated in step 2. This data-filtering procedure has the advantage of facilitating geovisualization by eliminating redundant details to reveal the fundamental characteristics of a specific behavior (Andrienko and Andrienko 2006) – in my case, the fundamental characteristics of temporal changes in the urban form of Milan. Previous research has shown the effectiveness of generalized representation in visual depictions of important spatial trends (Harrower 2003). Mainly employed to simulate urban growth in the Detroit region (Tobler 1970) and Washington, DC (Acevedo and Masuoka 1997), data filtering is an effective tool to allow the reader to focus on the analyzed phenomenon without being distracted by marginal characteristics of the model. Again, I should stress that the purpose of this part of the study was to detect changes at the urban or neighborhood scale, and not at the level of buildings: for this reason, I believe that a degree of generalization is justifiable.

- 4) To strengthen the reliability of the results, I used the distortion grids created in step 1 (see Figure 6) to generate “absolute” (i.e., historical maps vs. 2005 map) displacement surfaces for every historical map (see Figure 10).

The displacement surfaces were derived from the distortion grids using an inverse-distance weighted interpolator:

$$Z_u = \frac{\sum_{i=1}^n Z_i d_{iu}^{-k}}{\sum_{i=1}^n d_{iu}^{-k}} \quad (3)$$

This interpolator estimates an unknown value Z_u at u , routinely for a set of points n , as a weighted average of its surrounding points Z_i where d_{iu} is the distance between points i and u raised at k representing the effect of distance decay (Wang 2000). The resulting surface was used to estimate which areas in the urban-change probabilities surface created in step 3 were more likely to be positionally accurate, and to what level.

Although an absolute historical map displacement surface was created for each map relative to the 2005 map (see Figure 10), my primary objective was to study changes that occurred between consecutive historical periods (between 1737 and 1820, 1820 and 1884, and 1884 and 2005). This was accomplished by using the interpolator given in equation (3) above. In the case of the 1737– 1820 comparison, the resulting displacement surface is presented at the bottom Figure 11 (“Distortion”).

- 5) Figure 11 shows the 1737 and 1820 maps only, but the procedure described here was applied to every pair-wise comparison. The centre-left part of Figure 11 shows how the two maps were first digitized and then reconverted to an image format (“Raster 1737” and “Raster 1820” – steps 1 and 2); these two images were subsequently summed (“Sum”) and the result transformed into an urban change probabilities surface (“Probability (1)” – steps 3 and 4). The bottom part of Figure 11 shows the relative displacement surface generated in step 4 (“Distortion” – step 4). This surface was used to weigh the urban-change probabilities surface. To understand how the weighting process works, consider the case of a cell in the urban-change probabilities surface with a value of “high” (i.e., a cell in which change is likely to have occurred): if the deformation surface showed a low value of deformation for the cell, then we assigned the cell a high probability of change in the final urban-change map generated, which represents the final estimation of urban changes that occurred in Milan between 1737

and 1820 (“Final – Probability (2)”). This process was carried out for each cell and for all three map comparisons.

Results

The outcomes of the procedure outlined above are three surfaces representing the temporal probability of change for the periods analyzed (see Figure 12). Absolute comparisons (historical maps vs. 2005 map) show that overall the 1884 Bassani map has the lowest RMSE (~7.7 m) and that this map’s scale is approximately 1:4,000; the 1820 Cagnoni map has an RMSE of about 21.4 m and was drawn at a scale of 1:8,000; and the 1737 Cairolo map is the least accurate, with an RMSE of about 36.5 m, and was drawn at a scale of 1:10,000.

Table 1 shows the total percentage of cells falling into each of four categories of probability of change (none = 0–25%; low = 25–50%; moderate = 50–75%; high = 75–100%). The 1737 map has an RMSE of approximately 51.9 m with respect to the 1820 map, and the 1820 map has an RMSE of approximately 24 m relative to the 1884 map (see Table 2). Also note, in Table 2, that while the difference in RMSE between the 1820 and 2005 maps and between the 1820 and 1884 maps is low, the 1737 map shows a considerable difference in RMSE values between the absolute (1737 vs. 2005) and relative (1737 vs. 1820) map comparisons.

The graph in Figure 13 shows differences in areas of moderate and high probability of change (>50%) when an absolute map comparison (light grey) and a relative map comparison (dark grey) are examined. Except in the 1884 vs. 2005 case, in which relative and absolute comparisons are coincident, lower RMSE values for the absolute map comparisons (historical maps vs. 2005 map) indicate a higher degree of feature overlap between historical maps and the 2005 map than exists between historical maps (1737 vs. 1820 and 1820 vs. 1884). In this sense, the RMSE value is really an indication of the relative positional accuracy of the historical maps (relative, that is, to the 2005 map and to one another). The RMSE value is also indicative of the

lower overall positional accuracy of the historical maps compared to the 2005 map, which reinforces our rationale for using urban-change probabilities surfaces in step 3 of the methodology.

Natalia and Gennady Andrienko note that “in order to be able to think about data, the mind needs to perceive the data” (2006, 166). In exploratory data analysis (EDA), the analytical part is performed by the mind, which perceives the data when they are appropriately processed and presented. Geovisualization helps in achieving this objective, and one of the ways in which it accomplishes this goal is through data manipulation. The purpose of data manipulation is to simplify the original data set in order to make it easier for the user to detect and extract important trends from the data: in our case, to detect and extract historical trends concerning urban morphological changes in Milan. I performed data manipulation by superimposing a grid of 50 x 50 m – 10 times the original raster size – on the maps in Figure 12. In the new grid, 5-m-resolution cells representing moderate and high probabilities of change (50–100%) were aggregated and then counted. The resulting visual display is a so-called binned scatter plot (see Figure 14(a)), in which the size of the marker (the red dots on the map) is proportional to the size of the aggregation unit (the number of cells representing moderate and high probability of urban change in the grid). This first piece of information already provides interesting results, but additional insights can be gained using a parallel coordinate plot (PCP) for each historical period under study (see Figure 14(b)). The PCP was created using GeoVISTA Studio, a software package that can be used to build customizable applications for geocomputation and geographic visualization (Takatsuka and Gahegan 2002). The main purpose of the PCP, originally developed by Alfred Inselberg (1985), is to allow visual detection of the interactions among the variables of a system, represented on parallel vertical axes: two adjacent axes connected by parallel segments represent a high correlation between the variables plotted on those axes, while a

decrement or no correlation among variables is represented by a cross-connection. In the case under study, the first two axes of each graph represent the x and y coordinates, while the other three axes represent chronologically ordered high probabilities of change. The red lines represent the highest concentration of moderate and high probabilities of change for each period analyzed; they correspond to the largest dots on the map. As one can see in the graph, the high concentration of change in the period from 1737 through 1820 (PCP on the left) identifies two main clusters of change in a north and a south-central position, represented by the clustering of lines on defined portions of the west–east and north–south axes (if there were no concentration of change, the lines would be evenly distributed along the axes and connected more or less horizontally). The locations of the two clusters are shown on the map above the graph. If the clusters of highest probability of change were in the same location for the 1820–1884 maps as they were in the 1737–1820 maps, then the lines connecting the third to the fourth axis would be straight. Because this is the case only in minimal part, one can say that the zones with highest probabilities of change from the 1737 to the 1820 map do not correspond with those from the 1820 to the 1884 map. This is indeed confirmed by the map in the top centre of the figure. Even more different are the clusters for the period from 1884 to 2005 compared to those from 1737 to 1820, as demonstrated by the diagonal direction of all lines and also by the map in the top right-hand part of the figure. The second PCP, for the 1820 vs. 1884 maps, can be read in the same way. This time a geographical cluster is less defined but is still detectable in a south-west–to–north-east direction. Again, there is little correspondence with clusters from the periods 1737–1820 and 1884–2005. The third PCP shows a well-defined geographical cluster, as is confirmed by the map immediately above, and low correlations with the preceding maps.

Discussion

The temporal spatial patterns of change in Figure 14(c) show the distribution of urban change across the three intervals of time analyzed: the pattern of clustering in the binned scatter plots at the urban level, mainly located along the ancient Roman *Decumani* (represented by the dark crosses in Figure 14), appears to reflect broader international systems characterized by other competing centers of gravitation in which Milan is included and “polarized” over time. This “cloud of change,” represented by the blue outline in Figure 14(c) appears to be moving from southeast to north-west according to historical events that characterized the city of Milan.

During the earliest period (1737–1820, Figure 14(c) at left), changes are still concentrated along the major axis of the ancient and medieval city, represented by the road through the old south-eastern gate (the *Porta Romana*) connecting Milan to central Italy and Rome via Bologna. A second cluster of change, however, is clearly identifiable along the north-eastern axis; this is the road to Vienna, site of the Habsburg court and the centre of the Austrian Empire, which had been ruling the city since the beginning of the century (1706). Again, such spatial structure finds confirmation in the urban-renewal projects concentrated in the north-eastern districts of the city before and after the Napoleonic interlude (Ricci 1999). This gravitation along the north-eastern axis is still visible during the second interval (1820–1884, Figure 14(c) at centre). However, the map shows an increasing concentration of high probability of change in the western zones and less change in the city’s south-eastern districts, which become increasingly peripheral as the Italian peninsula became more and more marginal with respect to the European centers of world trade and politics. This shift could tentatively be related to the increasing westward cultural polarization of the Milanese bourgeoisie, which during the first half of the nineteenth century gradually turned away from Vienna to forge an alliance with Turin and the liberal western metropolises (Paris, London, Geneva), leading to the

birth of the unified Italian state in the second half of the century (Greenfield 1934; Limoli 1958). Finally, Milan's new western orientation clearly predominates in the third and last historical period examined (1884–2005, Figure 14(c) at right). The cluster in the figure highlights the marks of both the second wave of post-Unification restructuring (to which the central district's layout owes its final form) and the development of the Castle area, which had been started by Napoleon at the beginning of the nineteenth century. These events appear to be reflected in the urban morphology of Milan, to an extent and to a scale (neighborhoods in a city) that were unexpected.

I should stress that an analysis of the type described above relies on working with positionally accurate maps – that is, with maps that were created with the explicit purpose of faithfully reproducing the exact location of features on the ground. This is indeed the case for the 1737, 1820, 1884, and 2005 maps used in this study. However, I should note that even within this set, the later maps tend to be more accurate than the earlier ones, reflecting technological changes over time, especially with respect to surveying techniques. This is particularly true of the 1737 map, as discussed in this section – hence the probabilistic approach and generalizing functions included in my methodology.

Future directions and lessons learned will be discussed at the end of the dissertation in the Conclusion section.

Figure 3. The 1737 Cairolo map (Biblioteca Trivulziana, Milano).

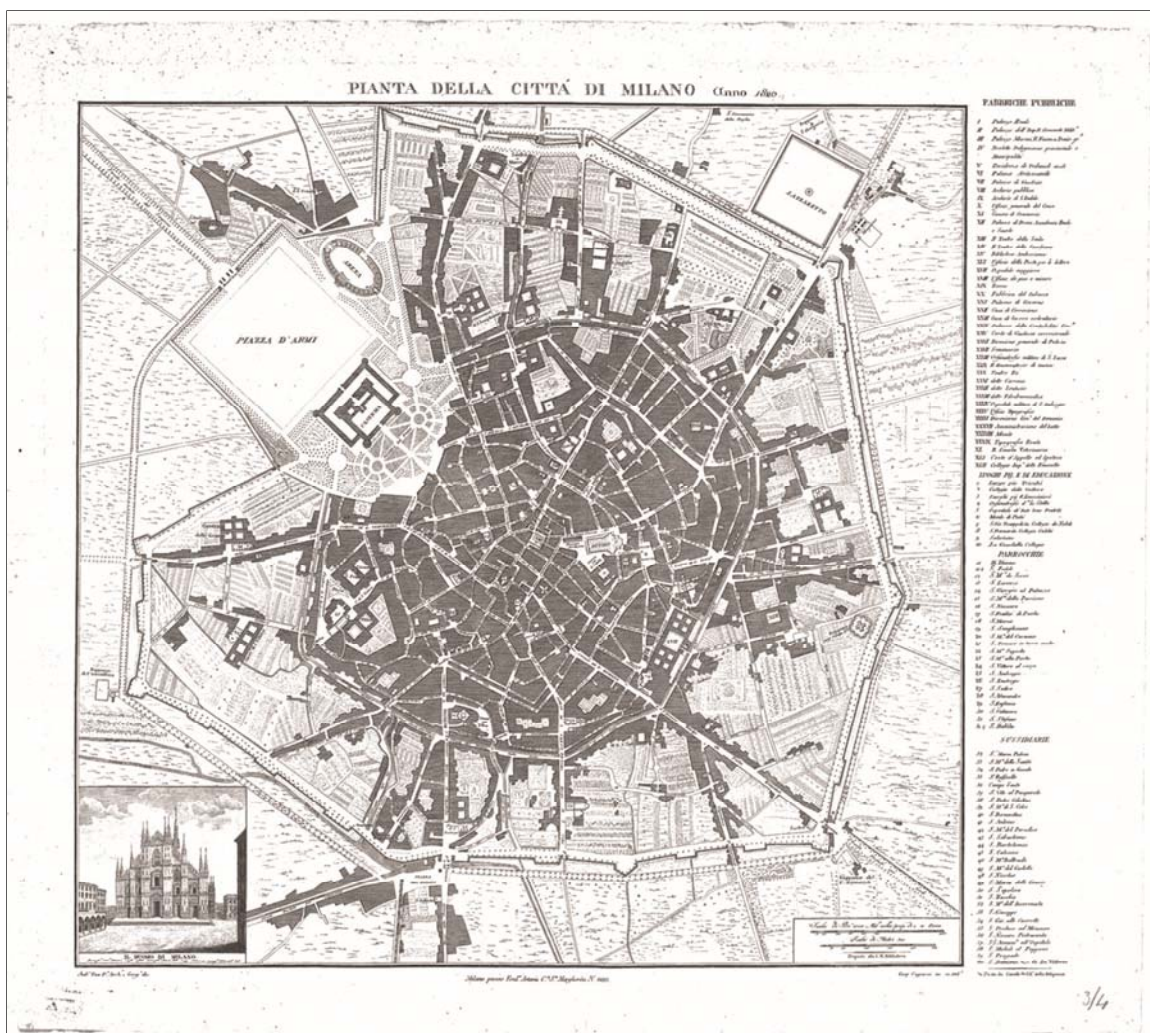


Figure 4. The 1820 Cagnoni map (Biblioteca Trivulziana, Milano).

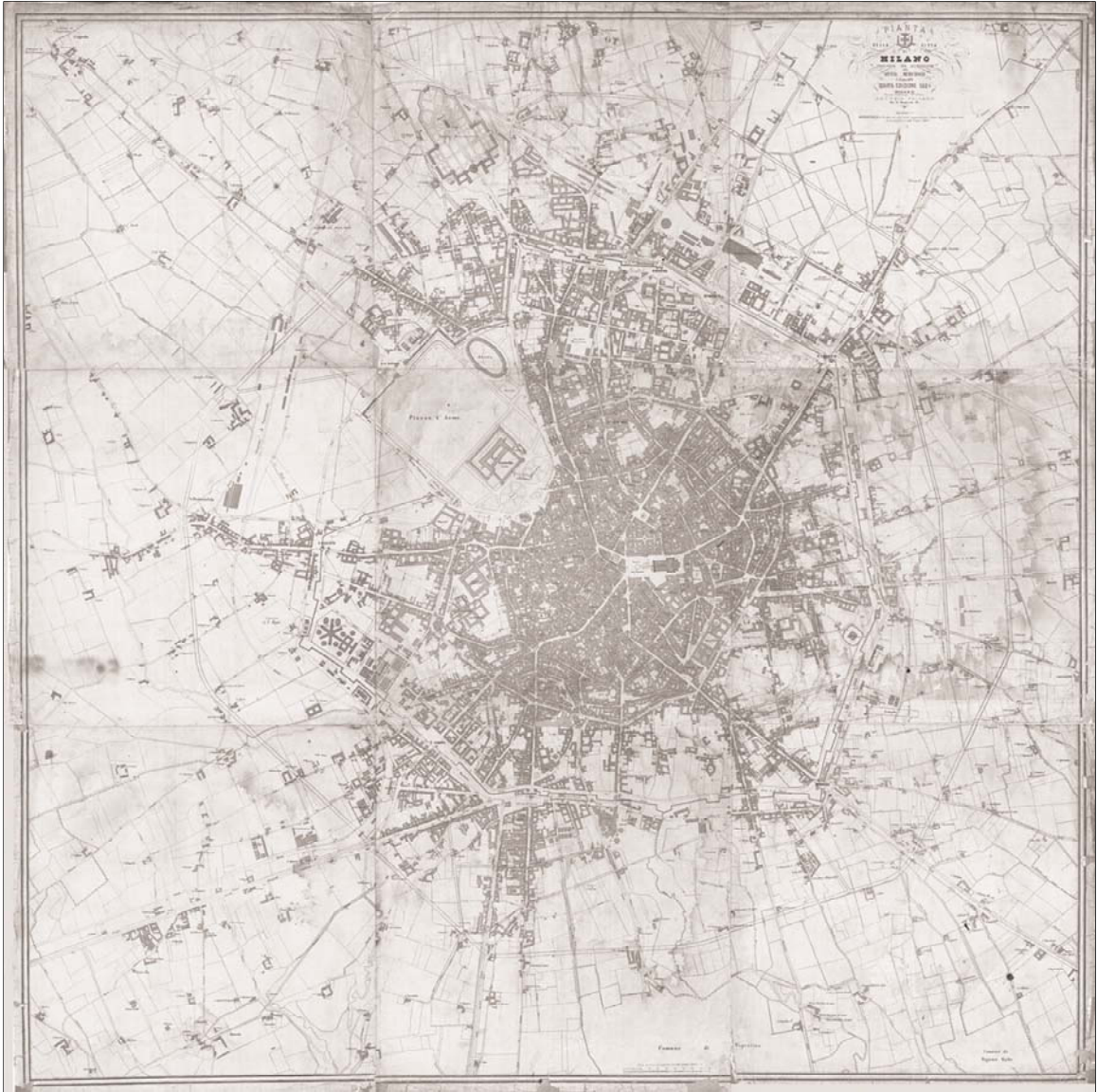


Figure 5. The 1884 Bassani map (Comune di Milano, Milano).

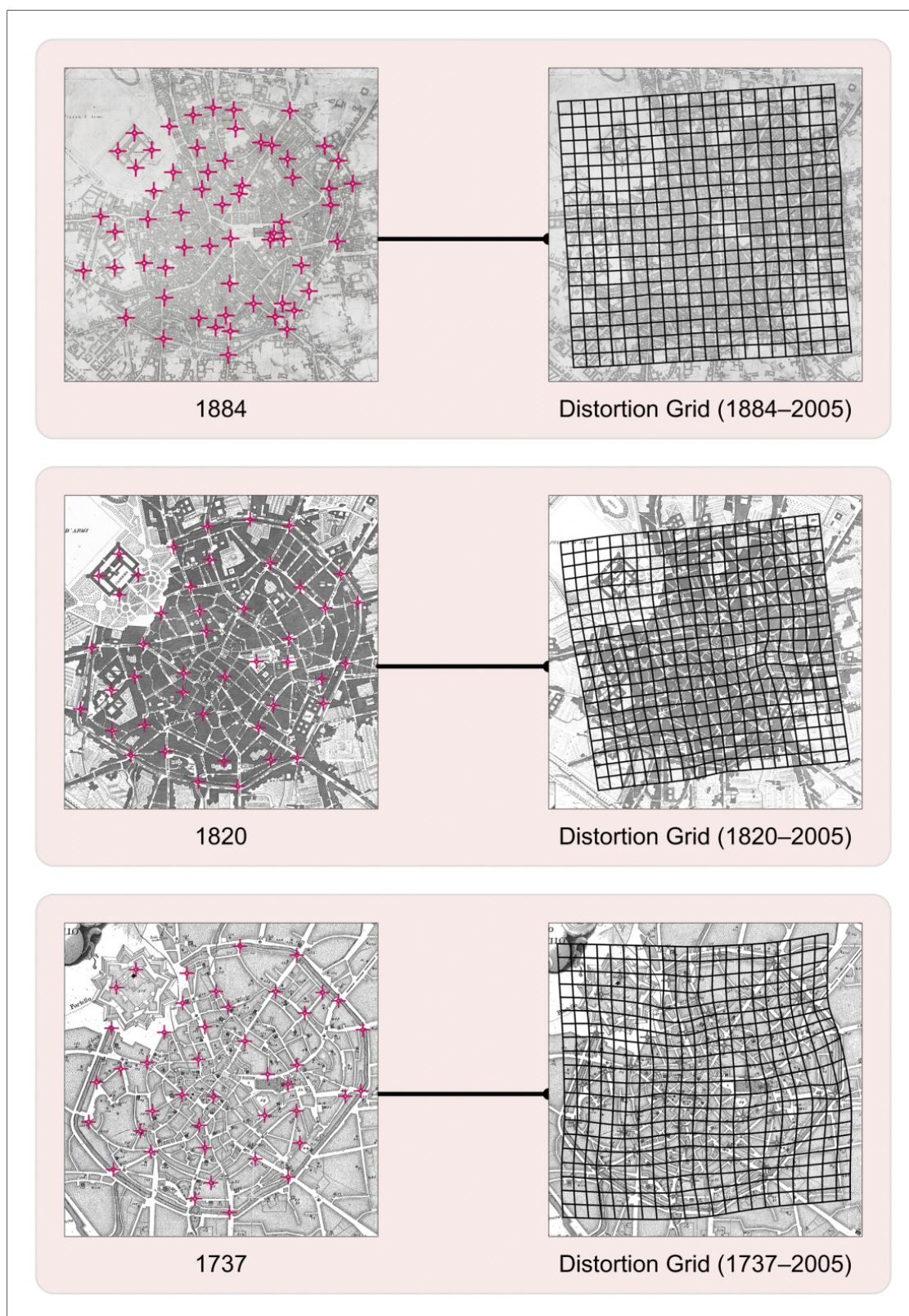


Figure 6. Control points and distortion grids of the historical maps under study (maps not to scale).



Figure 7. Neighborhood generalization and building amalgamation (map digitizing process).

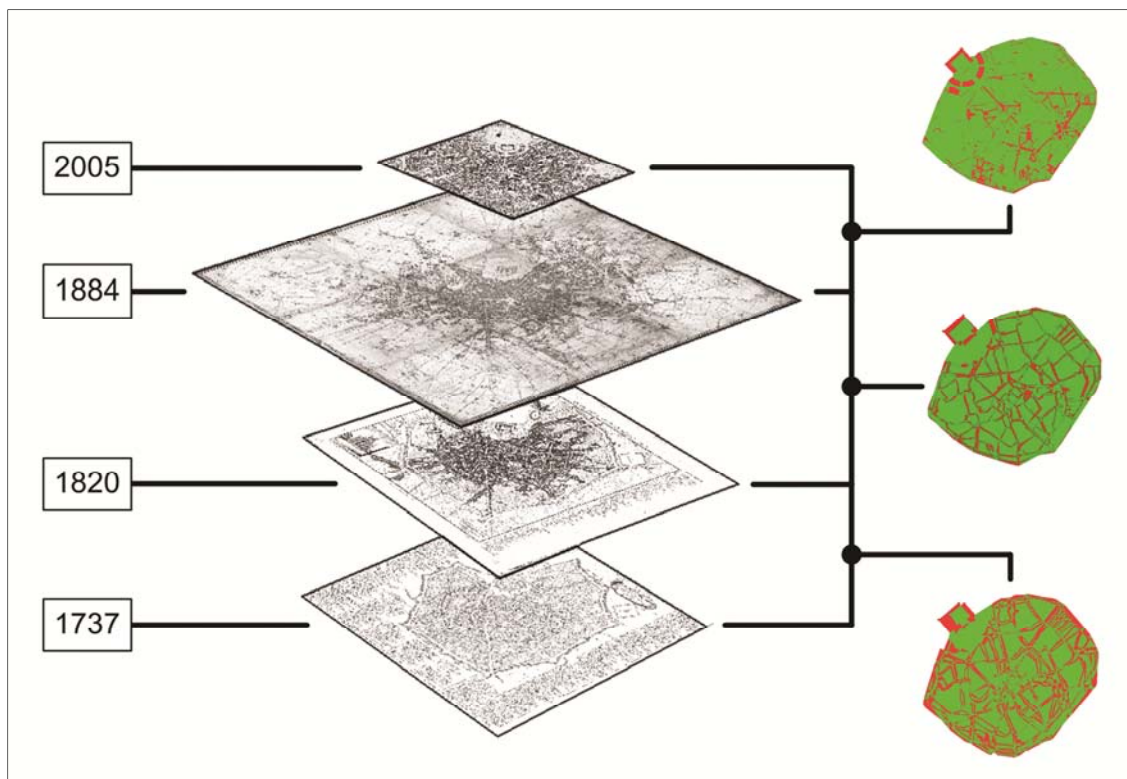


Figure 8. Historical map overlays and feature change (green: unchanged zones; red: changed zones).

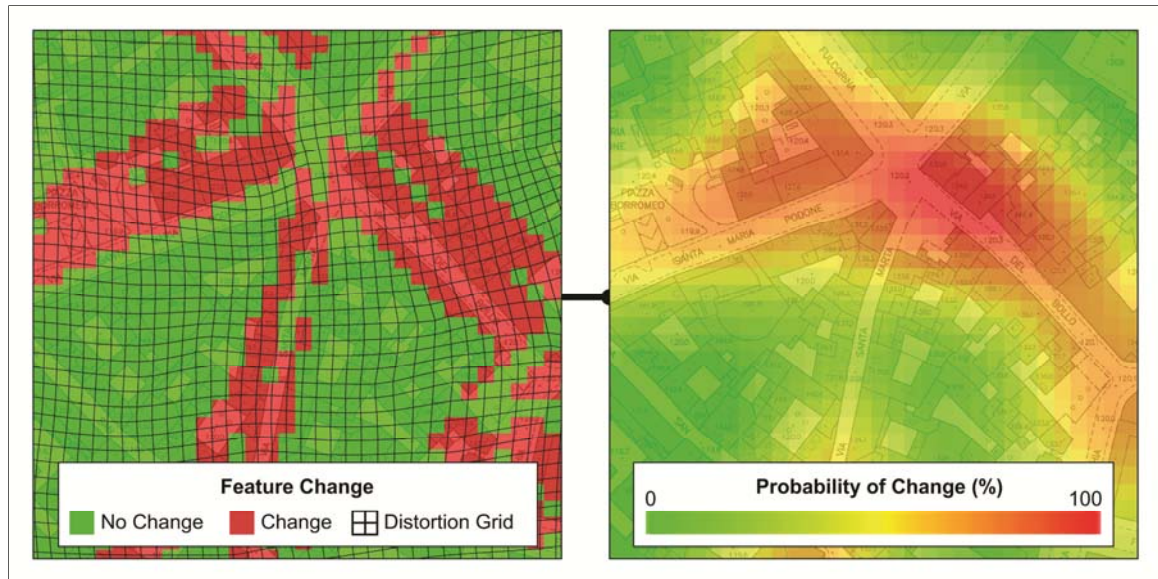


Figure 9. Feature-change detection (left) and creation of the urban-change probabilities surface (right). The example is that of changes occurring between 1737 and 1820, draped on the 2005 map.

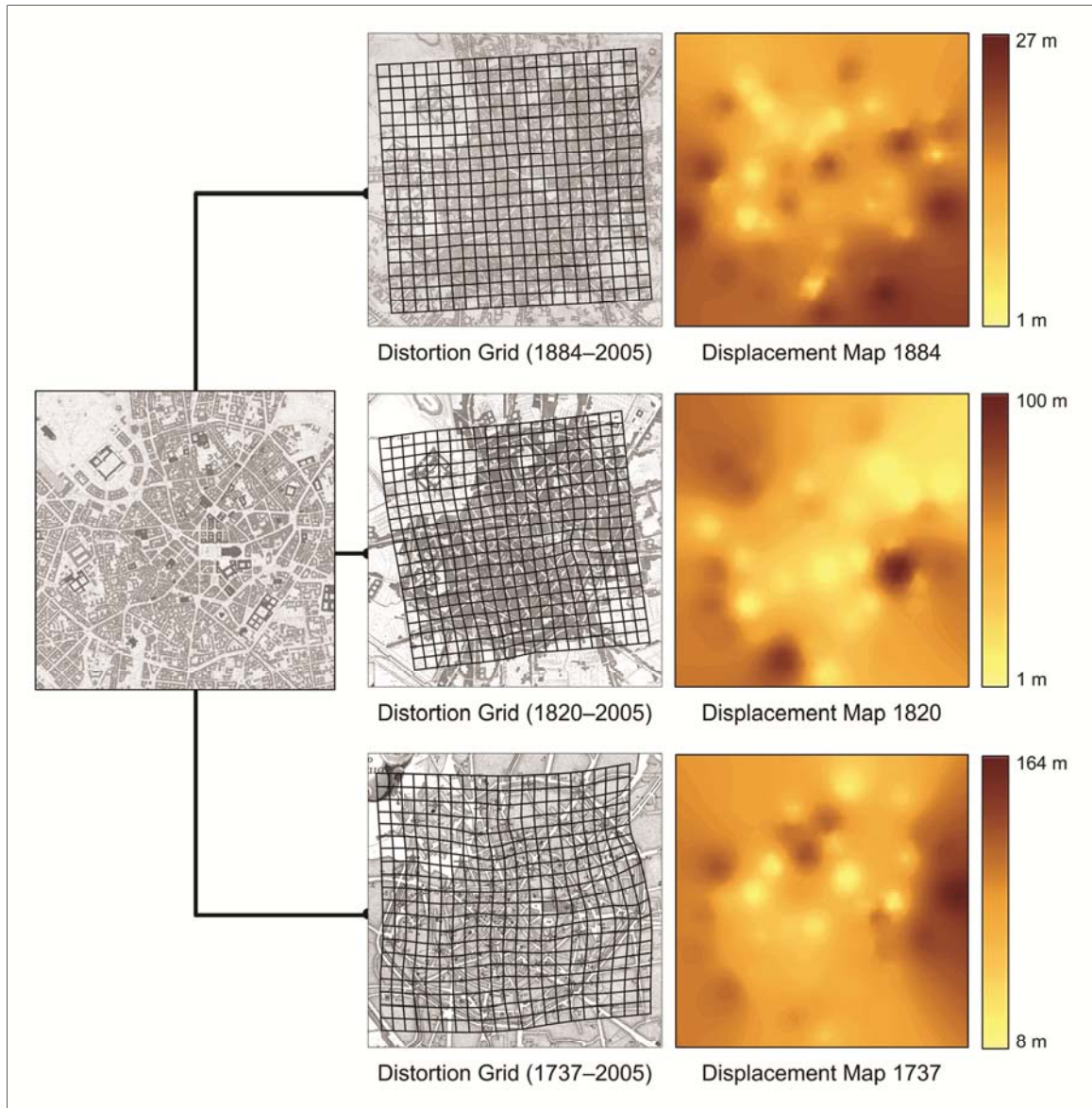


Figure 10. Distortion grid and displacement surface of the historical maps relative to the 2005 reference map.

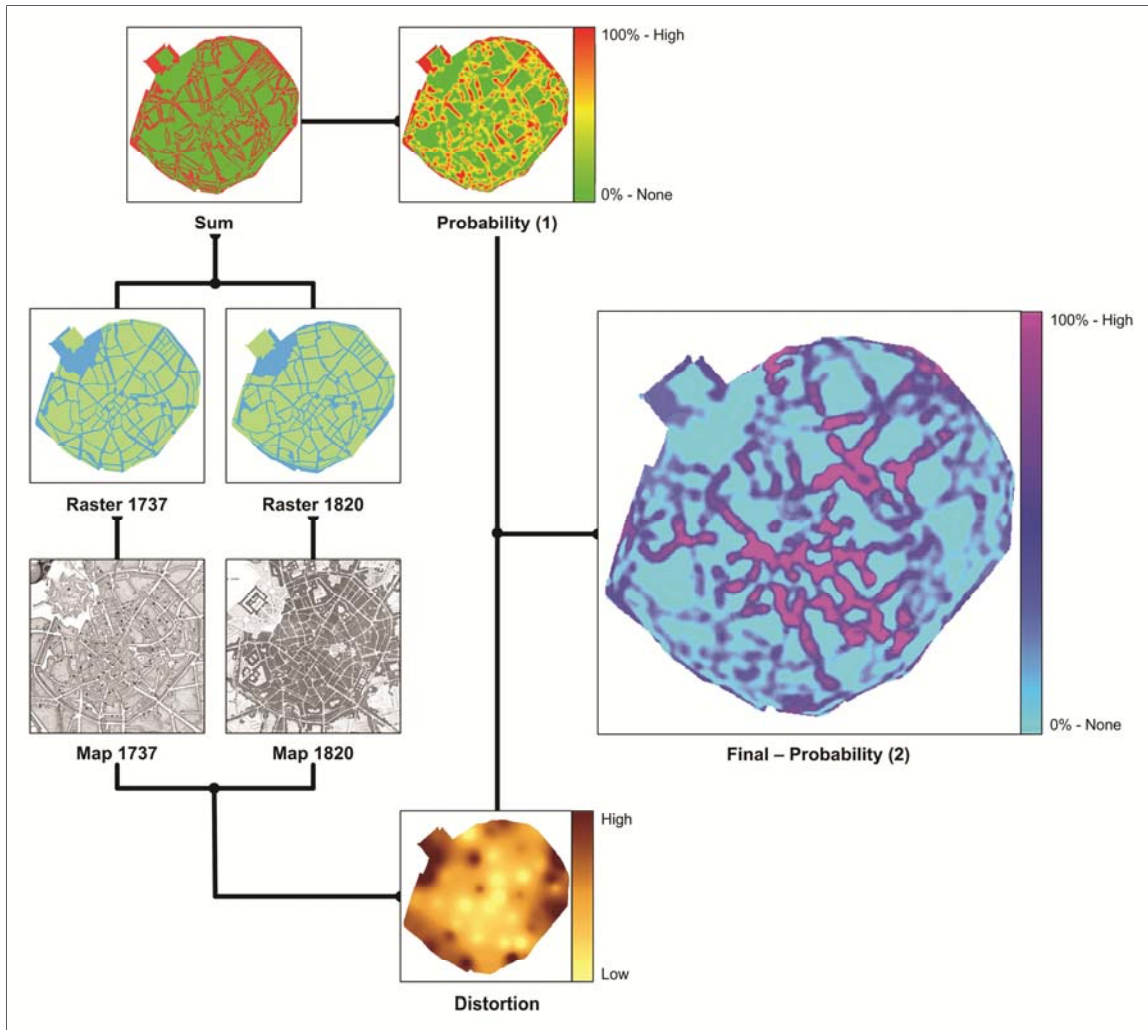


Figure 11. Derivation of the final urban-change map; the example shown is for the 1737–1820 time interval.

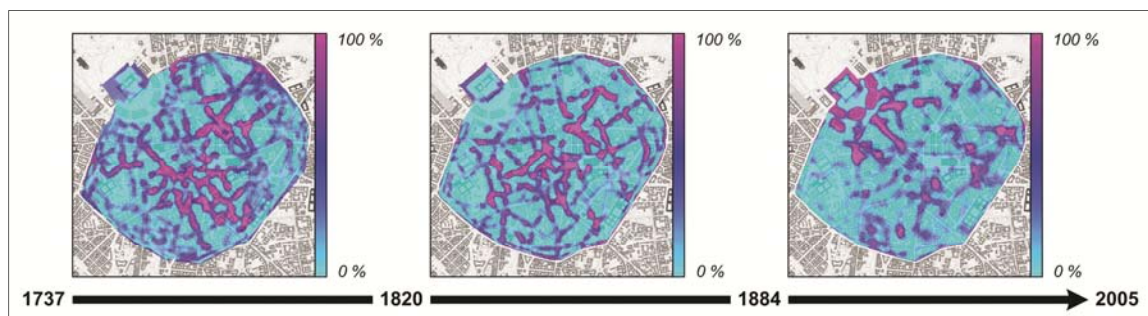


Figure 12. Surfaces representing the final temporal probabilities of change for the time period under study.

Table 1. Probability of urban change for the periods under study.

Periods	Urban Change (% cells)			
	None	Low	Moderate	High
1884 - 2005	71	22.5	5.2	1.3
1820 - 1884	63	25	10	2
1737 - 1820	54.7	33.7	10.2	1.4

Table 2. Comparison between relative RMSE (historical maps vs. historical maps) and absolute RMSE (historical maps vs. 2005 map).

Maps	Absolute and relative RMSE (m)		
	1820	1884	2005
1737	51.9	-	36.5
1820	-	24	21
1884	-	-	7.7

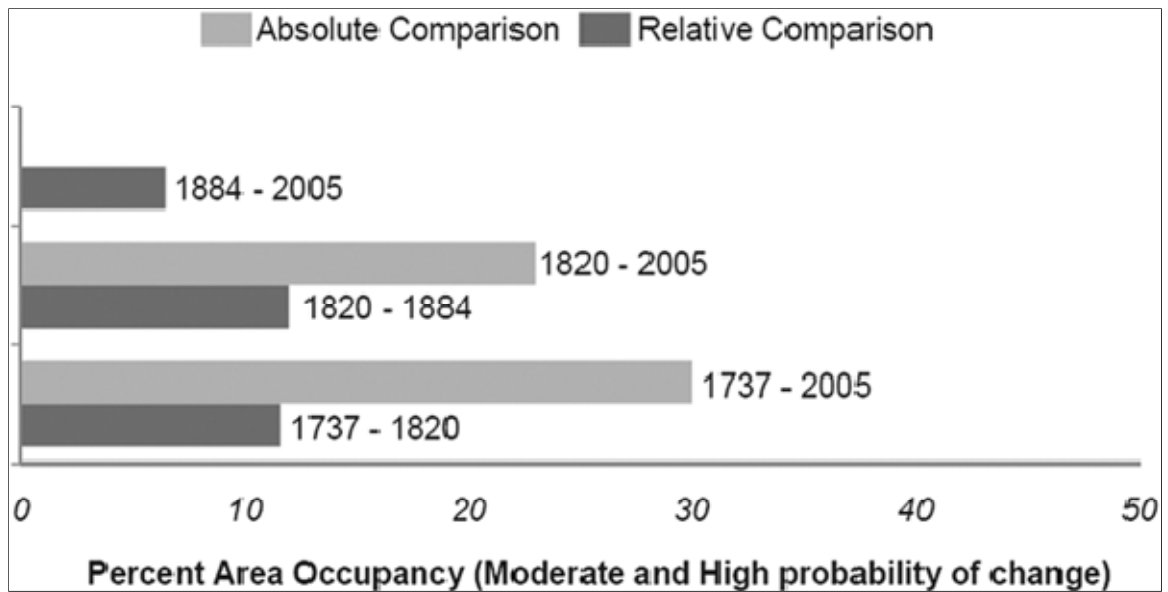


Figure 13. Percentage of cells falling into the categories of high and moderate probability of change. In light grey are comparisons between historical maps and the 2005 map; in dark grey are comparisons between historical maps.

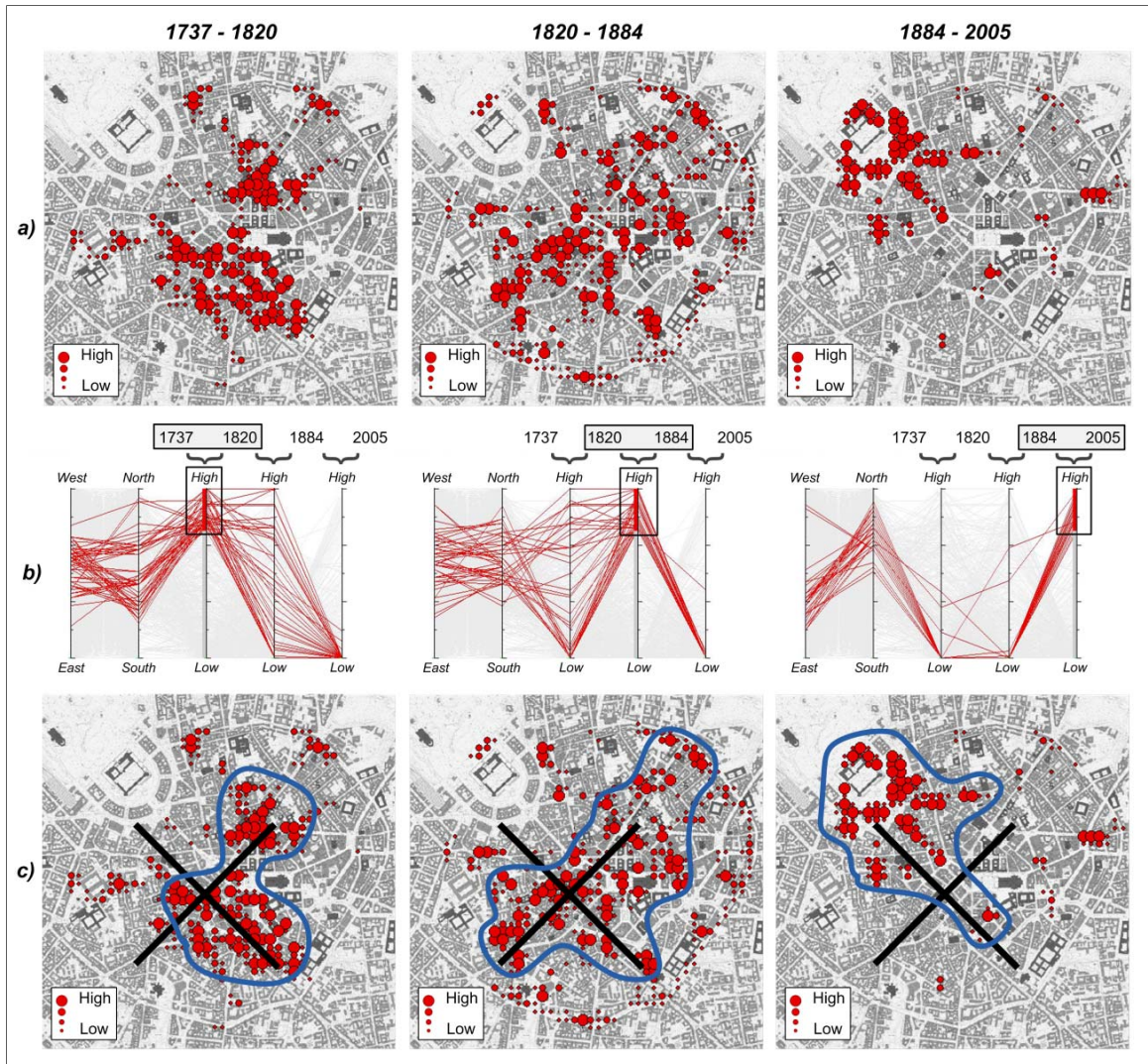


Figure 14. Spatial patterns of high probabilities of urban change, 1737–2005.

CHAPTER II

LAYERING THE TOPONYMIC TAPESTRY OF THE CITY

Objectives

In this chapter, I discuss how Historical GIS can be used to interrogate the current system of street-names embedded in the center of the city of Milan, considered as a ‘tapestry’ in which different ‘threads’ and ‘patterns’ can be recognized. The focus will be on the coexistence of fragments from different historical periods that have been left behind by the string of sociopolitical struggles and turning points that marked the city’s long political and social history. The place-names linked to the different hegemonic discourses and regimes that were inscribed into the city-text during the long history of Milan as an urban and metropolitan center will be read as the ‘layers’ in an ancient city discovered by an archeologist, partly collapsed into each another. To achieve this goal, the principles, methods and tools of GIScience and Historical GIS will be used throughout this chapter. I believe that a theoretically conscious and cognizant use of spatial-analytic methodologies could offer an antidote to “the longstanding tendency to tame the spatial into the textual” (Massey 2005), and contribute to the ongoing attempts to build fruitful bridges between quantitative and qualitative methodology in human geography (Kwan and Schwanen 2009).

In the past two decades, the field of toponymy has undergone a major process of reorientation (Berg and Vuolteenaho 2009). The traditional focus on the etymology and taxonomy of place-names has been replaced by a new concern in the authoritative *act* of naming as a social practice embedded in social and political struggles. This ‘critical turn’ and the

new interest in the politics of naming (Yeoh 1996; Azaryahu 1997; Alderman 2000; Azaryahu and Golan 2001; Rose-Redwood 2008) has crucially exposed “the essentialist claims to affixing stable identities to particular spaces” that were implicit in the traditional scholarship on place names and originated “an exciting new body of research, which situates the study of toponymy within the context of broader debates in critical human geography” (Rose-Redwood, Alderman and Azaryahu 2010, 454-455). The analysis of the texture of street-names in urban spaces has been invested by this new perspective that embeds the process of naming in the struggle between social groups for power and legitimacy. Once the system of street names has been reinterpreted as a ‘city-text’ and interpreted as a palimpsest which can be re- and over-inscribed, it appears evident that any street-naming regime is inherently instable and historically contingent. While the toponymic changes that often accompany major ideological struggles and power shifts have been the object of several of the studies that mark the ‘critical turn’ in toponymy studies, the works that analyze the process of multiple replacement of different regimes of toponymic inscription over long periods of time are still rare.

In the last decades scholars have increasingly read cultural landscapes as systems of symbolic inscription in a contested socio-political space (Meinig 1979; Duncan and Duncan 1988; Duncan 1990; Zukin 1991; Barnes and Duncan 1992; Baker 1993; Duncan and Ley 1993). While the interest of some authors has concentrated on memorials, statues and monuments (Johnson 1994 and 1995; Verdery 1999; Whelan 2001), others have focused on toponymic systems and the process of place naming (Tuan 1991; Kearns and Berg 2002; Conedera and others 2007; Henige 2007). In the cartographic context, the role of toponyms as both map elements and symbols of power has been debated since at least the 1980s (Harley 1988 and 1989; Wood and Fels 1992; Monmonier 1996; Jacob 2006; Wood 2010).

Place naming has been demonstrated to be a key element in nationalist discourses and efforts at community-identity building (Zelinsky 1983; Stump 1988; Rogers 1995) and the focus of the struggles over social and political individualities (Cohen and Kliot 1992; Berg and Kearns 1996; Gonzalez Faraco and Murphy 1997; Herman 1999). If mapping is a direct reflection of social power (Harley 1988, 1989, and 2001), the same can be said for the act of naming places as a symbolic control of public space (Robinson 1989; Pratt 1992; Azaryahu 1996). Through the naming and renaming of the street network of a city, the hegemonic discourses that provide legitimization to the existing socio-political order and the ruling authority are projected onto the physical territory and naturalized in the activity of everyday life (Yeoh 1996; Azaryahu 1997; Withers 2000; Azaryahu, A. Golan 2001). The act of naming has been described as a twofold procedure directly derived from the concept of remembering-forgetting (Gross 1990; Hoelscher and Alderman 2004; Hebbert 2005; Chang and Huang 2005; Legg 2007; Dwyer and Alderman 2008; Rose-Redwood 2008): a previous name (if it exists) is first eradicated along with its meaning, to be replaced by a new one carrying its own socio-political significance. Due to its immediate reflection upon the human environment, the act of street naming can be considered one of the most rapid manifestations of the appropriation of a territory (Levinson 1998; Light 2004), which explains why virtually every radical change in political regimes during the last century was accompanied by the renaming of street networks in urban centers across Europe and elsewhere (Richman 1983; Azaryahu 1996; Yeoh 1996; Azaryahu 1997; Light 2004). Thus, the streetscape has a wide significance in the cultural history of an urban place. Gross (1990) argues that, within urban environments, physical structures from the past represent a direct link to the history of the place, projecting the present to a time when they were new. As such, these structures were intended to convey specific messages when they were built. The present observer may interpret them as representing 'frozen' signs whose signified messages may or

may not be comprehensible; or, in the worst case, not be perceived as signs at all, thus losing their meaning and becoming unattached signifiers devoid of referents: “places of memory are sites where the symbolic imaginings of the past interweave with the materialities of the present” (Rose-Redwood 2008).

Azaryahu and Foote (2008) provide an extensive description of several ways in which spatial narratives can be anchored to a place. They note that historical events represented through landscapes can span from seconds to centuries in time and occupy a few meters to hundreds of kilometers in space. Such spatial configurations of history are conveyed through the landscape as landmarks, or paths, or embodied in areas. In spatial geometry terms, landmarks are points where events are tied to single and easily marked places like inscriptions at precise sites, or as lines when history is narrated along paths characterized by starting and ending point (e.g., gates), or as areas when events occur over a wide region (Azaryahu and Foote 2008). Dwyer and Alderman (2008, 169) suggest an interesting metaphor of this time-space bond: “in a manner analogous to the geologic process of sedimentation, uplift, and erosion, memorials undergo symbolic accretions over time as different historical meanings are layered onto them [...]”. As geological formations, spatial narratives are layered upon the city, accumulated and eroded by exogenous agents, revealing both ‘tectonic windows’ open to the past and isolated ‘klippen’ left in place by ancient ruling elites and hegemonic discourses of the past.

Following these authors, as well as my earlier work on morphological changes that have occurred in Milan at the intra-urban scale (Tucci, Giordano, and Ronza 2010), in this study I examine the streetscape toponyms of the downtown area as examples of iconographic texts, written throughout the urban space over the course of several centuries. Treated as networks, flows and arcs in analytical geography, streets clearly have a symbolic and representational dimension (Alderman 2000). By studying, mapping and highlighting these dimensions for the city

of Milan, I hope to demonstrate that Historical GIS applications can contribute to gain in-depth knowledge into their territoriality.

Starting from the ‘geological’ metaphor introduced by Dwyer and Alderman (2008), I propose another one: the cityscape as a multi-color ‘tapestry’ where different threads of different colors have been crafted and arranged in patches through struggles and replacements over the centuries. I will use this metaphor to highlight the co-existence of different narratives and conflicting ideologies within the structure of contemporary streetscapes. In this context, the street network of Milan, which has already been studied in its historical development and mutability (Arnaud 2008), provides a particularly rich example of historically layered urban landscape and is an ideal case-study for marrying historical geographic analysis with spatial-analytic methodologies. As such, it should be noted that the intent of this study is not to reconstruct the “linguistic toponymic cartography” (Lord Smail 1999) for the entire city of Milan, as the identification of the whole sequence of names for each street segment during all historical period from Roman times is far beyond the scope of this chapter. Although the methodology I propose here could be applied, fruitfully I think, to such a study.

Methodology

A fundamental step in Historical GIS applications is the construction of the database. In the case analyzed in this study, the starting point was the acquisition of the 2005 digitized street network for the city of Milan, courtesy of the municipality’s GIS office (Sistema Informativo Territoriale del Comune di Milano 2005). The acquired digital database was modified to fit the study’s needs by eliminating features and attributes, such as double lines and lane numbers, that were of no use in my analysis. For this study, I define a *street* as any two dimensional object that can be represented in a database as a line with a starting point and an end point. I then used the resulting network to take measurements of length; in the case of squares, I measured

the perimeter of the feature. After this initial phase of data pre-processing, spatial and thematic information was added to the geographical database.

The area chosen for the analysis is the historical center of Milan, the part of the city within the Early Modern (or 'Spanish') Bastions (*Bastioni*) that encompasses the original nucleus of the Roman and Medieval cities and the area continuously settled since the Renaissance (Figure 15). While almost all the built environment outside the *Bastioni* is the result of the fast and massive urban expansion that started in the Industrialization era after the 1870s, the downtown area displays most clearly the spatially and temporally layered nature of the city. The study area is divided in three concentric zones (left on Figure 15. See also Figure 2):

- The Roman zone: the space located within, or immediately attached to, the outline of the Republican and Maximian walls built between the 1st century B.C.E. and 305 C.E.. These walls were gradually demolished during the Middle Ages, although their mark is still partly visible in the street layout.
- The Medieval zone: the area located within, or attached to, the Medieval wall ring built between 1156 and 1171. While these walls were mostly demolished by the beginning of the 19th century, the canal that ran along them (the *Fossa interna* of the *Navigli*) was only filled during the Interwar and its layout is still clearly visible in the street pattern.
- The Early Modern zone: the area located within, or attached to, the *Bastioni*, the outer wall ring built at the beginning of the Spanish rule between 1549 and 1560 and partially demolished between the 1920s and 1930s.

For a more detailed explanation of the historical setting see also the chapter titled: "Milan Through the Centuries".

This subdivision allowed me to identify each street segment by its current toponym and by the historical zone within which it is currently included. In addition to splitting the street network into temporally-determined concentric zones, I divided it geographically by *Sestiere*. The *Sestieri* (plural) are the six neighborhoods arranged around the city's center (*Piazza Mercanti*) and named after the corresponding gates (right on Figure 15) into which the city was parceled until the end of the Austrian rule. Even after it lost official value for administrative purposes, the partition of the historical center into the six *Sestieri* remained the major focus for sub-urban local identity formation in the city's folk culture and an important grid in the locals' mental maps until recent times. In my analysis, I will first discuss temporal changes at the city level and then focus on how different historical periods have left their mark at the neighborhood level.

My main addition to the street database consisted of two pieces of information: the historical period when a certain street was physically built (the 'Object Age' attribute) and the historical period when the current (2005) toponym was assigned to that street (the 'Object Name Age' attribute). The value of the two attributes was assigned through a street-level exam of the existing local-historical literature on Milan's street names, as updated and consolidated in the most recent scholarship (Buzzi and Buzzi 2008). Published materials were complemented by an in-depth visual exploration of historical maps of the city, conducted following a simple principle: when a street was not present in a map of year X but it appeared in a map at similar scale of the year X+t, that street had to be created sometime between the years X and X+t. In this way, I was able to add to the local historical literature an estimation of the date of construction and naming of individual street segments. The periods chosen (see Table 3) capture historically recognized major points of discontinuity in both the political and urban history of the city. In the table, note the different coding of Object Age and Object Name Age adopted for the

Roman and Medieval periods: although both Medieval/Roman-derived (MRD) and Medieval/New (MN) are relative to the time before 1550, the former is associated with streets whose names were assigned during the Medieval period but which identified a Roman landmark, while the latter is associated with streets named in the Medieval period after Medieval landmarks with no link to Roman times.

The historical maps analyzed were acquired digitally from the City of Milan and the Biblioteca Trivulziana (Sistema Informativo Territoriale del Comune di Milano 2005; Biblioteca Trivulziana 2005). The list is as follows:

- 1551 – Matthäus Seutter
- 1600 circa – Author unknown
- 1786 – Six anonymous sheets attributed to Arcangelo Lavelli
- 1788 – Arcangelo Lavelli
- 1820 – Cagnoni
- 1844 – Giuseppe Pezze
- 1856 – Giuseppe Pezze
- 1910 - Town Planning Scheme (Piano Regolatore Generale, P.R.G.)

The resulting historical street network geographic database is composed of 650 unique segments, some of which are extensions of existing streets built in earlier historical periods. Figure 16 charts the number of segments/toponyms for each period in different zones and Figure 17 shows the percent of street segments by Object Age and Object Name Age.

As previously stated, besides the historical concentric zones, another geographical subdivision within the city center is taken into the account: the six *Sestieri*, the traditional neighborhoods of the historical city. By changing scale, the objective is now to discover and discuss local variations in the patterns emerged from the city-wide analysis.

The question here is if, and to what extent, GIS-assisted place-naming analysis can contribute to landscape and urban studies and to the work of cultural preservationists trying to make sense of the distinctive—even if not necessarily discrete or inherently unique— atmosphere of a place, that common-sense perception of residents and outsider observers alike often identified as the partitioning of continuous cultural landscapes, including historical cityscapes (Jackson 1994; Jivén and Larkham 2003). My aim here is not trying to discovering clearly demarcated and objective spatial identities, or to speculate about a *genius loci* that would identify each of them. Essentialist approaches to identity and place have long been criticized for assuming that an objective and universal sense of place exists in each locale. However, I argue that a sensible application of GIScience tools, particularly of multi-scale spatial analytical techniques, could help incorporating social positionality into the study of locales and inquire into those ‘fuzzy identities’ that are part of our daily experience of space, without taking on any essentialist commitments (Cohen 1995). In this perspective, the *Sestieri* are simply taken as sites for a medium-scale analysis of variations within the urban tapestry, with no *ex-ante* assumption that each of them must display any distinctive or predominant character. I simply asked myself whether a particularly high density of segments and/or street-names from a particular layer in the city’s past could be said to mark, wholly or partly, the *Sestieri*, thus attributing to portions of the urban space a slightly or strongly predominant (albeit not exclusive) character.

Results

The Historical GIS described in the previous section quantifies and visualizes the different layers that make up the streetscape of contemporary downtown Milan. Table 4 shows the number and percent of street segments by Object Age and Object Name Age. The values on the diagonal represent street segments that have retained their original toponym throughout

the periods represented. Above the diagonal are values representing cases of appropriation-by-renaming of a street created during an earlier period. The values below the diagonal refer to an extension of a pre-existent street: when a street segment was added to an already existing one, or a square reshaped or enlarged, the modified element kept the existing older name, thus originating the apparently contradictory case in which the name of an object is older than its date of construction. Apart from a few (eight) Roman-derived toponyms assigned to Medieval segments during the Middle Ages, all street names either refer to the time the street was built or to a later time. The table also reveals that the Medieval, Post-Unification and Twentieth Century periods tend to preserve their names.

As previous research has shown, a relationship may exist between the importance of a street and its physical dimension (Alderman 2000). When taking into consideration the mean street length in meters for each group (Table 5), and assuming—not unreasonably—that length equates importance, additional important characteristics of the streetscape become apparent. While the major influence of the Post-Unification period on earlier periods stands, the relative influence of Twentieth Century toponyms is somewhat diminished. What is clearly apparent instead is the influence of the Early Modern period on the Roman one and of the Austrian-Napoleonic period over the Early Modern. Interestingly, the Roman segments that have maintained their denomination have a longer mean length than those of the Twentieth Century layer, which are more numerous. From this perspective, then, the relative importance of Twentieth Century segments is somewhat lessened.

The following analysis highlights the political-ideological discourses that competing social elites, imagined as layers (described below) in an archeological site or patterns in a multicolor tapestry, have left on the streetscape of Milan through multiple processes of naming and renaming.

The Roman layer: the hidden palimpsest

The most striking aspect of the Roman layer (Figure 18) is its hidden nature. In fact, while much of the Roman street layout has survived to date (as recent archeological research has shown), and still constitutes the grid of the Roman zone (with some inroads into the outer zones), very few Roman toponyms have survived to date. Most of the original Roman layout, 76.5% of which is located in the Roman zone, 7.8% in the Medieval zone and 15.7% in the Early Modern zone, was renamed during the Middle Ages and renamed again during the Post-Unification period (as shown in Table 4). Only 10.8% of the total Roman street segments maintain Roman-derived Medieval toponyms, for the most part located in the Roman zone with a few in the Medieval one. Generally, these street names derived from demolished Roman landmarks that were transferred to churches during the Early Middle Ages. Examples are *via S. Giovanni sul Muro* (St. John at the Wall – after a church built next to the Roman Walls), *via S. Maria alla Porta* (St. Mary at the Gate), *via S. Vittore al Teatro* (St. Victor at the Theatre), and *via Circo*, after the church of *S. Maria al Circo*, (St. Mary at the Circus).

The Medieval layer: the resilient infrastructure

The analysis of the Medieval layer highlights the major event in the history of Milan's urban streetscape until the 19th century: the appropriation of the Roman layout by the Medieval city (Figure 19). Focusing on the two oldest zones (Roman and Medieval), not only are newly created Medieval streets filling the gaps left by the original Roman street layout, but they also penetrate into it. Within the two inner zones, most of the toponyms in use before 1859 date back to the Medieval period. Medieval street names originated from popular usage, and were given formal status only in 1786, when the first *ad-hoc* commission for toponymy (led by a member of a Milanese patrician family, Count Cusani) was appointed by the Austrian

government to give official sanction to existing street names (Buzzi and Buzzi 2005). Medieval toponyms clearly contributed to inscribe the two forms of social powers and ideological discourses that dominated the urban community during the Middle Ages into the urban space. Derived from local landmarks, Medieval toponyms are generally tied to the seals of social and political power of Medieval Milan: local patrician families whose homes lay on the streets (e.g. *Via dei Morigi*, *Via Amedei*) or Christian saints after whom local churches were named (e.g. *Via Santa Marta*, *Via San Clemente*). The first type comprises 83% of the total streets created or renamed during the Medieval period, with the remaining 17% being religious toponyms. The importance of the toponyms based on Christian saints in the symbolic infrastructure of contemporary Milan (a highly secularized city, like elsewhere in Europe) offers a striking example of the resistance that apparently 'defeated' regimes of signification can pose to new attempts of spatial inscription. In the case of Milan, this testifies to the hidden continuity between the Medieval city and the modern city. In fact, many Medieval toponyms in the contemporary city-text survived not only the demolition of the churches they were named after during Joseph II's anti-clerical regime (1780-1790), but, even more strikingly, also the comprehensive renaming wave that occurred after the Unification. Most of them were in fact retained by the commissions appointed by the Liberal Municipality during the 1860s (Brentari 2008). Besides pointing to the particular proximity between Liberals and Catholics within the Milanese elite during the Risorgimento (Reynolds 1951), this survival suggests the importance and the meaning that terms like 'resistance,' 'negotiation,' and 'compromise' between competing systems of signification may assume from a *longue durée* perspective, and their role in making any city-text inherently contradictory, heterogeneous and plural.

The Early Modern and Austrian-Napoleonic layers: the birth of the 'calculating state'

Compared to the Medieval period and also to later periods (Post-Unification and Twentieth century), the four centuries of foreign-absolutistic rule have left a quantitatively weaker mark on both the physical and the toponymic aspect of Milan's streetscape (Figure 20). However, it is in these centuries that Milan witnesses the emergence of the structures and practices of the modern state, including the 'political technologies' aimed at the production of 'governmental knowledge' in which the Foucaultian tradition identifies the core of the state-making process. The only Italian city to be fully involved in the wave of administrative rationalization that swept Western Europe in the 1700s, Milan bears several marks that date back to the Early Modern process of state formation. It is in fact around the civic and secular buildings built by the Spanish, Austrian, and Napoleonic rulers that the city's first 'public' urban spaces were built and named (*Biblioteca Ambrosiana, Piazza Velasca, Piazza Fontana, Foro Buonaparte*). Even more importantly, post-1750 Milan is an example of European city in which the new administrative techniques aimed at constructing 'calculable spaces' (from cadastral mapping to signage systems to postal codes) were consistently introduced. One of these techniques—house numbering—was directly tied to place-naming. Although the first, scattered cases of street purposively renamed by the state authority date back to the 16th century (e.g. *Via Rugabella*), a consistent state-sanctioned toponym assignment process was firstly introduced by the 1786 Cusani Reform along with a new centralized system to number the buildings. While only a handful of streets were renamed in 1786, the state asserted its authority by introducing new rules that directly reflected the emerging hegemonic discourse of the nominal independence of the 'state' from the 'society'—for example, no more street should be named after patrician families—and, even more basically, by claiming for itself the exclusive power to operate changes in the urban streetscape (Buzzi and Buzzi 2005).

The establishment of a firm regime of spatial denotation and governmental identification appears as a precondition for the kind of consciously commemorative place-naming in the modern sense, and its earliest signs are found in the toponymic layer dating back to the period of foreign rule. It is during the first Napoleonic occupation of Milan (1796-1799) that the recently-affirmed state monopoly of the act of street renaming is firstly used to express and disseminate a clearly identified ideological discourse and a specific narrative of nationhood completely independent from existing local landmarks. The renaming of *Via dei Nobili* (*Nobles Street*) into *Via dell'Unione* (*Union Street*), or of *Via di S.Teresa* into *Via della Moscova* (from the Napoleonic Battle of Borodino, in which Italian troops fought as part of the French Army), are the first examples in Milan of a practice that was to become common in the following periods. These toponyms have indeed survived to the present time through their restoration and inclusion in the Post-Unification place-naming regime.

The Post-Unification layer: re-writing the palimpsest, building the Nation

The decades between 1860 and 1920 witness the most systematic attempt to inscribe in Milan's streetscape an ideological discourse clearly tied to a set of power structures. Along with the Medieval layer, the Post-Unification one (Figure 21) has left the most profound mark on the contemporary city's historical center.

The Post-Unification revolution in the place-naming regime of downtown Milan, decided by the new Liberal Municipality between 1859 and 1865 (Brentari 2008), fits well within the patterns identified by several studies in the critical place-naming tradition, which have highlighted how the construction of "new regimes of toponymic inscription to promote particular conceptions of history and national unity" works through "honoring new sets of heroes, campaigns and causes" (Rose-Redwood, Alderman, and Azaryahu 2010, 457). Just as

other nation-building elites did in newly-independent nations across Europe and the post-colonial world, the new Liberal-Nationalist elite identified the reshaping of Milan's cityscape as part of the effort to build an Italian nation based on the liberal and bourgeois values of the Italian Risorgimento (Greenfield 1934). This profound restructuring had a considerable impact on both the physical and toponymic dimensions of the city's streetscape, resulting in the establishment of what can still be described as the basic symbolic infrastructure of the contemporary cityscape. Portions of the historical urban center were deeply reshaped (e.g., *Piazza del Duomo* between 1865 and 1884) to consciously conform to models of urban design that reflected those of major metropolises of the Western world like London and Paris (Greenfield 1934). At the same time, all the new streets and squares opened within the Roman and Medieval zones as well as inside the Early Modern ring (e.g., the outer section of the *Porta Nuova* district), and also nearly all the major preexisting segments, were named or renamed to commemorate the liberal-nationalist ideology of the Risorgimento. Examples include streets renamed after the national leaders of the independence wars (e.g., *Corso Vittorio Emanuele II*, *Galleria Vittorio Emanuele II*, *Piazza Cavour*, *Corso Garibaldi*, *Via Manzoni*); individual patriots (e.g., *Via Pellico*, *Via Manin*); Risorgimento's battlefields (e.g., *Corso Magenta*, *Piazza Mentana*, *Via Solferino*, *Via Marsala*); other Italian cities (e.g., *Via Torino*, *Corso Venezia*); Milanese liberal philanthropists (e.g. *Via Ronzoni*); and, as a mean to celebrate Italy's independence and her rising status among the 'civilized nations,' Medieval or Renaissance Italian writers and artists (e.g., *Via Dante*, *Via Bernardino Luini*). To stress the continuity between the Napoleonic Italic Kingdom and the new Kingdom of Italy, names introduced during the Napoleonic interlude that had been replaced by the Austrians after 1814 were also restored (e.g., *Via Unione*, *Via Moscova*, *Via Senato*).

The Twentieth Century layer: filling the gaps, complicating the tapestry

The post-1920 period, opened by the demolition of the *Fossa Interna* and the *Bastioni* walls, is characterized by the dramatic expansion of Milan beyond the borders of the Renaissance city. Compared to the Post-Unification, however, the period corresponding to the Fascist regime (1922-1945) and the post-WWII decades (Twentieth Century) has left a weaker mark on the toponymic tapestry of the city's historical core (Figure 22). Within an already dense street network, the creation of new streets and the assignment of new toponyms were mainly tied to a string of public work projects launched during the 1920s and 1930s and a few changes carried on in the post-WWII period as a result of the Anglo-American bombing raids of 1943-1945 (Crippa, Mericio, and Zanzottera 2002). The attempts by the Fascist government to inscribe the new symbolic regime into the cityscape by renaming important squares and avenues of the downtown area (e.g. *Via Larga* into *Via Adua* or *Piazza Mercanti* into *Piazza Giovinezza*) was reverted after 1945 with the return to the historical names, and therefore has left no mark on the texture of the contemporary city. The only new toponyms dating back to this period were introduced after 1945 to rename a few new streets created *ex-nihilo* during the Fascist period (e.g. *Via Littorio*, renamed *Corso Matteotti*), and a handful of *larghi* (small squares) celebrating post-WWII cultural celebrities whose names are tied to the post-war city (*Largo Callas*, *Largo Grassi*), in the familiar attempt to maximize the number of commemorations without altering the street infrastructure (Rose-Redwood, Alderman, and Azaryahu 2010).

Twentieth Century changes thus follow patterns already identified in the literature on commemorative place naming: like the Post-Unification toponyms, they evoke national political discourses independent of the local landmarks and contexts. However, the quantitative analysis presented in this study shows that no single narrative seems to have gained a clear hegemony

over the renaming process. The transition from the narrow franchise regime to the male universal suffrage during the 1910s led to the replacement of the ideological consensus of the Liberal age with a more fragmented pattern of party politics dominated by mass parties and competing political subcultures with radically different interpretations of Italian history (Galli and Prandi 1970). Consistent with these developments, what emerges from the analysis of the limited parts of the city center's streetscape that were left open to the renaming process after 1945 is a patchwork of competing political narratives that coexist with each other. Under the proportional political arrangements that dominated both the city's politics and the national political arena until the early 1990s (Galli and Comero 1992; Bogaards 2005), each of the major anti-Fascist political parties and political subcultures was given its share of the remaining space open to commemorative renaming within the historical center. Thus, alongside street-names assigned during the Liberal age and memorializing Risorgimento patriots, toponyms can be found dating back to the post-1945 period that celebrate the fathers of the Republican-Socialist tradition (*Via Mazzini*, *Corso Matteotti*, *Via Turati*) as well as the most prominent members of Milan's Catholic community (*Largo Gemelli*, *Via Cornaggia*). The postwar consensus on the principle of proportionality is pervasive enough to extend itself even to some of the new names given during the Fascist period and bearing a clear nationalist overtone: this is the case for a few toponyms that celebrate Italian war heroes, introduced during the Fascist regime but not explicitly linked to it, such as *Piazza Diaz* or *Via Bertoni*.

Figure 23 summarizes the number of street segments for the attributes Object Age (on the left) and Object Name Age (on the right) when the analysis is by *Sestiere*. Based on the occurrence of the attributes Object Name and Object Name Age (see Table 4), I also conducted a cluster analysis using Moran's I statistics (Moran 1950) on the subset of streets comprising the most frequent cases of street-creation/street-denomination. The clusters, or patches of the

tapestry, thus produced identify spatial patterns for streets created in the Roman, Medieval and Post-Unification periods (respectively Figure 24a, b, and c on the left side). These patterns were then compared with clusters defined by the location of streets created in the same three periods, with the difference that in this case street names came from periods different than the period when the street was created (Figure 24, right side). Note that as far as the creation of street segments was concerned, no statistically significant clusters were identified for the Early Modern/Austrian-Napoleonic and Twentieth Century periods—by itself an interesting result—and therefore these periods are not shown in Figure 24.

Starting from an analysis of when street segments they were created (Object Age) (Figure 23 left side), note the high incidence of Roman streets in the *Porta Ticinese* and *Porta Vercellina* districts, where several of the major Imperial Roman landmarks (like the Theater, the Circus and the Imperial Palace) were located (David 1992), and their nearly absence in the *Porta Nuova* district, the latest portion of the Roman city. The Roman street segments distribution is also shown in Figure 24a (lower left), revealing a cluster of street segments located mostly in the south-eastern sectors (the *Porta Ticinese* and *Porta Vercellina* districts). The incidence of Medieval streets segments, on the other hand, appears high in every district. Figure 24b (middle left) shows a fairly large Medieval cluster draping over portions of every neighborhood, together with Medieval streets filling the gaps left by the Roman network penetrating into this zone (see also Figure 19, dashed and bold black lines). This also confirms at the neighborhood level the importance of Medieval street toponyms already noted in the preceding section at the city level. The highest incidence of Early Modern/Austrian-Napoleonic street segments (Figure 23, left side) is found in the *Porta Romana*, *Porta Orientale* and *Porta Nuova* districts, although no statistically significant cluster is found for these historical periods. The occurrence of Post-Unification street segments is particularly high in the *Porta Vercellina* and *Porta Comasina*

districts and consistent throughout the entire city. This can also be seen in Figure 24c (upper left), in which streets created during the Post-Unification period tend to create evenly distributed clusters in the urban environment; apart from a very central cluster, corresponding to the renewal of the Duomo Square, the bulk of newly created Post-Unification street segments is located in the outermost zones (Medieval and Early Modern; see also Figure 20, dashed and bold black lines). Finally, the incidence of Twentieth Century street segments appears to be uniform throughout the entire study area, with a peak in the *Porta Orientale* district and with the exception of the *Porta Comasina* district, the latter due for the most part to the area's small extension. Note that no significant neighborhood clusters were detected for this period.

When taking into consideration the occurrence of toponyms for different periods (Object Name Age, displayed on the right side of Figure 23), the first noticeable aspect is the very low incidence of Medieval/Roman-derived toponyms. The bulk of the Roman streets received their current names during the Medieval period and, in part, during the Post-Unification decades (see also Table 4). As shown in Figure 24a1 (right side, bottom row), Roman street segments carrying a Medieval toponym create a cluster that overlaps, and almost completely replaces, the one composed by Roman streets (symbolized with a linear pattern). Marginal parts of the Roman street cluster in the *Porta Romana* and *Porta Ticinese* districts also carry Post-Unification names (24a2), although the latter sector, marked by the Roman heritage, partially resisted the renaming process.

Most of the renaming process operated on Medieval street segments was carried on during the foreign dominations (Early Modern and Austrian-Napoleonic) periods as well as during the Post-Unification period (also see Table 4). All the eastern sectors (Figure 23, right side) were affected, and the *Porta Nuova* district is where the bulk of this process took place. As we can see in Figure 24b (right side middle row), the Medieval street cluster occupying this

sector is replaced by Early Modern/Austrian-Napoleonic (24b1), Post-Unification (24b2), and Twentieth Century (24b3) toponyms (also see Figure 20, 21 and 22), which together penetrate into the very core of the Medieval cluster. Post-Unification toponyms are also relevant in the *Porta Vercellina* district, while *Porta Ticinese*—the heartland of the Visconti's family power, 1277-1447—appears to have better resisted the renaming wave.

Very few Post-Unification street segments are renamed during the Twentieth Century period, and Figure 24c1 (right side, top image) indeed shows only a few small clusters in the outermost zone of the city. Apart from a uniform, and rather scattered, wave of new street-names introduced during the Twentieth Century, no significant cluster indicating a specific core has been detected (also see Table 4 and Figure 22).

Finally, it is worth noting that, apart from one exception occurred during the Twentieth Century, all the clusters representing the renaming of street segments from a previous period are within the Roman zone. This fact differentiates Milan from other Roman-founded cities, such as London, in which the center of the Medieval city shifted outside the Roman zone. Milan, despite its long history of urban changes, grew mainly from within its core, generating a monocentric city in which every temporal layer has left its mark in physical and temporal succession.

Future directions and lessons learned will be discussed at the end of the dissertation in the Conclusion section.

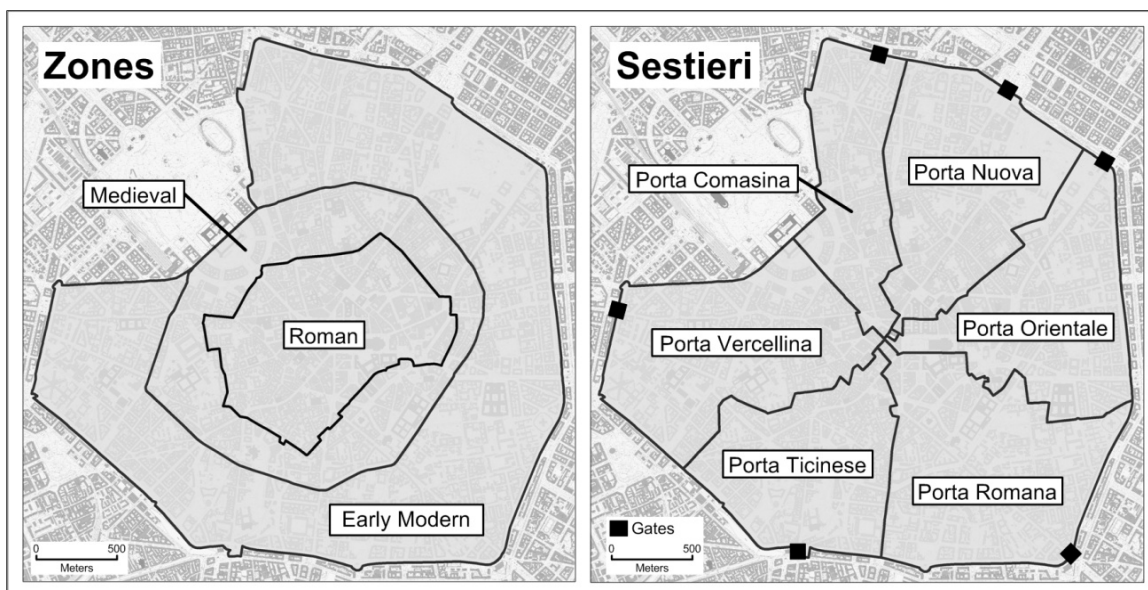


Figure 15. Milan's historical zones (left) and *Sestieri*, or districts (right).

Table 3. Time periods for Object Age and Object Name Age.

Object Age			Object Name Age		
Period			Period		
Roman	(R)	200 B.C.E. to 450 C.E.	Medieval/Roman-derived	(MRD)	Before 1550 C.E.
Medieval	(M)	450 C.E. to 1550 C.E.	Medieval New	(MN)	Before 1550 C.E.
Early Modern	(EM)	1550 C.E. to 1750 C.E.	Early Modern	(EM)	1550 C.E. to 1750 C.E.
Austrian-Napoleonic	(AN)	1751 C.E. to 1859 C.E.	Austrian-Napoleonic	(AN)	1751 C.E. to 1859 C.E.
Post-Unification	(PU)	1860 C.E. to 1920 C.E.	Post-Unification	(PU)	1860 C.E. to 1920 C.E.
Twentieth Century	(TC)	1920 C.E. to Present	Twentieth Century	(TC)	1920 C.E. to Present

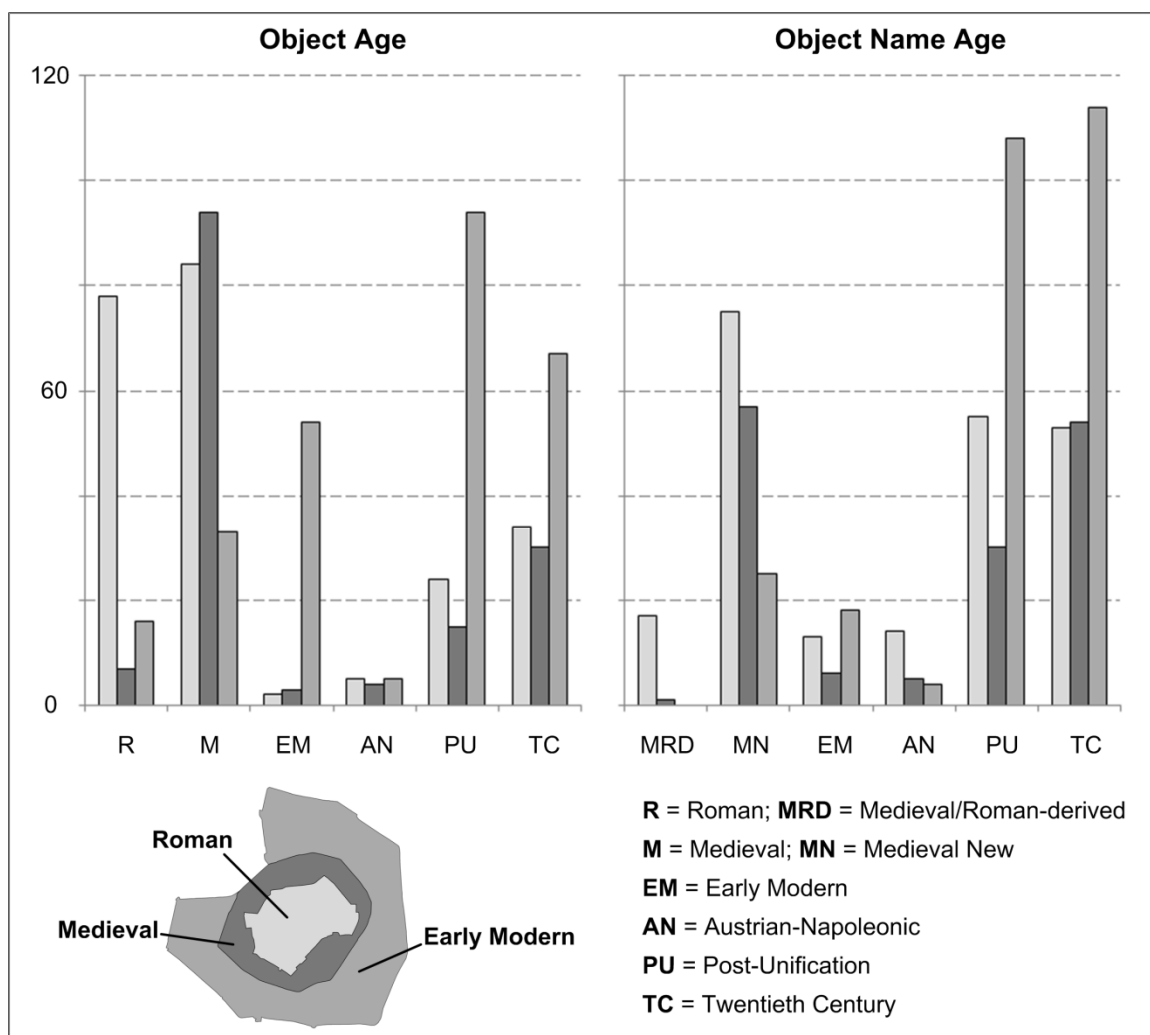


Figure 16. Number of Object Age (left) and Object Name Age (right) street segments by zone.

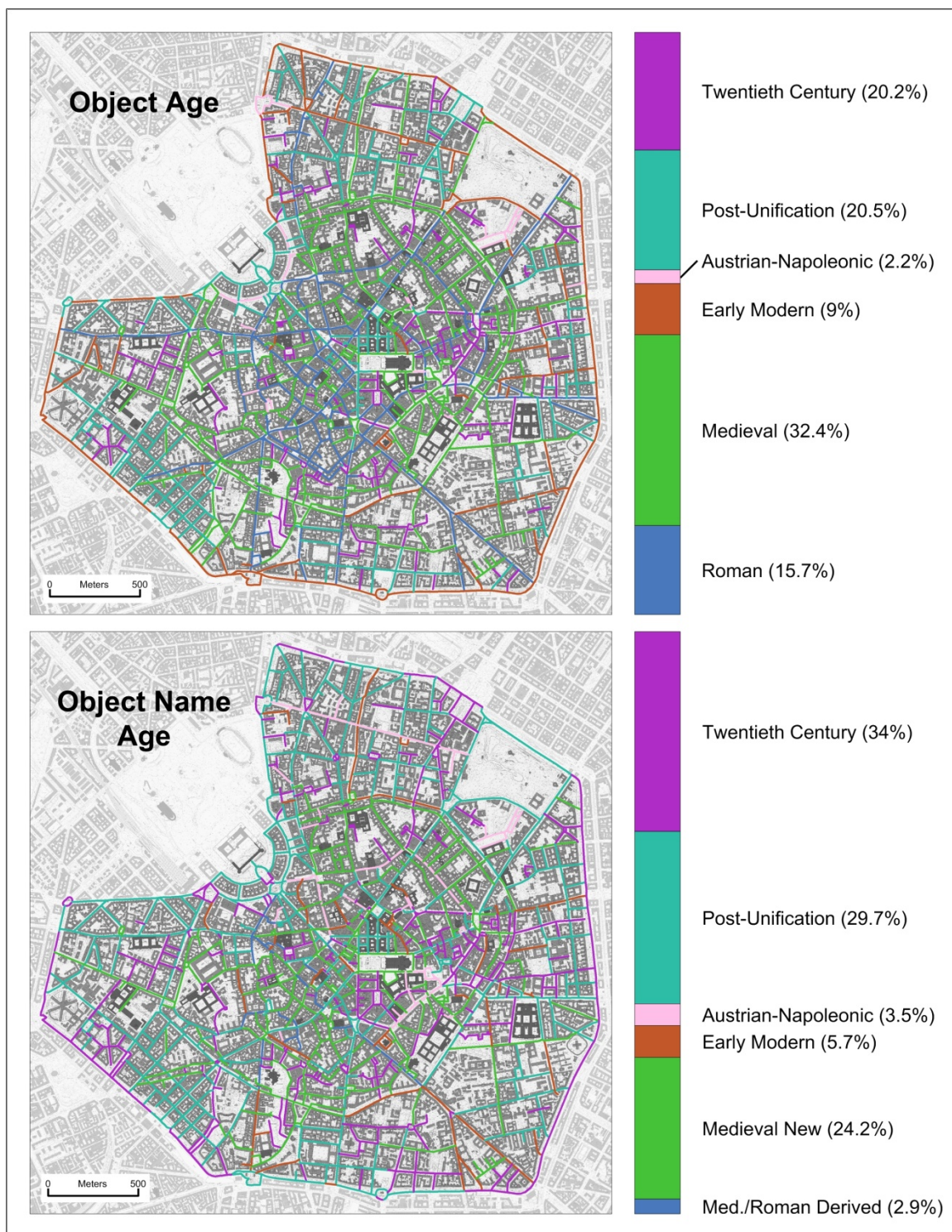


Figure 17. Location and percent occurrence of street segments by Object Age (top) and Object Name Age (bottom). See text for explanation.

Table 4. Number and percent of street segments by Object Age and Object Name Age.

	Object Name Age						Total
	<i>Medieval/ Roman- derived</i>	<i>Medieval New</i>	<i>Early Modern</i>	<i>Austrian- Napoleonic</i>	<i>Post- Unification</i>	<i>Twentieth Century</i>	
<i>Roman</i>	11 1.7%	41 6.3%	10 1.5%	6 0.9%	27 4.2%	7 1.1%	102 15.7%
<i>Medieval</i>	8 1.2%	111 17.1%	11 1.7%	8 1.2%	38 5.8%	35 5.4%	211 32.5%
<i>Early Modern</i>	0	0	16 2.5%	2 0.3%	19 2.9%	22 3.4%	59 9.1%
<i>Austrian- Napoleonic</i>	0	1 0.2%	0	7 1.1%	5 0.8%	1 0.2%	14 2.2%
<i>Post- Unification</i>	0	2 0.3%	0	0	101 15.5%	30 4.6%	133 20.5%
<i>Twentieth Century</i>	0	2 0.3%	0	0	3 0.5%	126 19.4%	131 20.2%
Total	19 2.9%	157 24.2%	37 5.7%	23 3.5%	193 29.7%	221 34.0%	650 100%

Relative importance

None	Low	Medium	High
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Table 5. Mean length (m) of street segments by Object Age and Object Name Age.

	Object Name Age						Total
	<i>Medieval/ Roman- derived</i>	<i>Medieval New</i>	<i>Early Modern</i>	<i>Austrian- Napoleonic</i>	<i>Post- Unification</i>	<i>Twentieth Century</i>	
<i>Roman</i>	192.6	154.9	335.6	272.7	345.1	96.7	230.0
<i>Medieval</i>	94.4	214.0	273.4	172.2	235.7	129.1	200.8
<i>Early Modern</i>	0	0	191.3	775.9	428.8	312.2	332.7
<i>Austrian- Napoleonic</i>	0	98.0	0	196.9	283.1	150.5	217.3
<i>Post- Unification</i>	0	173.4	0	0	212.7	185.9	206.1
<i>Twentieth Century</i>	0	162.6	0	0	161.5	135.4	136.4
Total	151.3	196.7	254.7	258.4	258.1	157.7	205.8

Mean street length

None	Short	Medium	Long
------	-------	--------	------

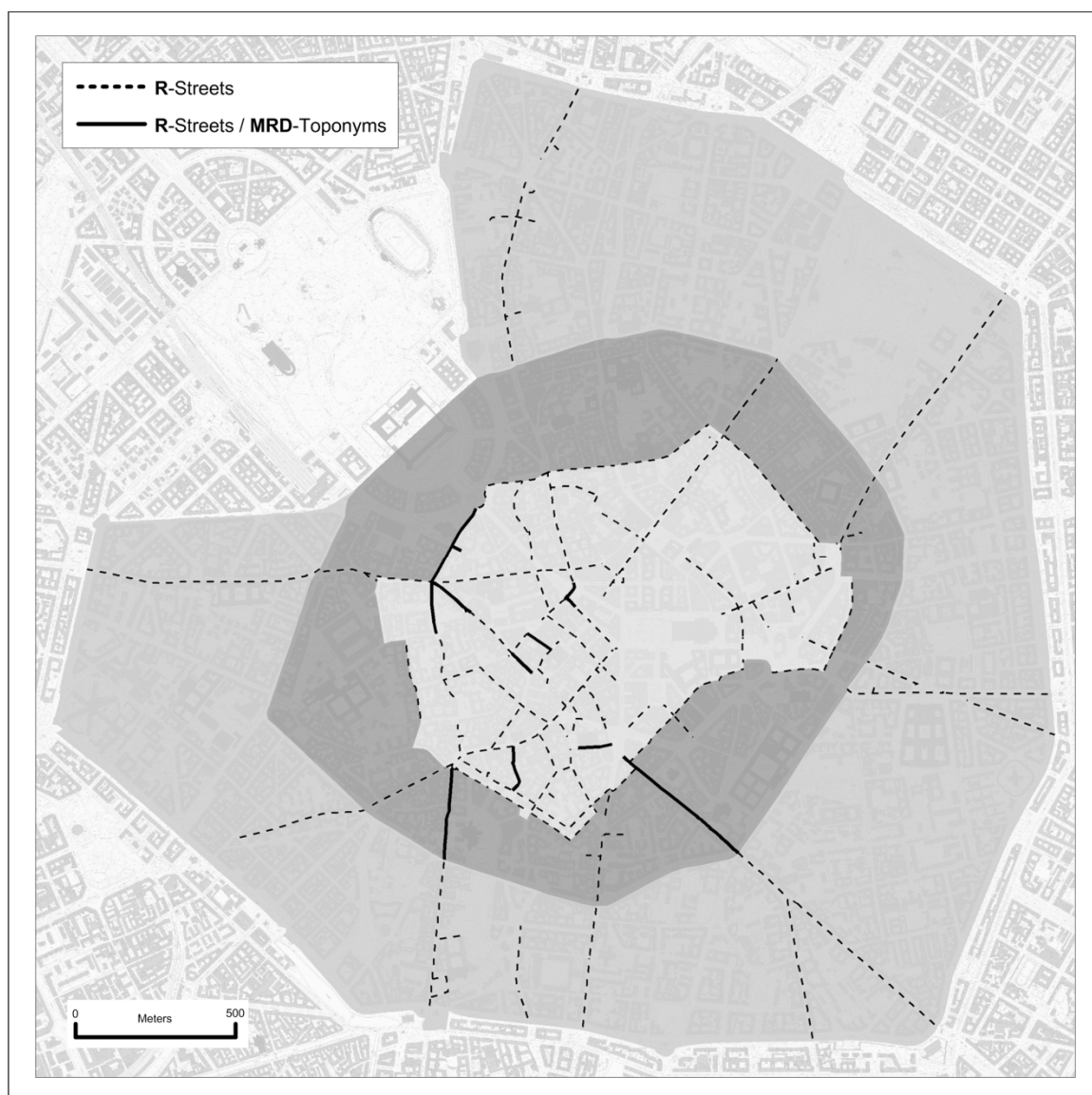


Figure 18 . The Roman layer. R stands for Roman, MRD for Medieval/Roman-derived.

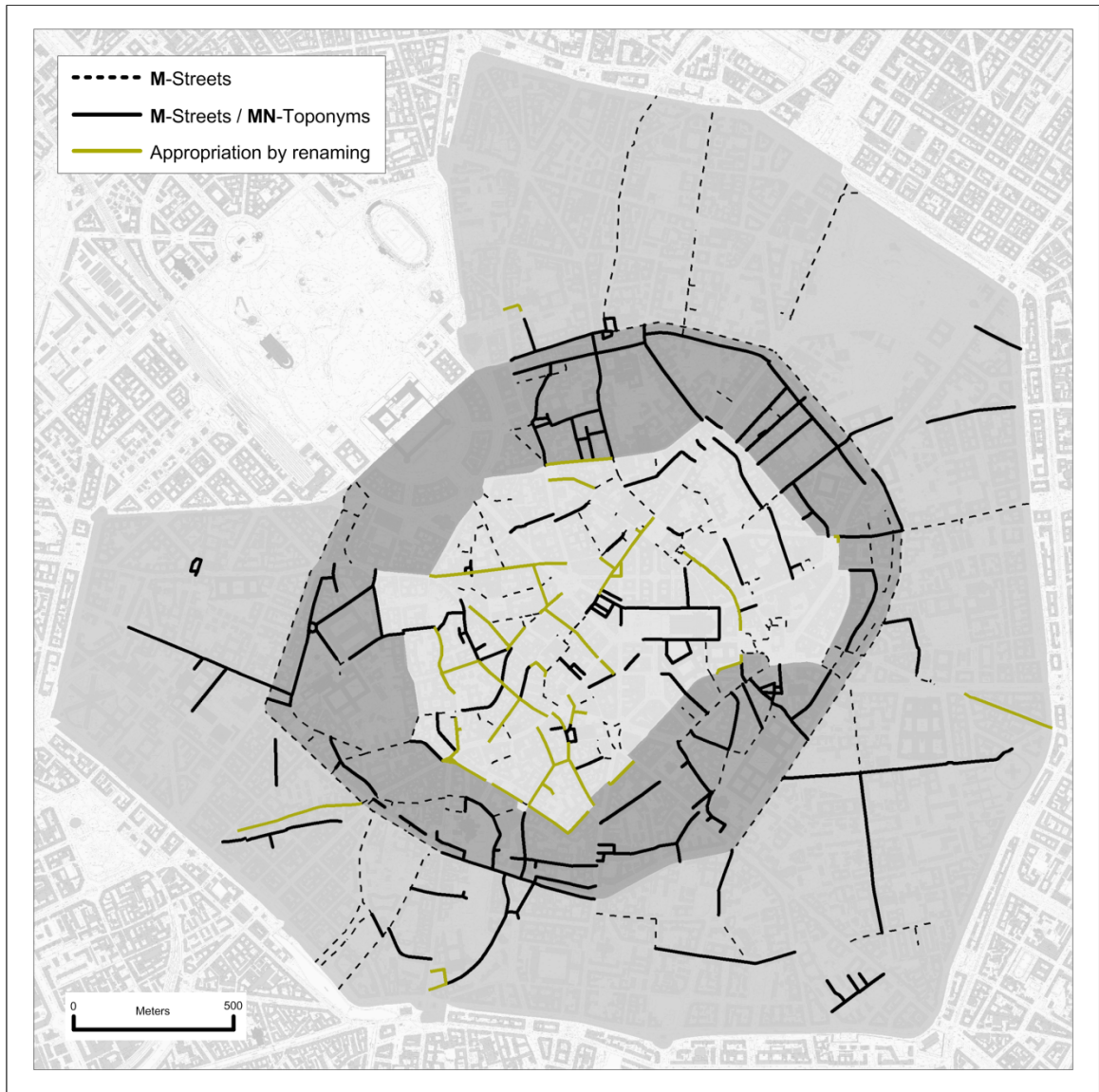


Figure 19. The Medieval layer. M stands for Medieval, MN for Medieval New.

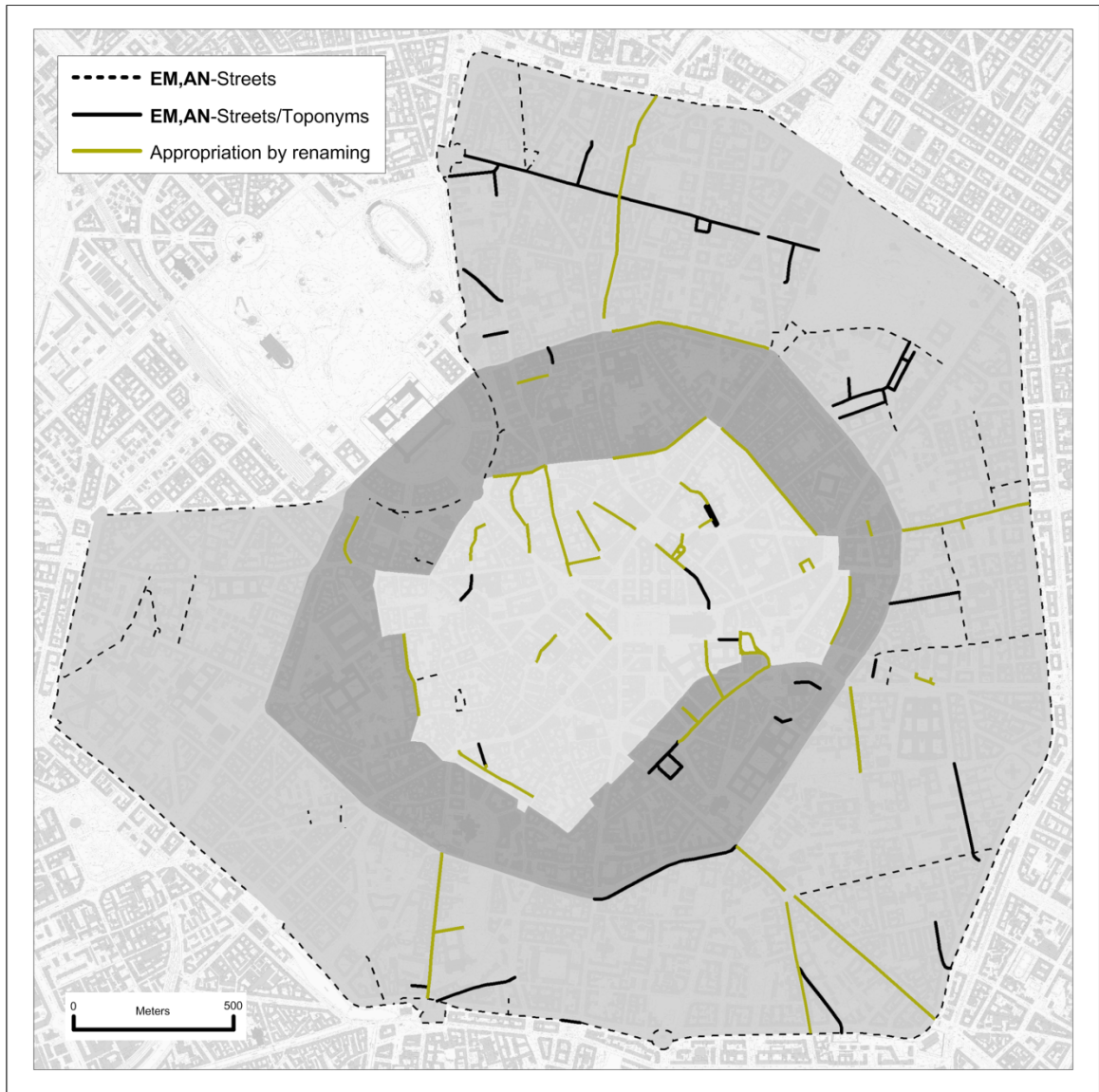


Figure 20. The Early Modern and Austrian-Napoleonic layers. EM,AN stands for Early Modern/Austrian-Napoleonic.

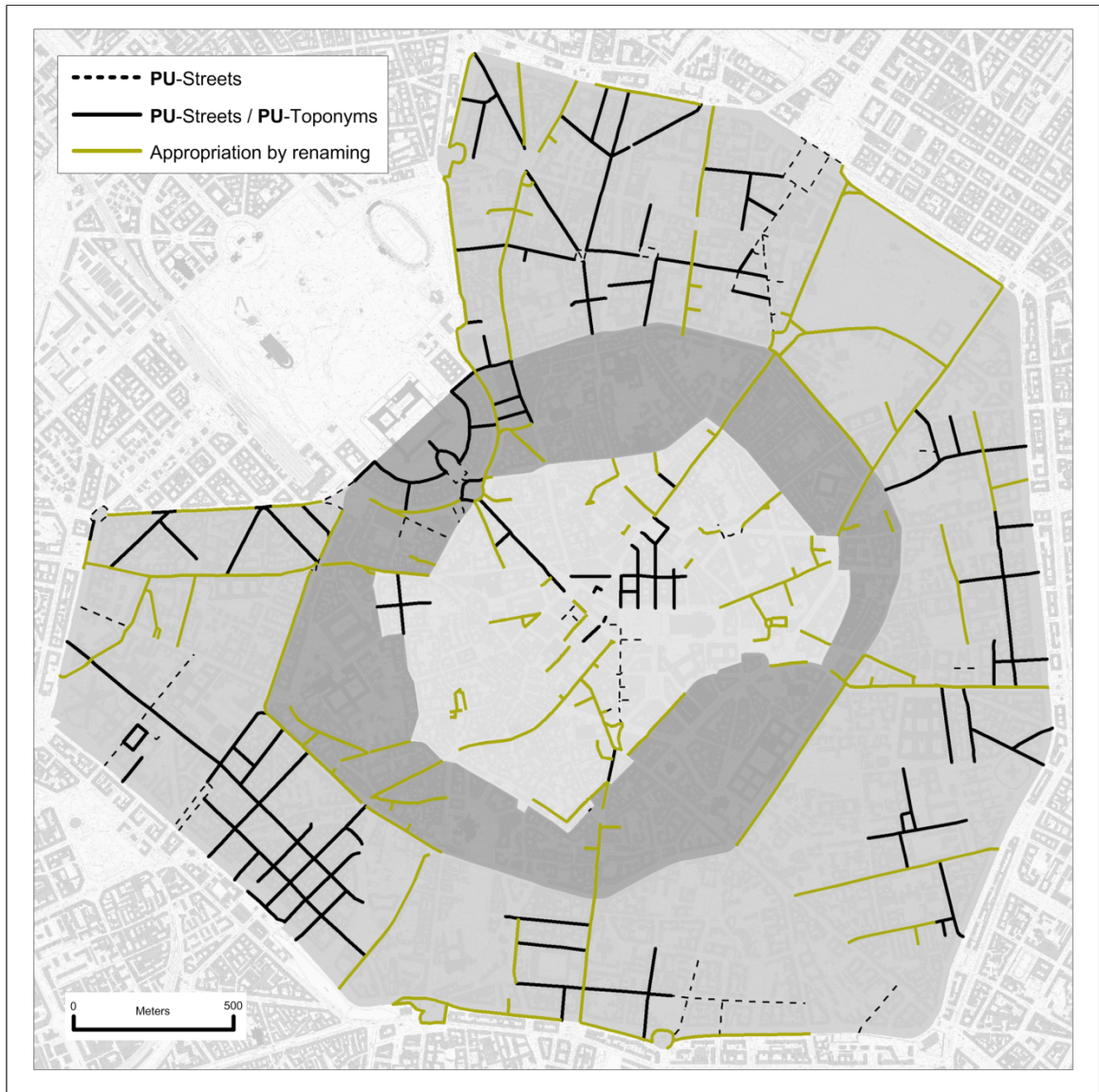


Figure 21. The Post-Unification layer. PU stands for Post-Unification.



Figure 22. The Twentieth Century layer. TC stands for Twentieth Century.

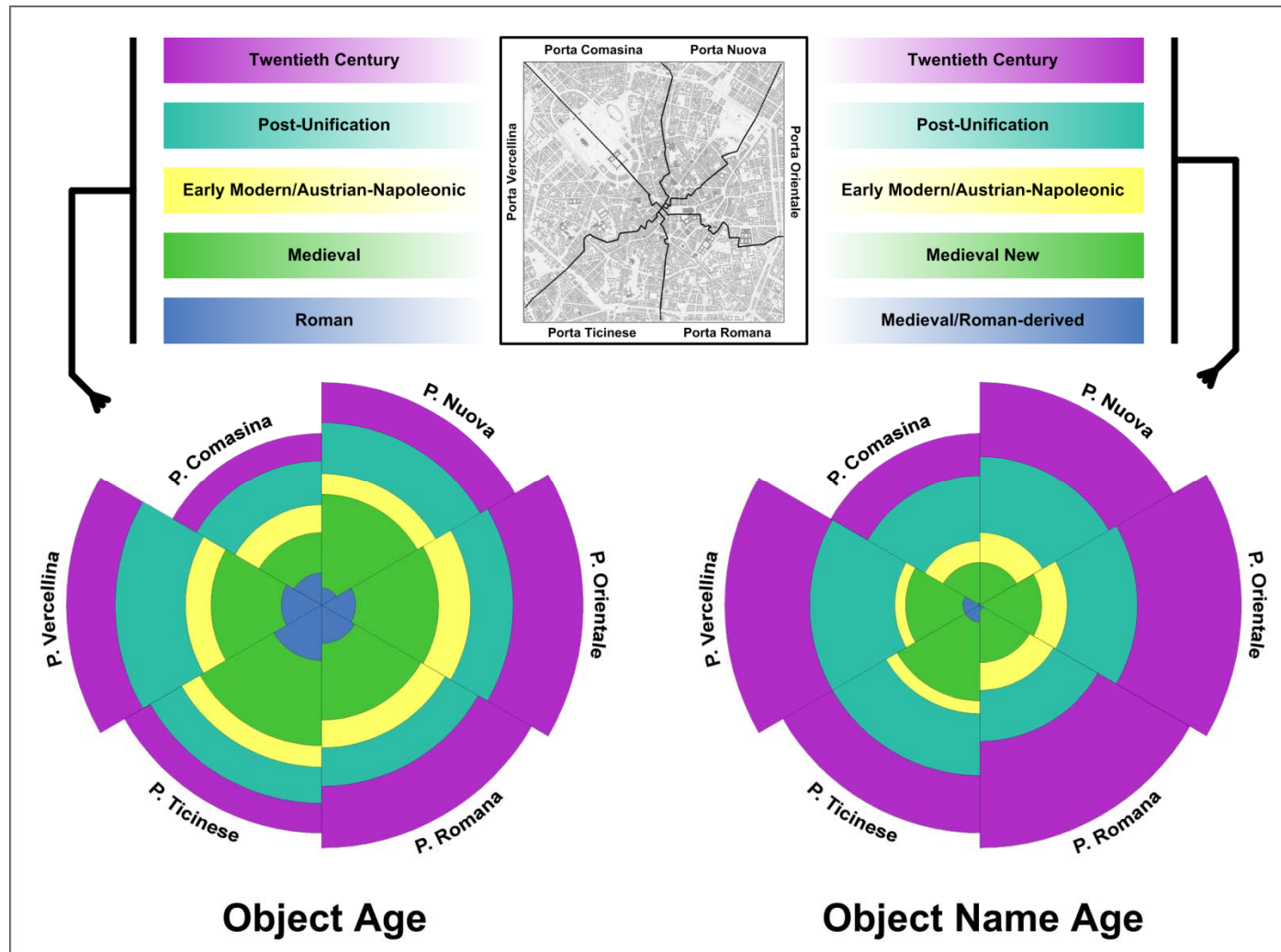


Figure 23. Polar bar charts representing the occurrence of street segments categorized by Object Age (left) and Object Name Age (right) by *Sestieri*. The wedges are proportional to the number of segments in the district (e.g., *Porta Nuova* = 105, *Porta Orientale* = 123, etc.)

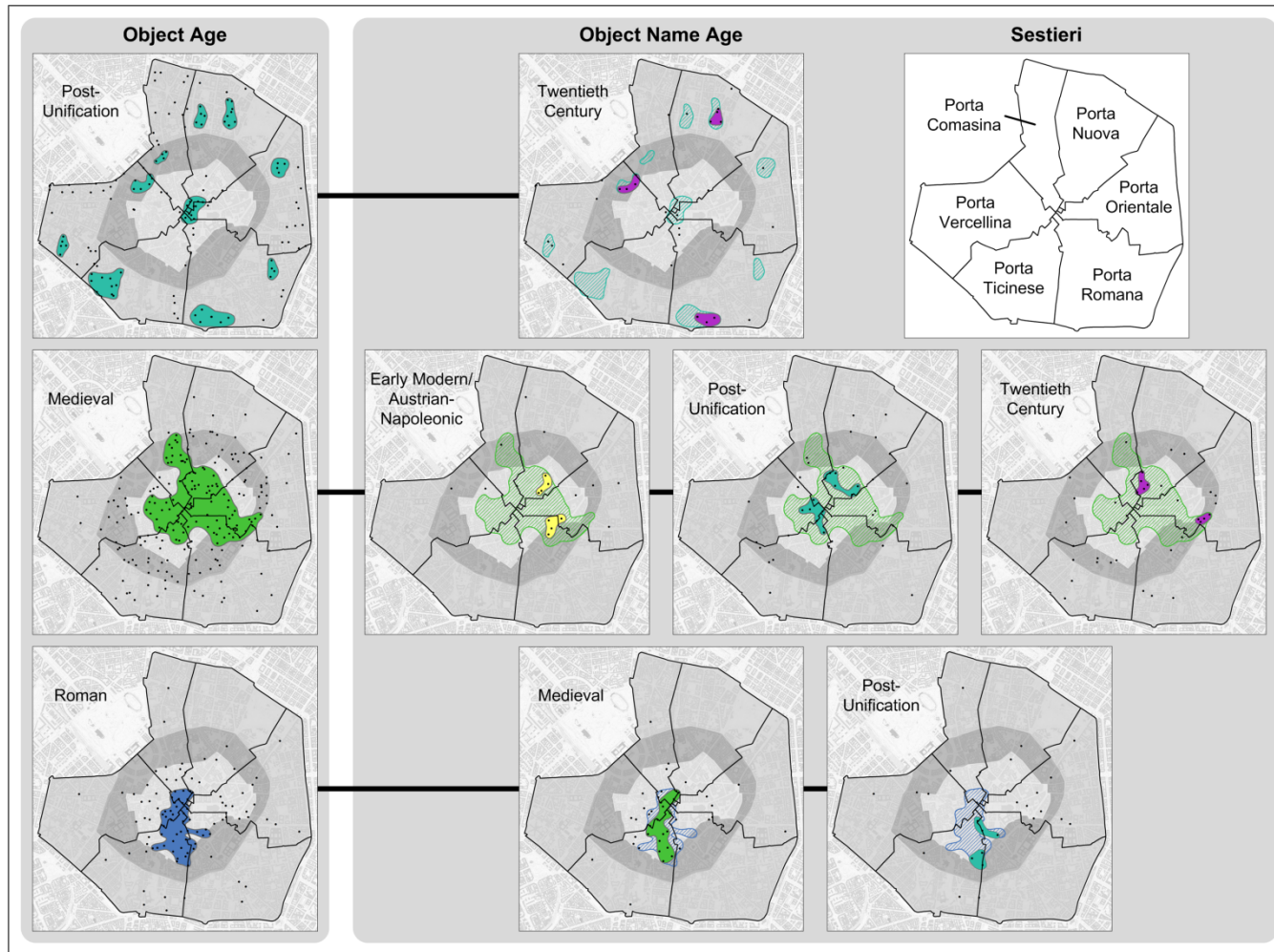


Figure 24. Neighborhood analysis: location of significant clusters of street segments categorized by Object Age (left) and Object Name Age (right). The right side shows when and where clusters of street created in a period (linear pattern) were renamed (solid color)—and therefore appropriated—in later periods.

CHAPTER III

POSITIONAL ACCURACY, POSITIONAL UNCERTANTY, AND FETURE CHANGE DETECTION IN HISTORICAL MAPS: RESULTS OF AN EXPERIMENT

Objectives

In the last two decades, the field of Geographic Information Science (GIScience) has witnessed a rise in the number and variety of uses and users of geospatial data and an increase in the analytical and computational powers of GIScience tools and methods (Fisher, Comber and Wadsworth 2006; Harding 2006; Stein and Van Oort 2006). At least in part as a result of these developments, spatial data accuracy and spatial data uncertainty have received considerable attention by the scientific community (Guptill and Morrison 1995; Burrough and Frank 1996; Lowell and Jatton 1999; Hunsaker et al. 2001; Foody and Atkinson 2002; Shi, Fisher, and Goodchild 2002; Zhang and Goodchild 2002; Shi, Goodchild, and Fisher 2003). Considering that historical maps typically carry a higher degree of inaccuracy and uncertainty when compared to contemporary geographic databases, it is not surprising that these two issues are of particular concern to historical cartography and Historical GIS (Plewe 2002).

Building on past work (Tucci, Giordano, and Ronza 2010), in this chapter I propose a methodology for identifying, classifying and measuring how positional accuracy and positional uncertainty affect the detection and measurement of urban change in a Landscape Pattern Analysis (LPA). The geographical unit chosen for the analysis is the building. As a case study, I compare an 1884 historical map of Milan with a 2005 cartographic representation of the city.

Here I start with framing the discussion in the broader conceptual context of the ontological differences between positional accuracy and positional uncertainty. Such discussion is useful considering that often the two terms are, incorrectly, used as synonyms in the literature.

Harding (2006) distinguishes the data producer's perspective (*internal*) from the data user's perspective (*external*) in spatial data quality, noting that both play an important role in the creation of reliable geographic products and analysis. Primarily from the data producer's perspective, models describing the components of geographical data quality have been proposed in standards such as SDTS (Spatial Data Transfer Standard) by the US Federal Geographic Data Committee (FGDC), and, internationally, in ISO 19115 by the International Standard Organization. Among the components of geographic data quality, positional accuracy has received considerable attention both in the academic world and in the broader community of GIS users. Positional accuracy is defined as the difference between the recorded location of a feature in a spatial database or in a map and its actual location on the ground, or its location on a source of higher accuracy. New technologies seem to have facilitated the work of researchers, especially in the evaluative aspect of measuring positional accuracy (Leyk, Weibel, and Boesch 2005), and generally a dichotomous relationship is established when discussing accuracy between what is accurate and what is not—called *error*—starting from the assumption that the objective level of inaccuracy is known. When the inaccuracy of a measurement is not objectively known, the measured feature is defined as uncertain (Hunter and Goodchild 1993).

The problem of estimating the positional accuracy of an historical map has typically been tackled using spatial-analytical tools (Oetter et al. 2004; Hessler 2006; Livieratos 2006; Pontius and Lippitt 2006), and this is the approach I will also follow. However, by employing methods for the evaluation of positional accuracy based on the calculation of the Root Mean

Squared Error, or RMSE, for the entire map (Andrews 1974; Murphy 1979; Hsu 1978; Strang 1998; Pearson 2001, 2004, 2005; Giordano and Nolan 2007), previous studies have often neglected to systematically analyze and attempt to model how positional accuracy varies across the map.

Another issue that usually receives little attention in the literature—including the articles cited in the preceding paragraph—is positional uncertainty. To be fair, distinguishing between uncertainty and accuracy is problematic, particularly when dealing with historical maps. Technological advancements, changes in cartographic production techniques, and progress in the field of surveying contribute blurring the line between the two, as do the variety of map purposes, periods of creation, and socio-cultural contexts in which maps are created. Obvious as these observations might sound, they underscore an important fact: when applying GIScience tools and methods to the quantitative analysis of historical maps, one has to carefully choose the map, the time, and the place. I will return to this point later in the discussion.

According to Battenfield (1993), uncertainty is an ambiguous concept, which arises from the imperfect understanding and modeling of the phenomenon under study, coupled with the use of imprecise, outdated and incomplete data (Harrower 2003). As stated by Couclelis (2003), uncertainty occurs simply because part of the information is unknown or, as Fisher puts it (1999), it cannot be known with precision. Although there are many definitions of uncertainty, there seems to be agreement on a few key concepts. Kardos, Moore, and Benwell (2005) identify three types of uncertainty: *attribute uncertainty*, which applies to differences existing between the semantic characteristic of a feature and the corresponding data stored; *spatial uncertainty*, which is relative to differences between the actual physical position of a feature and the corresponding data stored; and *temporal uncertainty*, the time difference between data acquisition and data utilization. Leyk, Weibel, and Boesch (2005) make a distinction between

production-oriented uncertainty, the case in which maps contain errors specific to the survey of a category of information; *transformation-oriented* uncertainty, which is relative to data processing and generalization; and *application-oriented* uncertainty, which is caused by semantic incomparability and incompatibility between a historical map and a present day application. Probably the best known conceptual model for dealing with spatial data uncertainty, and one widely cited in the literature (Fisher, Comber, and Wadsworth 2006), was developed by Fisher in 1999. According to this model (Figure 25), in *well defined objects*—those that can be unambiguously classified—uncertainty is caused by positional and attribute errors that can be calculated using a probabilistic approach. This approach is generally less suitable in the case of imprecise, limited or conflicting information, or when the information is qualitative (Comber, Wadsworth, and Fisher 2006). On the other hand, *poorly defined objects*—those that are difficult to unambiguously assign to categories—are affected by uncertainty because of *vagueness* and *ambiguity*. *Vagueness* refers to objects with unclear boundaries that can be modeled with Fuzzy-set theory approaches; *ambiguity* occurs when there are differences in the perception of the phenomenon (for example, the same person can be perceived as being tall or short by different observers; in this context, “tall” and “short” are examples of ambiguity). *Ambiguity* can in turn be classified as *discord*, when different possible interpretations of the same phenomenon are in conflict with each other, or as *non-specificity*, when several attribute value could be considered correct, with none more appropriate than another. In the case of *discord* and *non-specificity*, knowledge-based methods (*Dempster-Shafer*, or *endorsement* theory: see Srinivasan and Richards 1990 and 1993; Skelsey et al. 2003; Comber, Fisher, and Wadsworth 2004; Comber, Law, and Lishman 2004; Fritz and See 2004) are more suitable than stochastic ones, although stochastic approaches can be used to fine-tune knowledge-based methods in the definition of their rules (Comber, Wadsworth, and Fisher 2006).

In the context of Historical GIS applications, Plewe (2002, 2003) describes the nature of uncertainty and its propagation across historical data in the *Uncertainty Temporal Entity Model*. According to the model, when transposed in digital format, the *World* has to be structured in entities. Entities are assigned identities through a process that involves two major steps, *conceptual* and *physical modeling*, with the former representing the understanding of reality and the latter representing the conversion of this understanding to a form suitable to be processed in a digital environment. Both are relevant in this study, as the cartographic representation of a building involves both conceptual and physical modeling, and both can be affected by uncertainty, since entities are mere generalizations of the real referents; consequently the generated geographic dataset, also known as *asserted extent*, will be uncertain as well. Additionally, by the act of processing spatial information, we produce a new *asserted dataset* more uncertain than the original. In other words, uncertainty—like inaccuracy—is propagated. This is an important point, as the overlay operation—which is at the core of my proposed methodology—is a classical example of error propagation, and because there are consequences to the possible misinterpretation of analytical outcomes based on error-filled generated datasets (Wickham et al. 1997; Brown, Duh, and Drzyzga 2000; Carmel, Dean, and Flather 2001; Shao, Liu, and Zhao 2001; Mas 2005; Langford et al. 2006).

In a study on the nature and magnitude of uncertainty in the cartographic context, Lowell (2006) adds to the discussion by noting that the definition of uncertainty itself varies depending on whether we are dealing with *geopolitical* or with *interpretive* maps. The two are defined in relation to the concepts of *fiat* and *bona fide* boundaries as developed by Smith (2001). In the first case, *geopolitical* maps (corresponding to *bona fide* objects) are characterized by boundaries which exist by definition (e.g., political boundaries—Fisher's *well defined* objects), and the question to be asked is whether or not they are located in the correct position, without

inquiring upon their existence. The second type, generally linked to remotely sensed data and corresponding to *fiat* objects, is exemplified by maps in which the existence of the boundaries itself can be in question (existential uncertainty—Fisher’s *poorly defined* objects), given their subjective nature based on a classification system (e.g. land cover categories). In the case of urban historical maps, because of positional inaccuracy, likely deformation of the paper medium, and technological limitations, the digital representation of geographical features is intrinsically uncertain (Tucci, Giordano, and Ronza 2010). Assuming that positional uncertainty increases moving outwardly from the core of a feature and according to the ‘egg-yolk’ model representation (Cohn and Gotts 1996), I argue that what is initially thought of as the cartographic representation of a sharp boundary between built-up and unbuilt areas (Lowell’s *geopolitical* map), is instead more properly represented by a transition zone with varying width around every feature, and is therefore more typical of Lowell’s *interpretive* maps. In such a case, a map that could be classified as *geopolitical* in Lowell’s sense—as is the case of the 1884 map used for this study—tends to occupy a less clear position as concerns the differentiation between *geopolitical* and *interpretive* maps. This semantic ambiguity is one of the reasons it is so difficult to deal separately with positional accuracy and positional uncertainty in Historical GIS applications.

The above discussion frames my work. A systematic, if brief, exam of the differences between positional accuracy and positional uncertainty is useful to formulate research questions and hypotheses, understand the weaknesses and strengths of the analytical methods proposed, derive a set of appropriate assumptions, discuss the results, and develop procedures for the sensitivity analysis stage. In this chapter, I am dealing with *spatial uncertainty* as defined by Kardos, Moore, and Benwell (2005) and in the context of Fisher’s (1999) *well defined* objects (buildings footprints in a historical map). Such objects are affected by *production-oriented* and

transformation-oriented uncertainty (Leyk, Weibel, and Boesch 2005) that can be measured in probabilistic terms (Fisher 1999). Following Plewe's terminology (2002, 2003), the features examined (buildings) are subject to uncertainty as concerns their *conceptual* and *physical modeling*, with the latter likely to be more critical in determining the outcomes of the analysis. Furthermore, by employing spatial functionalities in a GIS environment—the overlay of two maps—uncertainty is propagated. Finally, we will use a contemporary (2005) map as source of higher accuracy to test the reliability of a historical (1884) map.

Although positional accuracy and positional uncertainty are conceptually different phenomena, it is very often difficult or impossible to differentiate between the two from an operational point of view—that is, to measure one separately from the other. This is especially the case in historical cartography, for the obvious reason that recourse to fieldwork is not an option. Assumptions then need to be made about the nature of what is being measured when detecting urban change using historical maps.

In a Landscape Pattern Analysis (LPA) —the study of changes that occur in a landscape structure over time—change detection is the most frequently studied using remote-sensing technologies and methods, but when using historical sources predating such technologies, historical maps are generally employed. In this case, I measure urban change by overlaying two maps, one created in 1884 and the other created in 2005. When maps are comparable in scale, purpose, objectives, style, and features represented—as is the case here—and when the aim of both maps is to accurately represent the situation on the ground—also the case here (the 1884 Bassani map has an RMSE value of 7.7 meters) —the more recent map is generally taken as the most accurate. More specifically, considering that the 2005 map (Figure 26) is an example of *Carta Tecnica Regionale*—the official Italian large-scale map subdivision and by design a highly

accurate map—it is safe to expect features on it to be more accurately represented than features on the 1884 Bassani map (Figure 27. See also Figure 5 Chapter 1).

The act of overlaying two maps introduces error in the results, a fact well documented in the GIScience and LPA literature (Chrisman 1989; Edwards and Lowell 1996; João 1998; Zhang and Goodchild 2002; Mas 2005). Langford et al. (2006) have shown that virtually every published work employing LPA techniques is affected by a considerable amount of error of due to spurious changes—typically, sliver polygons. More specifically, as defined in the context of a multi-temporal feature change map analysis, spurious changes are not imputable to actual modifications in land cover but are due solely to classification error and map misalignment in the overlay operation (Goodchild 1978; Chrisman 1989). They are therefore considered the result of uncertainty rather than inaccuracy. Using Leyk, Weibel, and Boesch (2005) terminology, I am dealing in this case with *transformation-oriented* uncertainty, which can be measured in probabilistic terms; and—according to Plewe’s terminology (2002, 2003)—the uncertainty is specifically introduced during the *physical modeling* step when converting real world entities to objects suitable to be processed in a digital environment.

Methodology

The first step in the procedure consisted in the generation of a layer showing urban change as represented in the two maps. Since I focus on methodological issues, I selected a sample area (Figure 28) rather than digitizing the entire city; the procedure described here, however, could be expanded to the entire city. The sample area was chosen because it includes examples of: a) changes that have actually occurred in the period under study, i.e., new buildings being built or old ones being demolished, in whole or in part; b) areas that have remained unchanged; c) uncertain cases, i.e., examples of “spurious changes” (discussed later in the chapter).

Features on the resulting overlaid layer were classified as “Changed” or “Unchanged” according to a simple principle: un-built (or built) areas on the 1884 map shown as un-built (or built) also on the 2005 map were classified as “*Unchanged*,” whereas built areas on the 1884 map corresponding to un-built areas on the 2005, or vice versa, were classified as “*Changed*.” The resulting binary map was subsequently filled with a stratified random sample of nearly 2600 6000 points, in which relatively more points were placed on changed areas (1 per 5 square meters) than in unchanged ones (1 per 30 square meters). Similar to what I did in step three of the methodology in Chapter 1, these points were assigned a value of 100 (100% change) if a change had occurred—e.g., a new building had been built—or a value of 0 (representing 0% of change) in case of no change. A Local Polynomial Interpolator was then used to generate a probability of change surface, with values ranging from 0 to 100 and a resolution of 0.5 meters on the ground. The result is shown in the background of Figure 32. The assignment of probabilities takes into consideration the effects of positional inaccuracy and positional uncertainty on the results of the analysis, assuming that the ‘egg-yolk’ method introduced earlier is appropriate to model how positional inaccuracy and positional uncertainty vary around the perimeter of buildings. By applying this logic throughout the map, however, I neglect to consider how the two might vary locally; in a sense, then, I am subject to the same limitations I noted while discussing studies that only use RMSE as an indication of the accuracy of the historical map.

In the second step of the analysis, I therefore tried to estimate the combined effects of positional inaccuracy and positional uncertainty on each feature separately from the others. To do so, I developed an algorithm, similarly to what Linke et al. (2009) did, centered on a reiterative segment distance calculation between the 1884 and 2005 maps. The polygons representing the 1884 and 2005 building footprints (Figure 29 - 1) were converted into their

outlines (Figure 29 - 2) and then overlaid on each other (Figure 29 - 3). A 5-meter grid (Figure 29 - 4) was then placed on the resulting layer. For each segment in each cell, I calculated the midpoint (Figure 29 - 5). I then developed a script to calculate, for each cell in the 5-meter grid, the distance between the 1884 and 2005 segment midpoints (Figure 29 - 6). Note that, although this method does not always necessarily return the minimum distance between two segments, it does insure that a distance value is calculated for any two segments, even when they intersect each other—which, by definition, would return zero as minimum distance. Even with this assumption, measurement errors are not relevant considering the grid cell size.

Initial data preparation was conducted in ESRI ArcGIS 9.3.1 using the software's *Model Builder* functionalities, while the *Geoprocessor* object and geoprocessing tools were used to create the script. The script was written in Python, an interpreted language that is quickly becoming a standard in the scientific community (Langtangen 2009; Lutz 2009; Ceder 2010). The pseudocode, a mixture of code and plain English (Aho, Hopcroft, and Ullman 1974; Baase 1978; Horowitz and Sahni 1984) describing the algorithm, is presented in Table 6 and visually described in Figure 30.

The first part of the algorithm (Figure 30 – 1 and number 1 in Table 6) opens the grid layer and checks if a field called **DIST** is present. If **DIST** is present, the field value is set to zero; if it is not, a field is created with a value of zero. After the initial data preparation, a conditional statement counts how many features are contained into each instance of the grid layer (*Cells*) by checking the value of the field named “**COUNT**”. If this value is less than two (Figure 30 – 2 and number 2 in Table 6), the value of **DIST** is set to an arbitrary high distance of 10 meters. By using 10 meters as a cut-off value, I imply that whenever footprints from the same building appear in different cells, then the building must have actually changed between 1884 and 2005. The robustness of this assumption is tested in the *Results* section of the chapter. Note also that the

algorithm checks if the number of features is less than two because cases in which this value is equal to one indicate that the building footprint is present in only one map; if the returned value is equal to zero, no building footprints are present in the cell.

The third and the fourth parts of the algorithm (Figure 30 – 3 and 4 and number 3 and 4 in Table 6) check for the remaining cases. If the count returned in the conditional statement is equal to or greater than two—and thus meaningful for our study—I need to make sure that the features in the cell come from both the 1884 and the 2005 footprints, i.e., I am not dealing with the case of multiple features from the same map: this is case three in the numbered list on Table 6 (see also Figure 30 - 3). I should point out that even when cell contains one 1884 feature and more than one feature of the 2005 map, or vice versa, the minimum distance function would work on the closest feature. This is insured by the characteristics of the tool used (ESRI, 2009). Case number 4 in Table 6 and in Figure 30 - 4 assigns the arbitrary value (10 meters) to the remaining cases, that is, to multiple features of either the 1884 or the 2005 building footprints.

Once the **DIST** field was populated with all the distances between the 1884 and the 2005 segment footprints, the resulting values were classified into four categories (Table 7).

Results

Table 7 orders the distance values assigned by the algorithm to each cell in four classes, which can then be used to weight the probability that changes detected between the 1884 and 2005 maps—as shown in the probability surface map in Figure 32—might have actually occurred. The weight is the theoretical effect on the results of step one of the analysis of the combined effects of positional uncertainty and positional inaccuracy as introduced by the overlay function.

The contour map in Figure 31 depicts levels of combined inaccuracy and uncertainty in the representation of features as shown on the 1884 map. These values are also shown in Figure 32. The contour map was produced using the distance values assigned by the algorithm to each of the 5-meter resolution cells in the grid. As expected, these values are at their highest around the perimeter of buildings, and especially when buildings run parallel and in close proximity to each other (cases 1, 2, 3, 4, 5, and 6 in Figure 31) and when a building faces a wide open space (cases 8 and 9 in Figure 31). It is difficult to speculate as to the reasons for these differences, especially considering that exceptions to the two rules are readily found (see cases 7 and 10 in Figure 31). But, regarding the first six cases, during the generalization process cartographers routinely resort to positional shifts in the representation of features to make the map more readable. For 8 and 9, the accurate location of a building in the absence of nearby features to be used as visual clues is problematic, especially using the relatively limited technologies available to the 1884 cartographer—remote sensing and GPS have greatly facilitated the work of the contemporary GIScientist.

I am now in a position to be able to discuss how, taken together, positional accuracy and positional uncertainty inform the discussion on the detection of urban changes. This is done in Table 8. In cases in which there is little combined inaccuracy and uncertainty in the measurement (“Very low” category), the likelihood for the changes detected to be real rather than an artifact of the cartographic production process combined with the error inserted by the overlay functionality, decrease, as should be expected, but not dramatically. For features most likely to have changed (“Probability of change (%)” between 76% and 100%), the likelihood that these changes are real has dropped by 22 percentage points, to 78.2 per cent. Similar patterns can be observed in the 26 to 50 per cent category (dropped by 13 percentage points, to 86.7 per cent), but the interpolator does not appear to perform as well in the 51 to 75 percent range. It is

not clear why the problem with the 51 to 75 percent range, but I can speculate that the procedure performs better in areas that either have changed substantially or in areas that have not changed very much; it is the intermediate cases that are the most difficult to model. In the case of least likely probabilities—between 0 and 25 per cent—values do not seem to have been significantly affected by positional inaccuracy and positional uncertainty: this is probably due to the fact that the area under study includes a large square, virtually unchanged between 1884 and 2005 (Figure 28).

To test the reliability of my results, I conducted a series of experiments shifting the original grid used by the algorithm in different directions (vertically and diagonally), as shown in Figure 33. This was done because the algorithm assumes that whenever the footprint of a certain building (as shown on the 1884 and 2005 maps) appears on two separate 5-meter resolution cells, then the change must have occurred in reality on the ground. However, there are cases in which the footprints of the same building might be very close but just happen to be on different cells. In this case, the algorithm would return the established cut-off 10 meters value, whereas the true value should in fact be lower. By shifting the grid horizontally and vertically I can account for these cases. As a visual inspection of Figure 32 reveals, the effect on the results of shifting the grids is negligible, thus revealing that errors of this type are few. This is confirmed by summary statistics for the three grids (the original grid and the two shifted ones) in cases for which the value of **DIST** is different than 10 meters (Figure 34). I also ran a *Kruskal-Wallis one-way analysis of variance by ranks* test (Table 9) to determine if there was a statistically significant difference among the grids; the null hypothesis was that the population distribution functions for the three grids were identical, while the alternative hypothesis called for the three populations to have different medians. With a Kruskal-Wallis value (H) equal to 0.360 and a p-value (0.835) exceeding the established significance level of 0.05, I fail to reject

the null hypothesis, therefore I can confirm that there is no statistically significant difference among the three samples. This confirms the robustness of my model.

I also experimented using grids of different dimensions—respectively, of 10 and 2.5 meters—before settling on the 5-meter grid used in the analysis. In the case of the 2.5-meter grid, the size of the cell was so small that in the large majority of cases only one feature from either the 1884 or the 2005 map fell into the cell, thus leaving a large number of cells with no values. The opposite—too many features—occurred when I employed a 10-meter grid. In the end, a 5-meter grid is a good compromise. Note that the choice of an appropriate cell size depends on factors such as the cartographic properties—scales, mostly—of the maps used in the analysis as well as the urban history of the area under study. Should the algorithm be used to detect urban changes that occurred in Venice (Italy), for example, a smaller cell would be advisable, considering how close to each other buildings frequently are in that city. In any event, the algorithm is applicable to cells of any size.

Finally, note that the algorithm only measures changes in the location of a building, not in its actual physical appearance: a building could have been razed and replaced by another one with the same shape and perimeter, and the algorithm would record a no change.

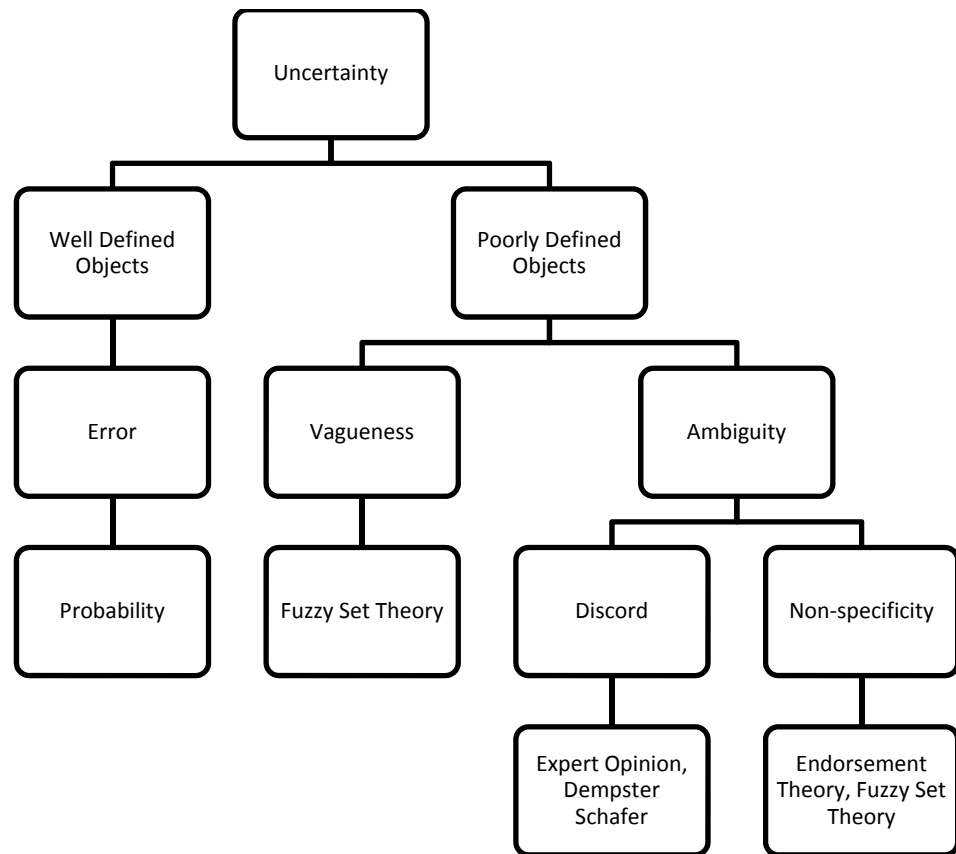


Figure 25. Fischer's uncertainty model.

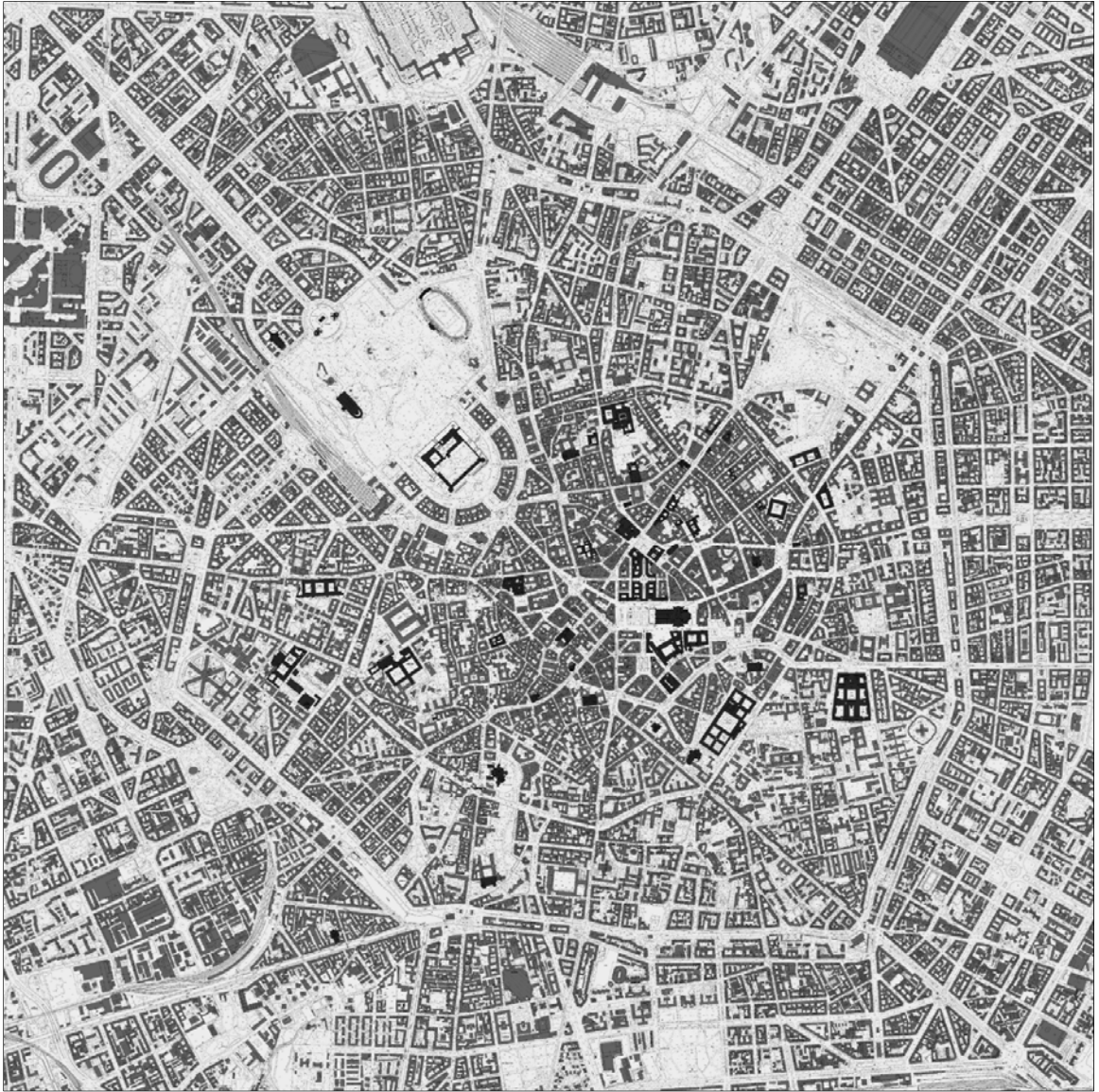


Figure 26. The 2005 CTR map (detail). Scale 1:5000.

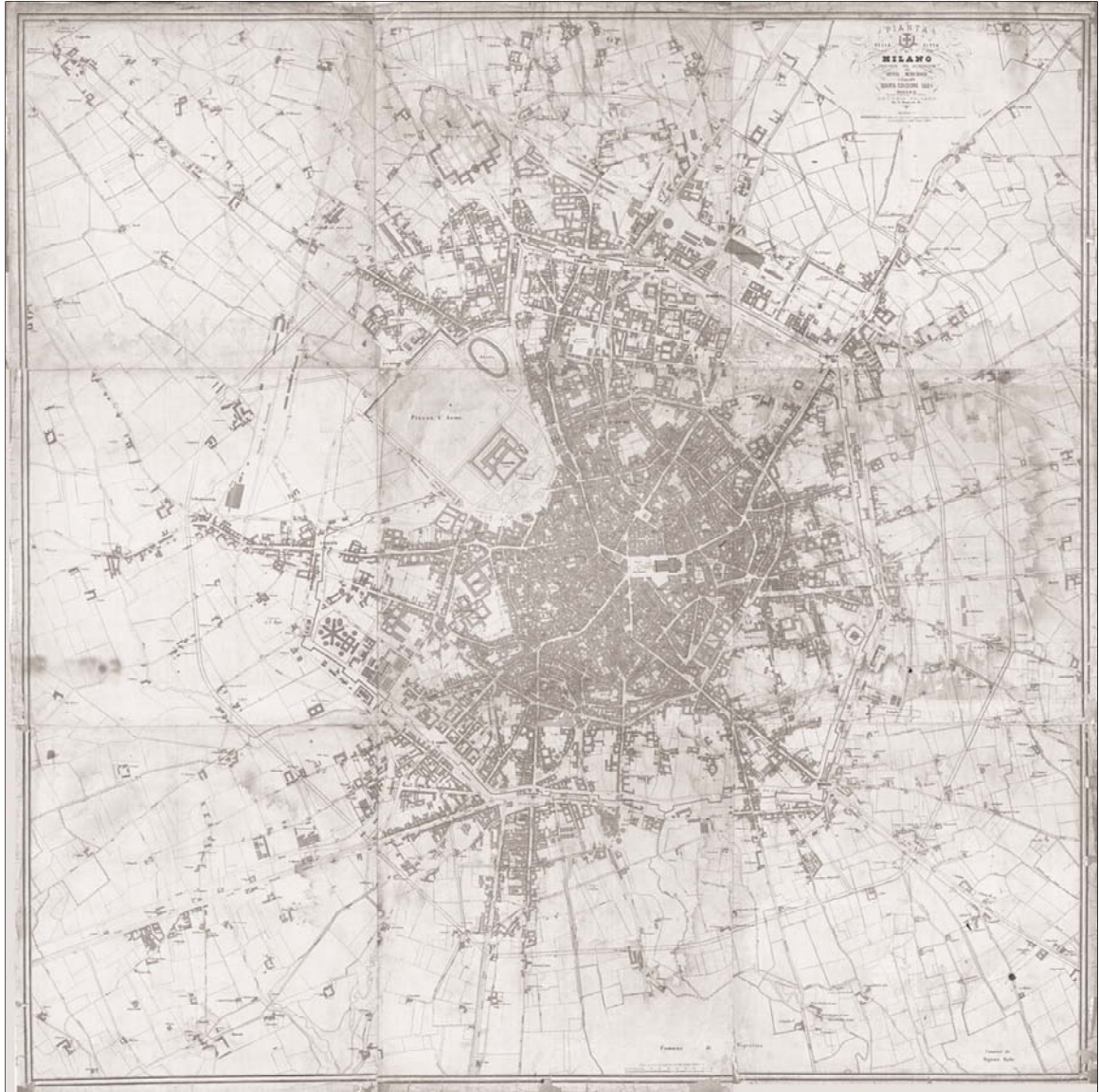


Figure 27. The 1884 Bassani map (Biblioteca Trivulziana, Milano). Scale 1:4000.

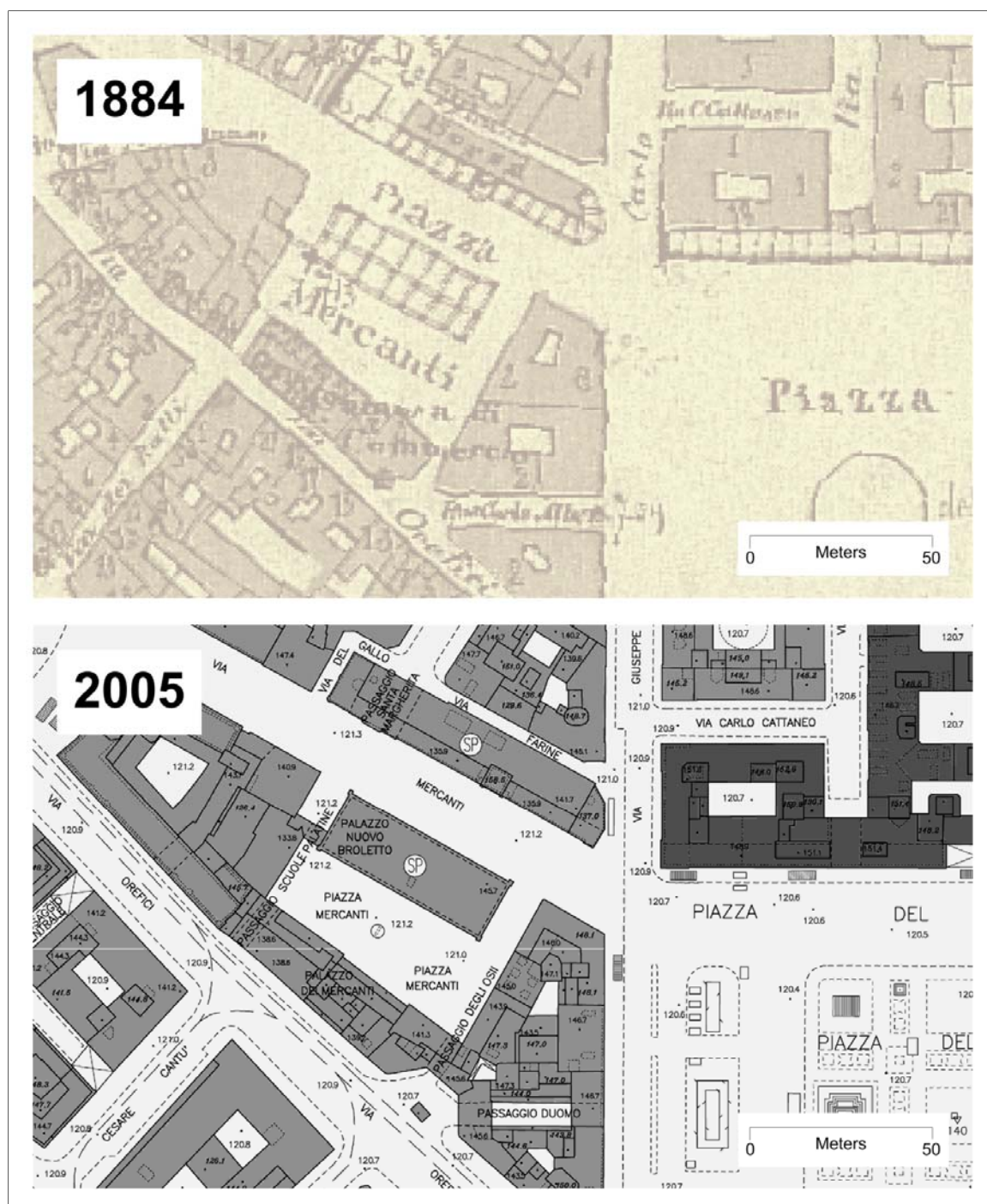


Figure 28. Area under study.

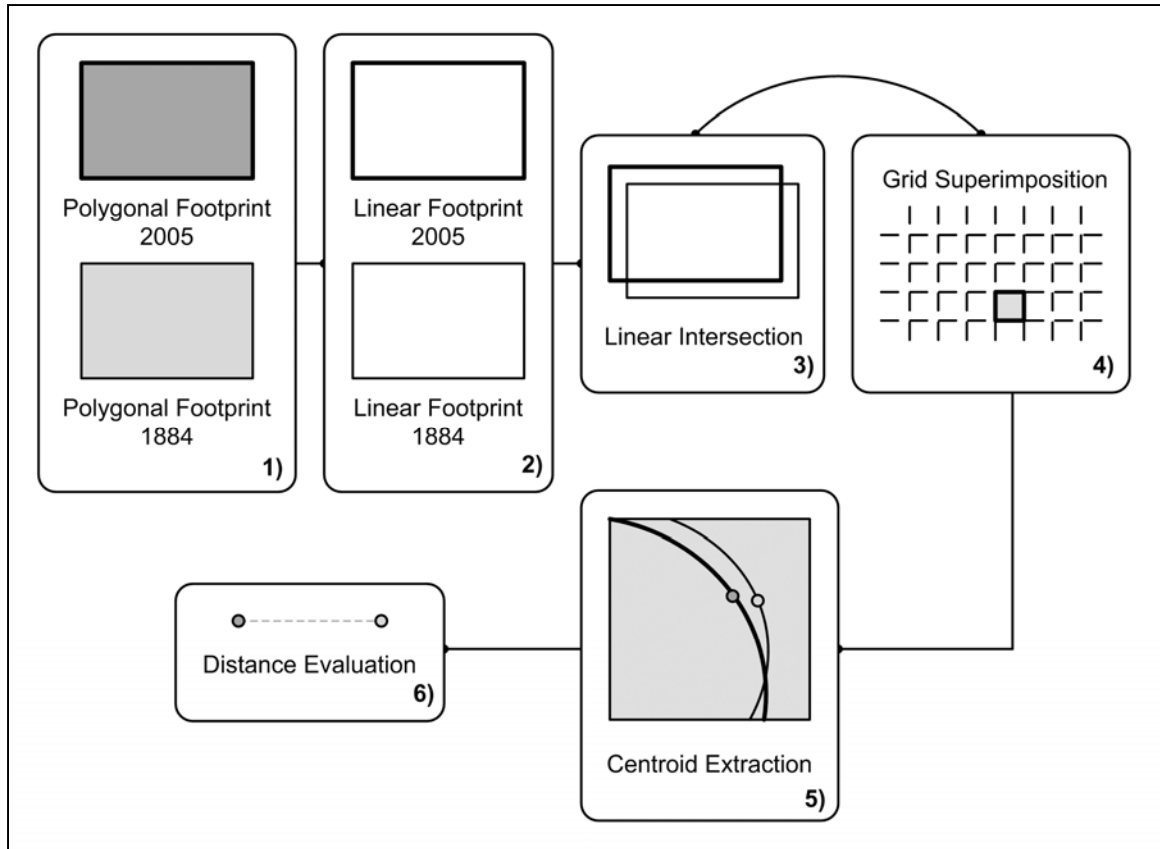


Figure 29. Visual representation of the methodology workflow.

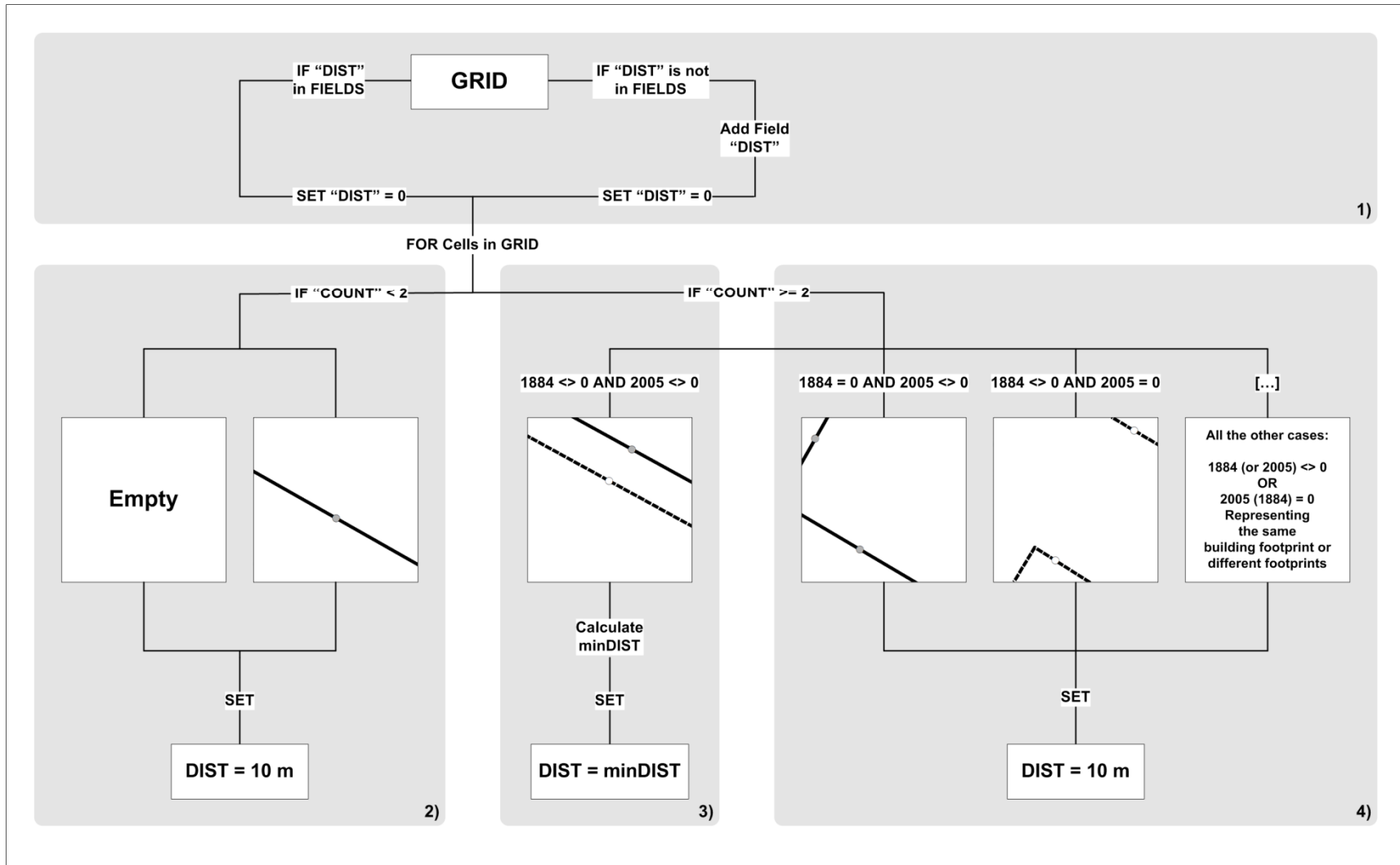


Figure 30. Flowchart representing the algorithm.

Table 6. The algorithm.VARIABLES DESCRIPTION:

- **GRID** = The grid layer
- **FIELDS** = List of fields contained in **GRID**
- **1884** = Points (centroids) representing the segments generated by the intersection of the grid with the 1884 footprint building outline
- **2005** = Points (centroids) representing the segments generated by the intersection of the grid with the 2005 footprint building outline
- **DIST** = Field representing the distance between 1884 and 2005 (the maximum possible value is set to be 10 meters; see text for an explanation)
- **COUNT** = Field representing the number of features (both **1884** and **2005**) contained inside each instance (*Cell*) of the grid layer (**GRID**).
- **minDIST** = Minimum distance between **1884** and **2005**

PSEUDOCODE:

Note: the steps in the pseudocode are numbered to match Figure 6.

```

1)
  GET GRID
  READ FIELDS in GRID
  IF DIST is in FIELDS THEN
    SET DIST to zero
  ELSE
    ADD Field DIST
    SET DIST to zero
  ENDIF
2)
  GET GRID
  FOR Cells IN GRID
    READ COUNT
    IF COUNT < 2 THEN
      SET DIST to 10 meters
3)
  ELSE
    IF 1884 <> 0 AND 2005 <> 0 THEN
      CALCULATE minDIST between 1884 and 2005
      SET DIST = minDIST
4)
  ELSE
    SET DIST to 10 meters
  ENDIF
ENDIF

```

Table 7. Distance measurement categories: combined levels of inaccuracy and uncertainty.

- *Very low*: 4 meters <= DIST <= Highest evaluated distance (~ 6 meters)
- *Low*: 3 meters <= DIST < 4 meters
- *High*: 2 meter <= DIST < 3 meters
- *Very high*: DIST < 2 meter

Table 8. Probability of change and combined levels of inaccuracy and uncertainty.

		Inaccuracy and Uncertainty				
		Very Low	Low	High	Very High	Total
Probability of change (%)	0 - 25	98.5%	.0%	.0%	1.5%	100.0%
	26 - 50	86.7%	.5%	1.3%	11.5%	100.0%
	51 - 75	72.9%	2.4%	2.7%	21.9%	100.0%
	76 - 100	78.2%	3.5%	4.1%	14.3%	100.0%
Total		87.8%	1.1%	1.5%	9.6%	100.0%

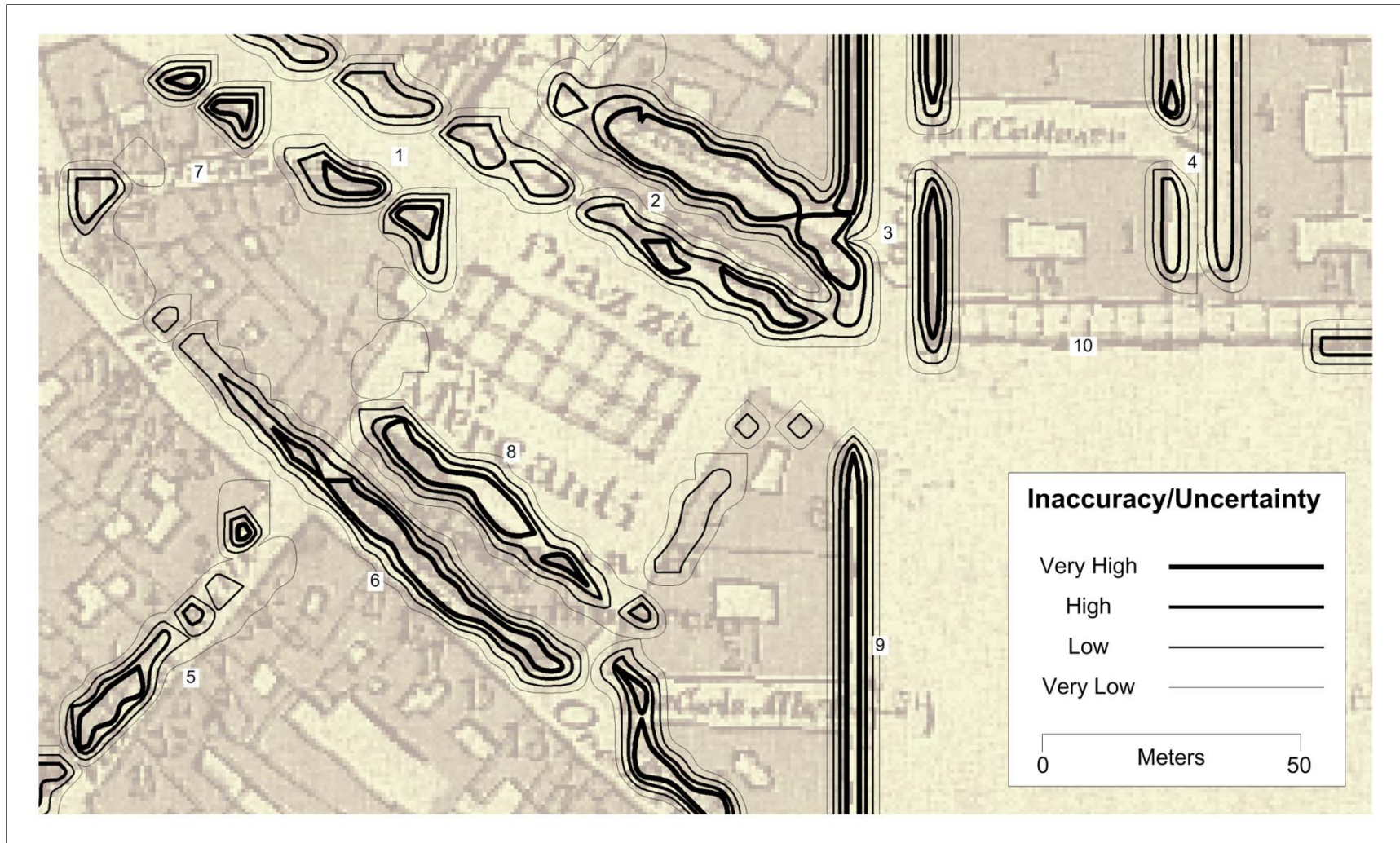


Figure 31. Contour map showing the combined levels of positional inaccuracy and positional uncertainty for the 1884 map. See also Table 2.

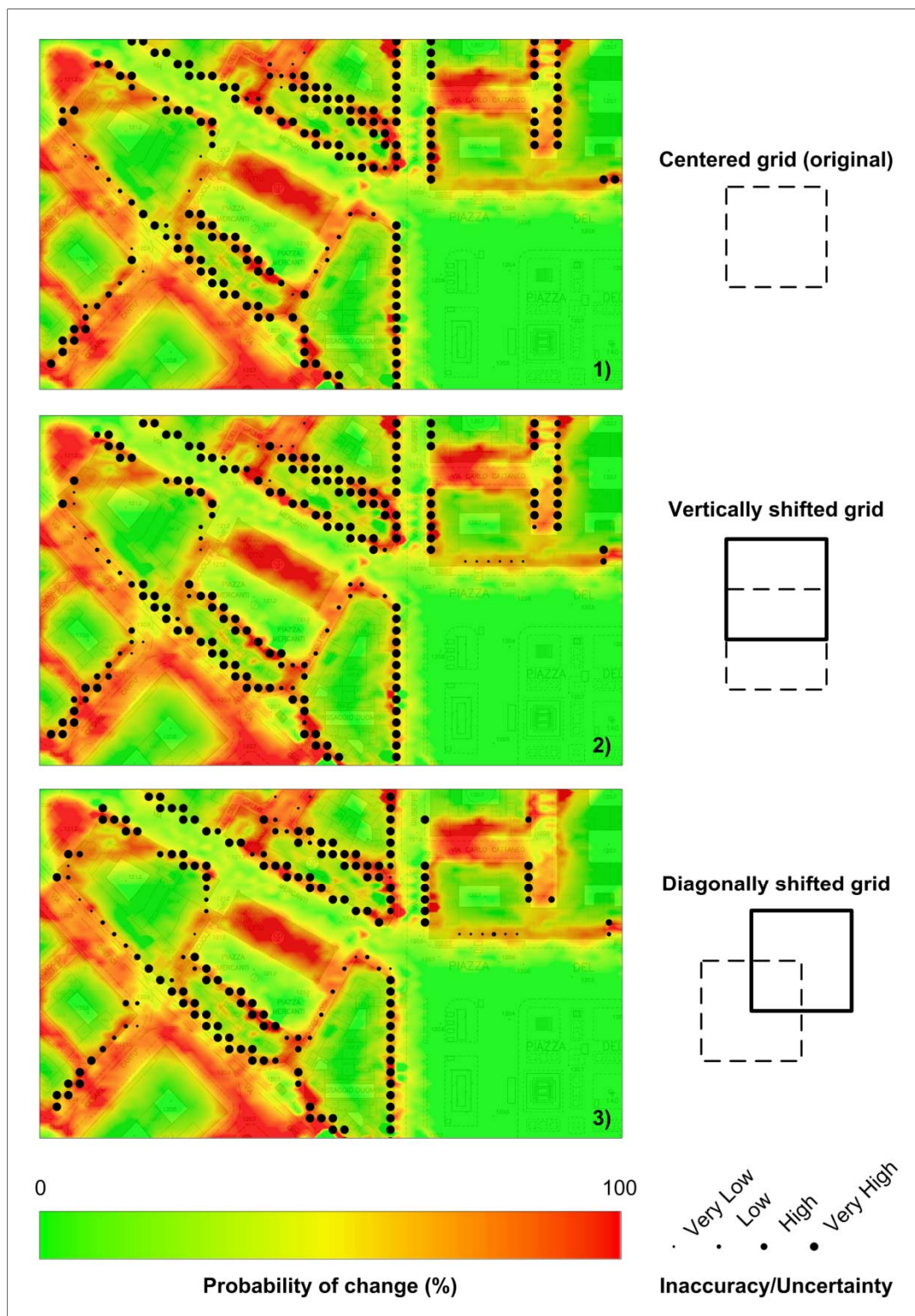


Figure 32. Combined effects of positional inaccuracy and positional uncertainty on probabilities of urban change for the three grids: 1) original (centered), 2) vertically shifted and 3) diagonally shifted.

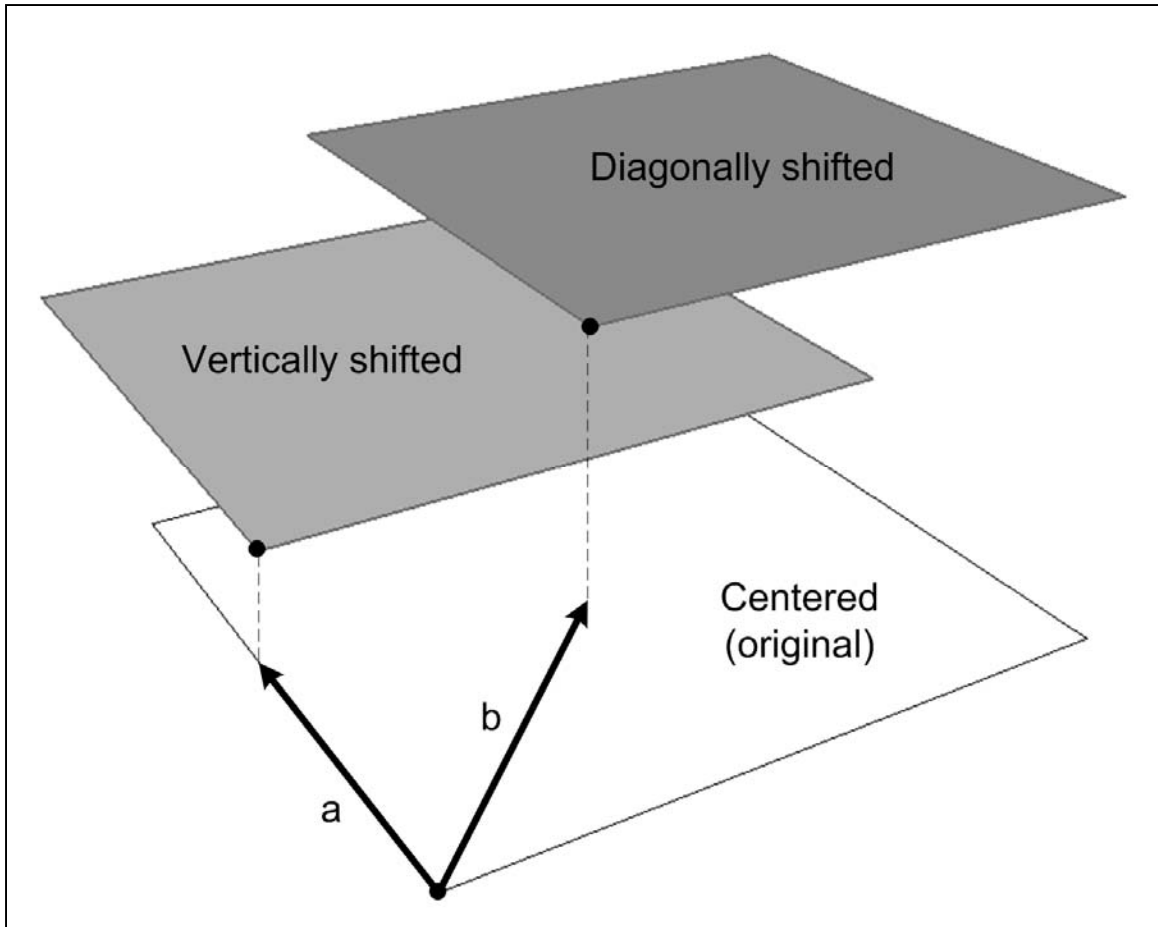


Figure 33. Reliability of results: original (centered) grid and derived grids (vertical or horizontal shifts).

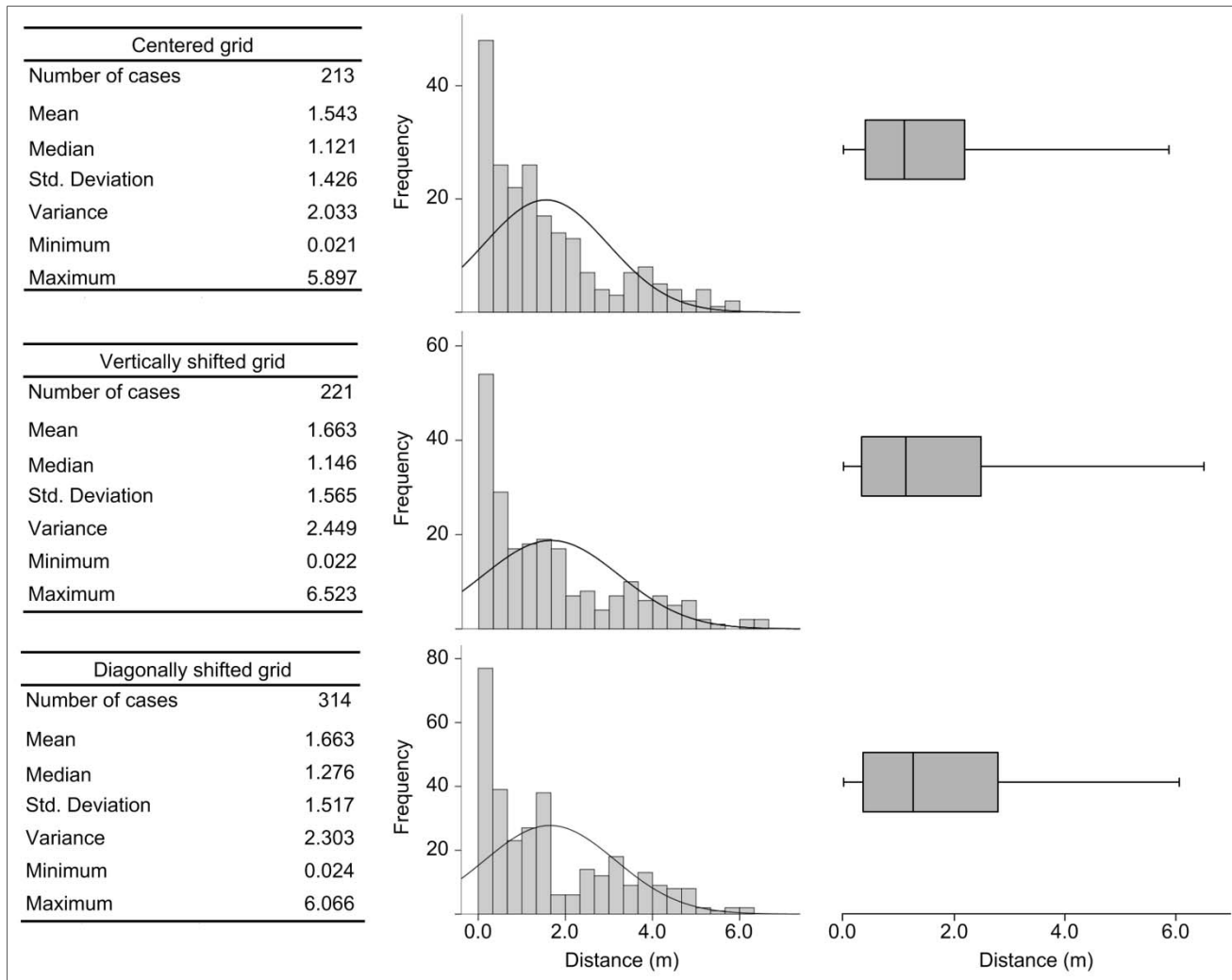


Figure 34. Descriptive statistics, frequency histogram and box plot of the three grids: original (centered), vertically shifted, and horizontally shifted.

Table 9. Results of the Kruskal–Wallis test.

Kruskal-Wallis (H)	0.360
df	2
Asymp. Sig.	0.835

CONCLUSIONS

First Chapter Achievements

In the first chapter of the dissertation I applied a spatial analytical methodology and geovisualization techniques to detect and discuss the changes that have occurred in the urban environment since 1800s. Lindsay (1980) notes that historical geographers are more interested in the study of patterns that change over time than in analyzing what does not change. Although one might also argue that no change may be as interesting as a lot of change, the quantitative approach of GIScience can be used to complement the more qualitative approach of traditional historical geography and historical cartography, in order to discover spatial patterns that are not immediately evident. To understand the advantages of this approach, one need only try to detect urban change by visually comparing Figures 3, 4, and 5, as opposed to studying the maps in Figure 14. The use of spatial-analytical methodologies not only facilitates our understanding of the urban change that has occurred in Milan since the mid-eighteenth century but also helps us to understand the relationship that exists between those changes and national and international historical events.

The first chapter concerns geovisualization and how it can help the researcher to achieve an insightful “visual thinking” on the data extracted, “a method for seeing the unseen” (McCormick, DeFanti, and Brown 1987, 3). The results I have arrived at using this methodology can be shown to be consistent with the findings of local scholarship: virtually all the areas of change mentioned in a monumental summa of the historiography of Milan’s urban fabric (Pellegrino 1984, 1985, 1986, 1987, 1988, 1991) are also identified in my analysis. But spatial

analysis and geovisualization techniques also led to the discovery of additional areas of urban change in the city. These are more peripheral areas, which had in general been neglected by local studies of urban history (Pellegrino 1984, 1985, 1986, 1987, 1988, 1991, being the most comprehensive example), which tend to focus on the more central and architecturally prestigious parts of the city. In this context, the present study also enabled me to detect a few broader patterns of urban change that had previously remained hidden. Visual histories of the city and architectural textbooks often tend to focus on the history of a limited number of highly visible landmarks in the built environment, and consequently they trace the “spirit of place” of modern Milan to the post-Unification era and to the interwar and postwar periods. By contrast, the scale of the analysis employed in this chapter shows that the impact of changes dating back to the Austrian and Napoleonic periods is more substantial and more widely diffused.

Second Chapter Achievements

The focus of the second chapter was the analysis of the street names currently inscribed in the historical center of the city as a reflection of its long and contested social and political history. Fragments of all the different toponymic regimes and hegemonic discourses that took over one after the other over time have remained inscribed in Milan’s street network, originating a complex tapestry in which different pasts revive and conflicting ideologies co-exist. By cross-querying information regarding street toponyms with information about its temporal and spatial variations the researcher is able to create dedicated period-based visual displays of the street network and inquire about the presence of spatial patterns by mean of quantitative cluster analysis.

Tuan (1991) notes how the construction of a place is not only represented by the mere transformation of the physical space, but is also comprised of historical and social events, large or small, that accumulate through time. In this context GIScience and Historical GIS can

contribute to discover the interplay of conflicting ideologies and the various spatial narratives inscribed in a place. Furthermore, this study can also show the potential of my approach in the broader context of cultural preservation in urban settings. Gross (1990)—writing before the age of the Internet—has noted how the increasing use of new technologies and media, and the relative information overload that their use can provoke, has caused signs from the past to retain less and less power in conveying their messages, thus converting urban environments into ‘anti-memory’ places. Combined with traditional historical analysis, GIScience and the Historical GIS approach can be of great benefit to the historian and cultural preservationist, by unearthing previously hidden historical urban features as well as offering useful geovisualizations to display and popularize the history embedded in the cityscape.

As Hiller and Knowles (2008) point out, “historical geography has traditionally been concerned with discovering the underlying social and economic processes that shaped rural and urban landscapes over time,” whereas GIScience is more concerned with the unearthing of and geovisualization of spatial patterns. Historical GIS tries to combine the quantitative approach of GIScience with the qualitative method more traditionally used in historical geography and history. To put it differently, both the questions I asked myself and the tentative interpretations I provide here would have been impossible without the construction of a geographical database. By employing the tools and methods of GIScience I was able to quantify and analyze data about several hundred street segments varying spatially and temporally across the over two thousand years of history of the city, an achievement hardly accomplishable without creating a Historical GIS and applying spatial analytical methods.

Through a simple count of the number and length of street segments, as well as the employment of more sophisticated tools like cluster analysis, I was able to single out the impact of each regimes on the contemporary cityscape and more locally on the city center’s historical

neighborhoods. Of the five layers I built corresponding to the political regimes that shaped the history of Milan, two—the Medieval and the Post-Unification—have emerged as fundamental in shaping Milan’s streetscape as we know it today. More specifically, the importance of Medieval street toponyms in contemporary Milan not only reminds us of the crucial role of the Middle Ages in the shaping of the layout of the European cities, but also that the almost exclusive emphasis on authoritative, centralized naming by the modern state is a result of the fact that the majority of studies in the cultural politics of place-naming so far have focused on the 20th century. This result contrast and complement the findings of the first chapter and can be explained with a change in the scale of analysis and, from a historical point of view, by examining the broader European context in which Milan is situated. For example, the renewal projects carried on before and after the Napoleonic interlude on *Porta Nuova* district - the most Medieval district and the one facing Vienna, the center of Austrian Empire - is related to the renaming process of portions of the street network that occurred first during the Austrian-Napoleonic period and then in the Post-Unitarian period; likewise, the progressive westward expansion of the city during the Post-Unification period is reflected in the high incidence of toponyms of this period in the *Porta Vercellina* district as well as a another cluster in the Castle area. (Compare Figure 14 with Figures 23 and 24 and see chapters one and two for explanations.) Rather than being a problem, then, by examining the data at different scales I was able to bring to light patterns of toponymic changes that have an historical correspondence, if not explanation.

Third Chapter Achievements

In the third chapter I have proposed a methodology for detecting the effects of positional inaccuracy and positional uncertainty on the results of urban change detection analysis at a higher spatial resolution (the building) than the one employed in the first chapter

(the city). The choice of such a high resolution is justified by the high level of positional accuracy of the two maps and by the fact that both maps are at a large scale. Considering that the overlay of two maps created at different dates is a routinely performed and widely accepted technique for detecting urban change—and spatial change in general—I have also argued for an integral incorporation into urban change detection procedures of a careful evaluation of the effects of positional accuracy and positional uncertainty, specifically as concerns the sensitivity of its analytical results to local variations. My results indicate that certain spatial configurations of features—such as buildings running in parallel—might be more prone to the combined effects of positional accuracy and positional uncertainty, but whether these results can be generalized to other historical maps is left to a future study.

Besides contributing to the HGIS and historical cartography literature, the methodology and algorithm presented in this paper could be used for testing the reliability of any feature change detection analysis in the LPA context. As Figures 31 and 32 and Table 8 show, positional accuracy and positional uncertainty are not uniformly distributed; on the contrary, they affect various features in various locations on the map in different ways. Studies in which the positional accuracy of historical maps is based on the calculation of RMSE values fail to examine systematically how inaccuracies and uncertainties vary across the map, except for selected locations where additional information might be available.

The Role of Scale

Previously introduced in the Significance section, as a final remark I deal with the concept of scale and its crucial influence on historical geography analysis. Even though each of its chapters can be taken as a stand-alone study, when analyzed all together, this dissertation has to be seen as an investigation of the spatial history of the city of Milan. Throughout this

work, GIScience and its methods have been used as a useful tool to inquire on the history of the place under different scale, both spatial and temporal.

Table 11 shows a Spatio-Temporal matrix summarizing periods analyzed, spatial scale, GIS data models, tools, and methods employed in this dissertation. The raster data model, map algebra and geovisualization techniques were used at the smallest scale (city-wide). The micro scale analysis was able to unearth new and neglected areas of urban change as well as detect patterns in land use change acting at urban and in a broader European context (Johnston and Barra 2000). The outcomes achieved were in part in disagreement, at least as far as the built environment is concerned, with the local studies of urban history.

Shifting the analysis at a larger scale (neighborhood and street-wide scale), deepening the temporal span, and taking into consideration a different phenomenon such as the semantic interpretation of the streetscape toponyms, the results achieved are more in line with the traditional historiography of the city. In particular, cluster analysis confirmed not only the predominance of the Post-Unification period in shaping the history of the city, but also added the Medieval layer as key period in this process.

The mixed vector/raster data model for the largest scale analysis was employed more for technical and cartographic purposes. The scripting automation applied on a subsample of a historical maps previously use in the analysis of the first chapter, was determining for inquiring on the positional accuracy and uncertainty of the map. At such large scale, the focus was more on the actual cartographic production (areas more or less accurate) rather than the history of the place itself.

In the course of my study of the history of Milan, conducted with the tools and methods of GIScience rather than with more traditional qualitative methodologies, I have come to appreciate even more the high complexity of the urban landscape and how socio-economic

events contributed to its formation. The contribution of GIScience has consisted principally in the discovery and visualization of patterns of change at different spatio-temporal scales. In particular, the analysis performed in this dissertation is based on a series of historical maps and ancillary documents, which are used to reveal different aspects of the history of the city. The study of its concentric growth around the ancient Roman core, as well as the variety of events that have occurred in the period analyzed, show that a geographical interpretation of past events with a GIScience approach can truly represent a pivotal point to understand the shaping of the urban form. In this context, scale is an essential element of the analysis, and varying scale can lead to different outcomes. Rather than being seen as a limitation, a multiscale analysis has lead to the discovery of multiple spatial and temporal layers of the history of the city. The analytical outcomes of the first chapter, for instance, show that historical trends embedded in the wider European context are more visible at the city-wide scale of analysis. Most likely, the effects of these trends on changes in the urban morphology of Milan were not reported in the historical literature we examined because this literature focuses largely on local events. Conversely, the agreement between the results of the second chapter with the local historiography is probably due to the analytical shift from the smaller to the larger scale of analysis. GIScience in this respect is used as a “time machine” that can be used to switch in time and space over different periods and geographical extents.

Future Directions

Possible future extensions of this research should concentrate more strongly on its interdisciplinary nature. For example, one could examine the nature of historical and geographic data and their ontology, as well as how to best integrate maps and ancillary and archival data. More specifically, the results of the first chapter could be further tested by including in the source materials other historical maps from a variety of historical periods. Starting from the

consideration that a map is a substitute of the reality, not its representation, but nonetheless is trusted as “ground truth,” to which extent can a cartographic production of the city be considered a reliable historical document? This study would mainly focus on establishing an historical-geographical metadata model, aimed to qualitatively rank maps on the basis of their reliability and historical authority. The results of the second chapter could be extended to include the built-up environment with a study of the vertical development of the city as opposed to its expansion in two dimension. From a different point of view, the database used in the second chapter could be examined at a different (and finer) temporal granularity. This last point was actually a suggestion from a reviewer of the *Journal of Historical Geography*, where the paper was eventually published. As concerns the third chapter, I believe a worthy research objective may consist in the development of a taxonomy of spatial patterns of historical cartographic representation and their relation to issues of positional inaccuracy and positional uncertainty. Given the methodological similarities between this chapter and the first, a study of patterns could complement other types of information in trying to determine which maps are more or less reliable and to which period they belong.

Finally, in this dissertation I have tried to show what valuable role GIScience can play in historical research. By employing quantitative and qualitative methodologies and geovisualization techniques, I have been able to bring to lights new aspects of the urban history of Milan. To this end, GIScience has been an extremely valuable approach to guide the the collection, analysis, and geovisualization of historical data, both confirming long held beliefs and, in some cases, also generating new explanations, hypotheses, and questions.

Table 11. Spatio-Temporal matrix.

		Space (scale)		
		Small (City-wide)	Medium (Neighborhood- Street)	Large (Building)
Time	Contemporary	Raster Data Model: Map Algebra and Distortion correction. Geovisualization for Urban Change Pattern Detection.	Vector Data Model: Semantic interpretation of street network. Historical layer detection. Cluster analysis	Mixed Vector and Raster Data Model: Scripting Automation for Positional Accuracy/Uncertainty Issues
	Modern			
	Medieval			
	Roman			

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