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research

The study of urban fabric dynamics in long time spans. Modelling, analysis and representation of spatio-temporal transformations

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The requirements for understanding the dynamics of urban fabric over long time spans are to be able to analyze situations at different times as well as the process of transformation between these states. Historical data thus needs to be modeled by deconstructing their spatio-temporal properties. The implementation of this model in a GIS provides an original means of processing the information: the results of the spatial and/or temporal analyses lead to a true interpretation of the urban dynamics.
Keywords: Spatio-temporal modeling, spatio-temporal analysis, urban fabric, GIS, Tours

L'appréhension des dynamiques d'un tissu urbain dans le temps long demande de pouvoir analyser à la fois les situations à différents moments, et les processus de transformations entre ces états. Pour atteindre ce double objectif, il est alors nécessaire de modéliser les données historiques en déconstruisant leurs propriétés spatio-temporelles. La mise en œuvre du modèle dans un SIG permet un traitement original de l'information : les résultats obtenus à partir des différentes analyses, spatiales et/ou temporelles, aboutissent à une véritable lecture des dynamiques urbaines
***Mots-clés**: analyse spatiale, morphologie urbaine, SIG, Tours*

Introduction

The study of towns over long time spans usually consists in producing a series of maps giving details of different states of the historical topography[1]. This type of representation raises two main problems for the archaeologist or historian working on urban dynamics. First, time is always broken down a priori, either in an abstract manner and by century,

[1] Many recent works use GIS for the study of urban topography: Pinho, Oliveira 2009; Lilley, Lloyd, Trick 2007; Arnaud 2008.

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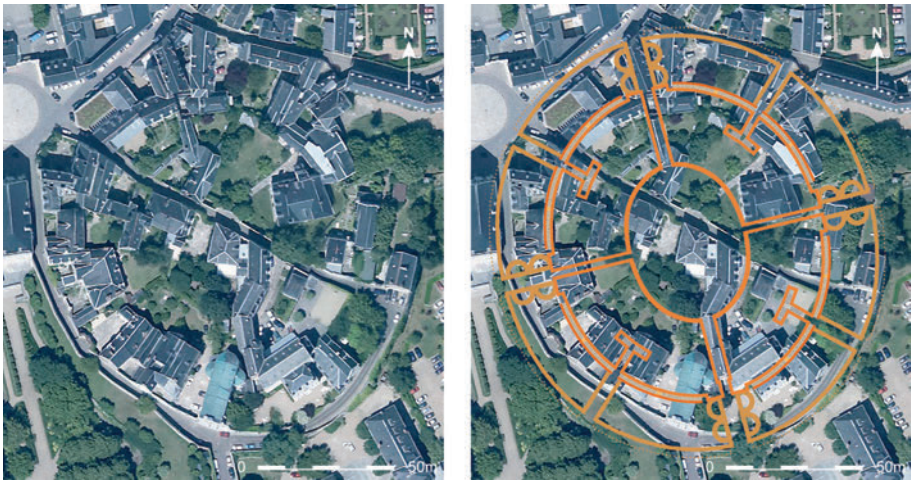

Fig. 1. Aerial view of the current urban fabric covering the site of the Roman amphitheater in Tours. On the right, the overlay of the reconstituted plan of the Roman building.

or on the basis of specific periods in the political history of the town. This breakdown prevents any specific research into the temporality of the town and its own rhythm of functioning. Secondly, these maps only represent a series of snapshots and not processes, i.e. long phenomena which last over time. Urban dynamics can only be seen in a biased and partial manner through empirical comparison of these maps.

The analysis of urban dynamics requires specific research into the processes underlying the town transformation. This raises the questions of how to model these dynamics and represent these spatio-temporal processes.

These questions were central to a doctoral study in archaeology on how the urban fabric in the City of Tours developed from the site of a Roman amphitheater to a canonical district (5th-18th centuries) (Lefebvre 2008). Through research into the transformation of a Roman building into mediaeval urban fabric (fig. 1), the aim of this project was to provide a new approach to interpreting traditional historical topography, looking at both the situations and the functional, spatial and temporal transformations of part of the town over long time spans.

This article describes the main methodological background of the research in terms of analysis of the dynamics of the urban fabric. The first section tackles the questions underlying knowledge-building: this involved defining first the historical objects and their relationships, and then the principle on which they could be modeled and how this model could be im-

plemented. Leading on from that, the second section proposes a new way of representing the dynamics of urban fabric through a spatial (or cartographic) and then temporal (or chronographic) prism (Lefebvre 2010). The third part presents the current orientation of this research. Will be presented briefly the work focused on the one hand, on the generalization of the method through the creation of a tool for ergonomic analysis and on the other hand, on the establishment of a corpus of cities to study in order to define models of urban trajectories.

1. Modeling the dynamics of the urban fabric

The methodological principle chosen to model historical information was largely inspired by the OH_FET theoretical model thought to analyze the topography of the city of Tours (ToToPI) (Lefebvre, Rodier, Saligny 2008; Rodier, Saligny 2010). Considerable changes were however needed to adapt the model to the specific issue of the transformation of the amphitheater into urban fabric, and on a different scale of analysis centered on the organization of two particular blocks, rather than the whole urban space. However, as in the OH_FET model, a systemic approach was used to understand the dynamics, based on the notion of complex objects and simple objects.

1.1. The historical objects of the urban fabric: the Constituent Elements (EC)

The first modeling step consisted in identifying and defining precisely the nature of the object studied in relation to the research topic. In order to understand the dynamics of the urban fabric over long time spans, this object must have a connection with all the present and known changes which have occurred in the space and chronological period examined. Following a principle laid down by GIS specialists (Peuquet 1994; Thériault, Claramunt 1999; Saint-Gérand 2005) in an essay about the town, Henri Galinié suggests that, to be valid, each of these historical objects must meet three fundamental criteria (Galinié 2000): 1) a location (where is it?); 2) a date (when did it exist?); 3) an interpretation (what is it?). By combining these three properties, the "life" of each historical object can be defined, i.e. a fixed state. In this way, any modification, i.e. any change in one of these properties, leads inevitably to its disappearance and the creation of a new object. The way the historical objects as a whole have been transformed can thus be perceived, and from there the dynamics of the urban fabric can be analyzed.

In the study of how the Roman amphitheater site was transformed into urban fabric, the historical object selected as being relevant on the district scale is called the Constituent Element (EC). It concerns a particular type of occupation of space such as a dwelling place, a courtyard, a garden, etc. (for the complete list of social uses, see §1.4.1).

1.2. Modeling space and time: Spatial features (ES) and Temporal features (ET)

1.2.1. Modeling space

Each historical object is thus defined by location, date and social use. To study the dynamics of the urban fabric, i.e. its transformations, I took the concept of spatial modeling proposed for ToToPI (Galinié, Rodier, Saligny 2004). The principle consists in deconstructing space into simple objects called Spatial features (ES), which correspond to the smallest possible geographical unit. Each ES forms a portion of space with unique geometric properties (position and shape) defined by a specific time course; ES are semantically neutral objects, and only through their association with others can the importance of a historical object (EC) at a given time be reconstituted. The spatial dynamics can then be understood by investigating the relationships between Spatial Features (ES) and Constituent Elements (EC).

1.2.2. Modeling time

Modeling time is based on a similar principle to deconstruction into simple objects. In the same way that historical objects are divided up geometrically into Spatial Features, the "life" of these ECs is divided up into Temporal features (ET), each corresponding to a portion of time defined by a unique date and duration. These features thus form an uneven division of time reflecting the transformation of historical objects as a whole, i.e. the time pattern of the urban fabric. Moreover, analyzing the relationships between ETs and ECs provides details of many aspects (thematic and/or chronological) of the structure of time.

1.3. The conceptual model of the process of urban fabric formation

In sum, in the global model, the Constituent Element (complex historical object) is formed by the association of several Spatial Features (simple spatial objects) with several Temporal Features (simple temporal objects) and a social use.

This way of structuring information can be summarized in a global

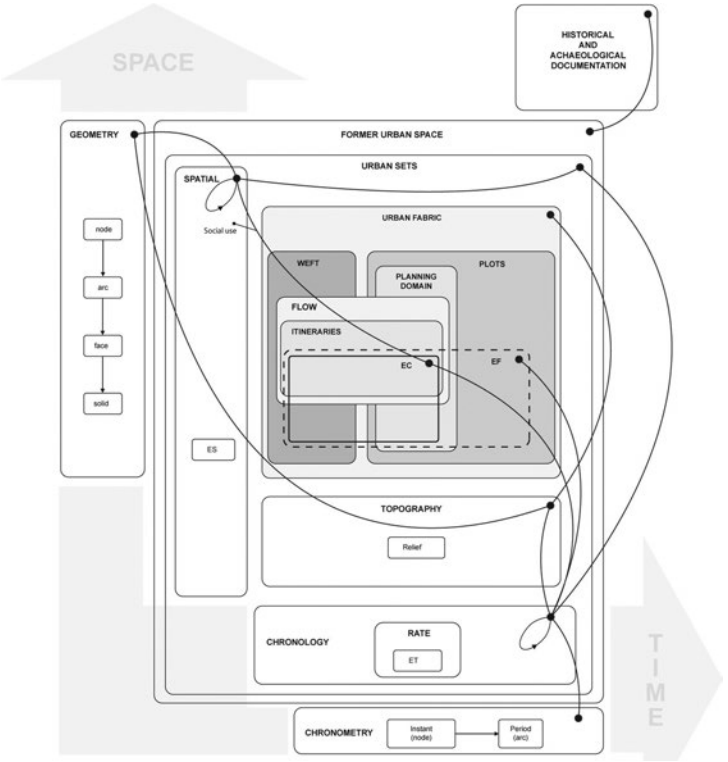

Fig. 2. The conceptual data model.

schema called the Conceptual Data Model. Its formalization using the HBDS method (Hypergraph Base Data Structure) (Pirot, Saint-Gérand 2005) creates a link between the study topic and the Geographic Information System (GIS) in the ESRI ArcGis 9.2 software.

Figure 2 represents the Conceptual Data Model as it was used for studying the formation of urban fabric on the site of the Roman amphitheater in Tours. In this schema, the modeling of space is shown by the thick horizontal arrow and that of time by the horizontal axis. The historical object is in the centre of the schema, linked to the spatial and temporal dimensions and associated with a social use.

1.4. The deconstruction of historical data relating to the Roman amphitheater site

Comparison of the different traditional sources used in historical studies (excavations, architecture, textual, planimetric and iconographic

documentation) gave rise to a corpus of 463 Constituent Elements (EC). Next, the functional, spatial and temporal properties were characterized and then modeled and incorporated into the GIS for analysis to account for the dynamics of occupation.

1.4.1. Identification of social uses

In contrast to time and space, social uses were broken down prior to modeling. Thirty uses were identified to describe the urban fabric at the intra-parcel level:

7 Basilica
9 Bastion
10 Cathedral
11 Cell
13 Chapel
14 Road
15 Cemetery
16 Citadel
18 Stone wall
19 Cloister (portion)
20 Collegiate church
22 Courtyard
23 Kitchen
24 Servants' quarters
26 Stable
27 Parish church
28 Boundary wall
31 Ditch
36 Garden
37 Latrines
38 Dwelling place
39 Oratory
42 Square
43 Door
44 Postern
45 Well
46 Street (portion)
47 Sacristy
49 Waste land
50 Tower

These functions are associated with the ECs by a relationship of 1 to n. In this way, as an EC has a single function, it follows that there are as many relationships as there are historical objects. Analysis of the functional dimension is thus based on 463 relationships.

1.4.2. The division of space

On the principle of modeling based on the non-redundancy of space, the 463 Constituent Elements making up the data base resulted in a division of the continuous space into 541 Spatial Features (fig. 3). The spatial dimension of the ECs, i.e. of the historical objects, was reconstituted by a combination of geographical objects (the ESs), namely a total of 1069 relationships. By applying this principle of informational modeling, the ES do not relate to any historical reality, unlike the links which combine them to form the ECs. Queries relating to space concern precisely these relationships.

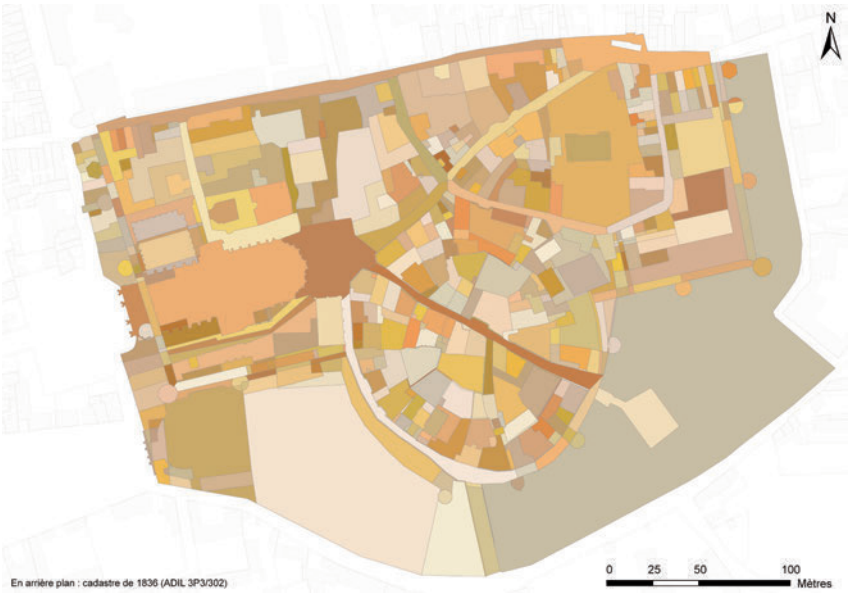

Fig. 3. Map showing the division of the study zone into Spatial Features (ES). Each color represents an ES.

1.4.3. Division of time

On the same modeling principle as for space, i.e. based on a non-redundancy of time, the 463 Constituent Elements in the data base resulted in a division of time, between 350 and 1800, into 101 Temporal Features (fig. 4).

These ETs have no real historical meaning: it is the association of several features which acquires a historical meaning when it reconstitutes the temporal dimension of an EC. In this way, as for space, the time of the historical objects (EC) is reconstituted by combining several ETs. There are a total of 8107 relationships associating ECs with ETs. It is these relationships which have a historical meaning and which can be interpreted, unlike the ETs: queries regarding time as a whole (temporal, spatio-temporal or temporo-functional) concern these relationships.

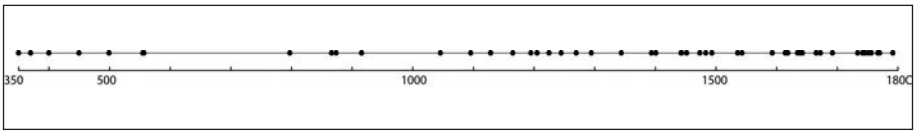

Fig. 4. The division of time into Temporal Features (ET).

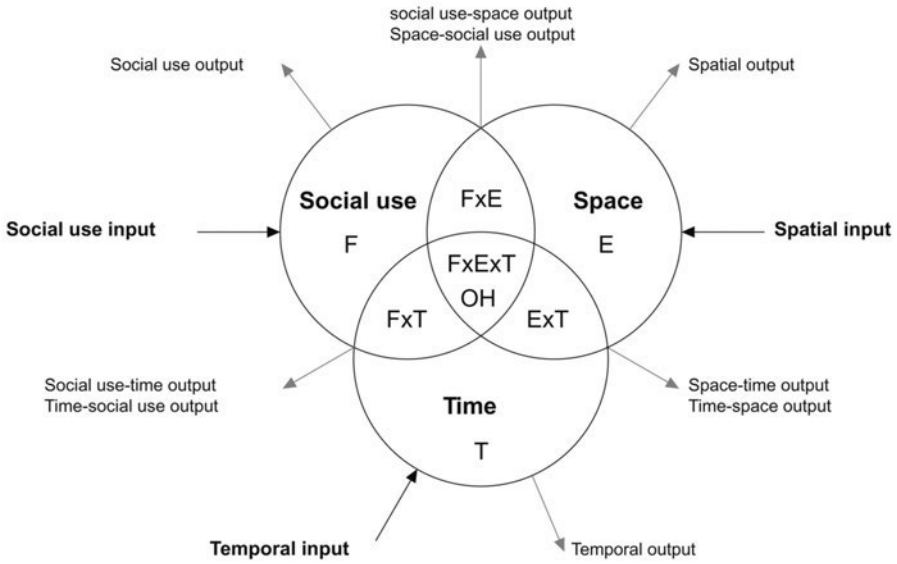

Fig. 5. Diagram of the modeling, analyses (outputs) and inputs of the system.

2. Spatio-temporal representation of the results

By dividing up space, time and social use, and then combining these features, it is possible to reconstruct the historical objects (the ECs) as a whole. This method reveals the complexity of the system studied with three possible inputs corresponding to these three dimensions (fig. 5). These inputs function as queries to which six types of analysis (or outputs) represent responses revealing a particular aspect of the system's dynamics.

One by one, or two by two, figure 5 illustrates the six types of analysis emerging from this system of representing the urban fabric: three unidimensional, i.e. space (E), time (T) and social use (F), and three bi-dimensional which are the Cartesian products of space and time (E x T), time and social use (T x F), and social use and space (F x E).

In many respects, these analyses produce original results compared to studies of historical topography. However, while cartography provides a framework which can represent the spatiality of geo-historical phenomena (Grataloup 1996) the representation of time, which is an integral part of it, has never really been tackled. After presenting the different types of analysis which are possible with this model, the final paragraphs of this article will look at the question of how the time aspect of the dynamics can be represented.

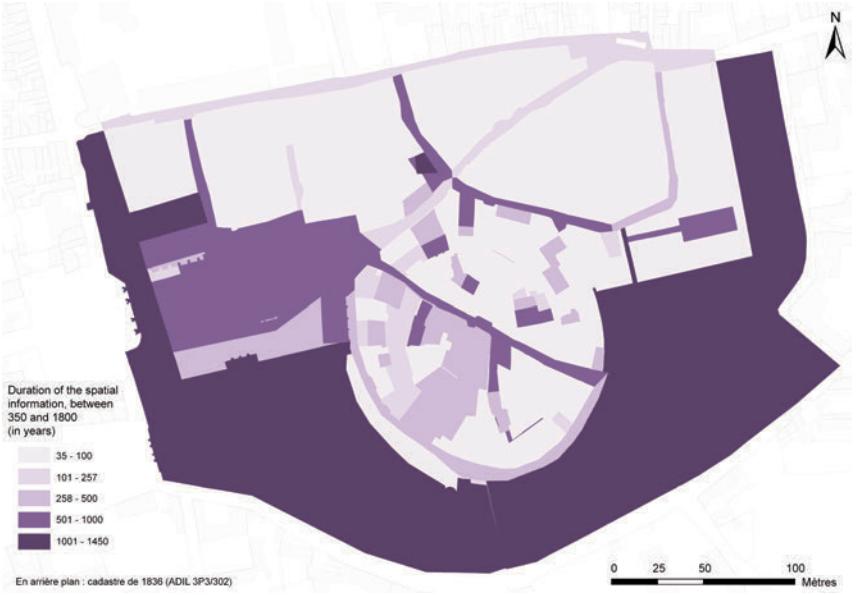

Fig. 6. Map showing the duration of the spatial information, between 350 and 1800.

2.1. Spatial input – cartographic representations

2.1.1. Spatio-temporal analysis

Using the above model, a spatio-temporal analysis can be carried out by deconstructing historical information. The outcome of this analysis illustrates the duration of the data in the form of a map, in other words, the distribution of the historical objects (EC) in the space-time continuum.

In the absolute, it should be possible to document space fully throughout the chronological period studied. However, the historical sources, notably archaeological, are incomplete: space is documented neither homogeneously nor continuously through time. This can introduce a bias in the analysis which can be summed up in the expression "source effect".

A representation of space in response to one or more ETs highlights the spaces documented within the time period of the study, and if necessary over which cumulated duration (fig. 6).

The result of this analysis does not provide any historical information as such: it is however essential, because it illustrates the duration of the spatial information. The spatio-temporal analysis thus figures as a prerequisite for all spatial queries: their cartographic representation must be used as an index of reliability in interpreting the results of these analyses.

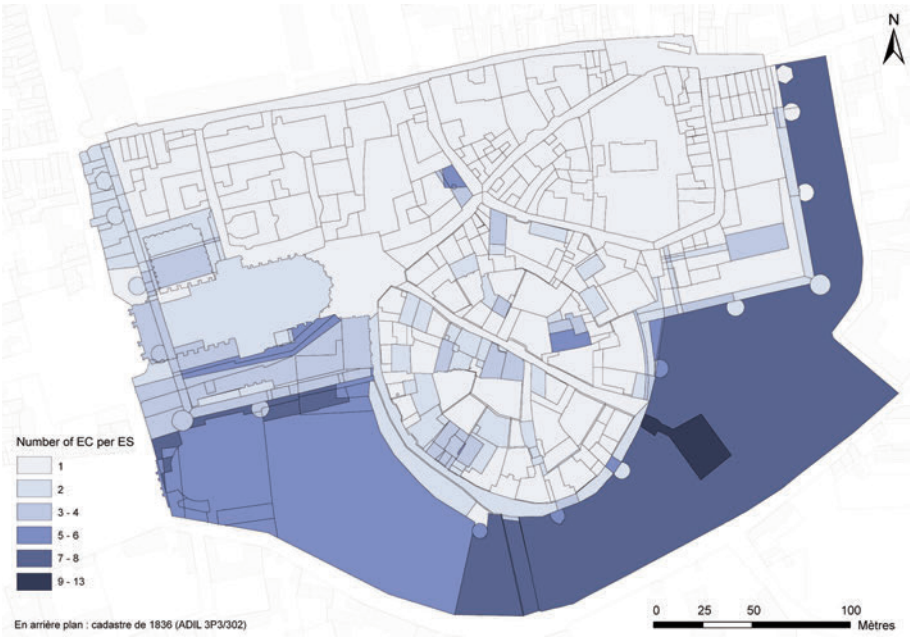

Fig. 7. Map showing the incidence of spatial features.

2.1.2. The spatial analysis

Using this model, the spatial analysis provides a cartographic representation of the transformations over long time spans. By dividing up historical objects (EC) into ES, and then re-combining them through relationships, it is possible to know how often each portion of space is associated with a historical object. This corresponds to identifying the occurrence of utilization of space. This type of analysis thus illustrates all the changes of state, spatial and/or functional.

This single map (fig. 7), i.e. a static representation, thus reveals the accumulated transformations of space, in some way mapping the changes in the uses of the site.

2.1.3. Spatio-functional analysis

The objective of the spatio-functional analysis is to separate the changes in social use from those linked to space. The model can be used in a fairly simple way to show the functional diversity of the space, in other words, the number of different social uses associated with each ES. This is illustrated in Figure 8. Examination of this map shows that the space

Fig. 8. Map showing the number of different social uses associated with each spatial object.

corresponding to the amphitheater experienced only a limited number of changes in use during the Middle Ages and the Modern era. On the other hand, over long time spans, the space to the south of the old building has experienced more changes of use (function).

Apart from these remarks, it is difficult to interpret this map in that it does not take into account the occurrence of spatial features. It is however important for the analysis to show the correlation between the occurrences of the Spatial features (ES) (i.e. the transformations) and their functional variety.

This involves trying to calculate, for each portion of space, a value illustrating the persistence of the social use during the transformation. To be comparable throughout the space, this value must be established by dividing the number of occurrences by the number of social uses for each ES. The values obtained for each ES are shown in Figure 9 which illustrates the continuation of social use in the transformation of space.

On this map, the higher the value is, the greater the stability of the ES in terms of social use, whereas the lowest figure (close to 1) indicates the greatest variability. The calculation of this value is particularly important because it allows an entity which is appeal for example in a single relationship and has a single social use to be distinguished from one involved

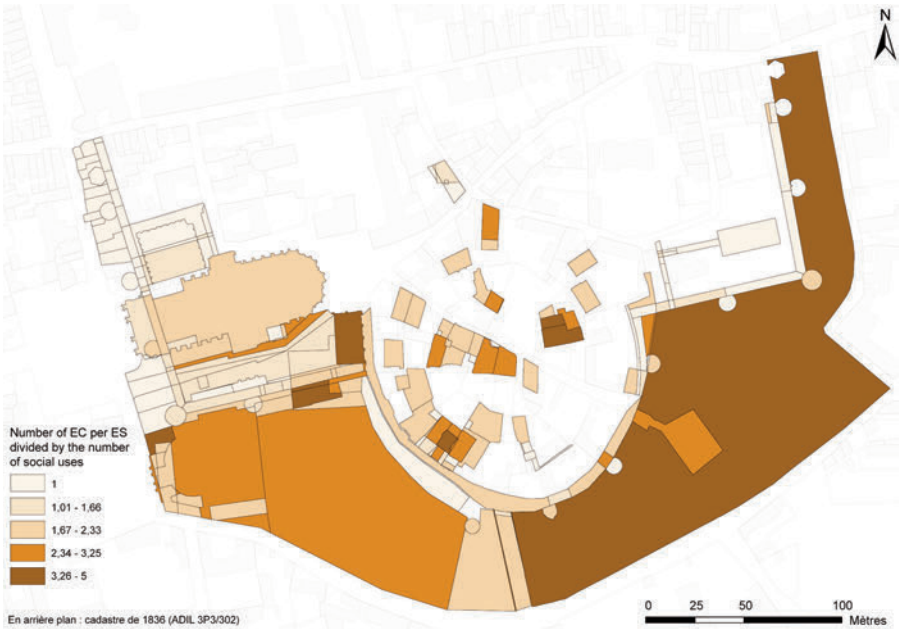

Fig. 9. Map showing the continuation of social use during the transformation.

in four relationships but which nevertheless has a single social use.

Comparing this map (fig. 9) with the previous one (fig. 8) shows that there is no direct link between the continuity of the functional dimension and the number of social uses.

These different maps make it possible to represent several aspects of the dynamics of the site over long time spans. They show that over and above the general dynamics of occupation there are behaviors which are specific to changes in space and others which are specific to changes in social use.

However, on their own, they cannot describe the time and the pace of these dynamics, because they compile the transformations for a period as a whole without providing the details. These spatial analyses must be complemented by temporal analyses in order to grasp the whole process of how the urban fabric is formed.

2.2. The temporal input – chronographic representations

2.2.1. Temporal analysis

In the same way that it is possible to create a map of the occurrence of spatial entities, a graph representing the occurrence of temporal entities

can also be produced from the model. Figure 10 shows the result of this temporal analysis, showing the number of times that the ETs are involved in creating the OH. The distribution of the occurrence of the ETs in time illustrates the rhythms of the system. This graph provides a historical perspective of the way the urban fabric is formed over time. Without analyzing this figure in detail, it is important to point out that the sharp rise in the number of historical objects at the end of the 18th century can be explained by the interplay of data. This rapid growth coincides with the appearance of old maps of the town which considerably improved knowledge of the occupation of the site. This is a further example of the "source effect".

The temporal analysis can also be used to characterize the nature of the changes of occupation. For each ET (in other words, for each change in the interplay of data), it is possible to know the number of historical objects which appear compared with the number which disappear.

When the number of objects which appear is greater than those which disappear, the transformation corresponds to a splitting up of the occupation; when this ratio is reversed, the transformation corresponds to a tendency towards a fusion of the historical objects. If the two values are equal, the space has only been renewed or reorganized while the occupation has been neither divided up nor merged.

In the following graph (fig. 11), the black bars represent new appearances and the grey bars represent disappearances. The long bar in 1765 indicates that a large number of historical objects were created at that date. This again highlights the source effect linked to the use of information contained in the first parcel plan of the town.

While the temporal analysis reveals the rhythm of the dynamics of the historical objects, the results are inadequate to explain the detail of the changes, and in particular to distinguish between changes in space and in social use.

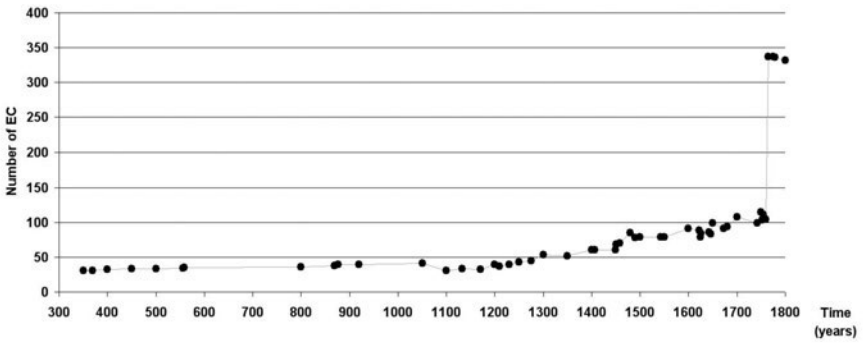

Fig. 10. Graph of the occurrence of Temporal Entities.

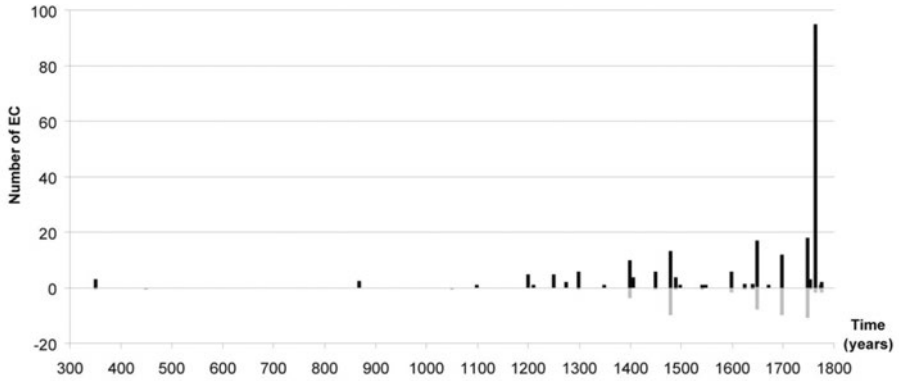

Fig. 11. Chronology of the relationship between the appearance and disappearance of historical objects on the site of the Roman amphitheater. The positive values in black refer to appearances; the negative values in grey refer to disappearances.

2.2.2. The temporo-functional analysis

The model allows a temporo-functional analysis to be carried out to show the trends in social use over time, in other words the functional behavior of the historical objects. This type of analysis illustrates changes in the functional diversity and the place held by each function in the history of the site occupation.

Figure 12 shows that the number of functions increases over time, but that this progression is not linear in detail. This type of graph highlights a certain number of regular or irregular trends which require a historical explanation.

While the appearance of certain social uses and their growth can depend on the source effect (for example the growth of functional diversity from 1100), this does not seem to be the case for their disappearance. Thus, the decline in functional diversity which can be seen from the end of the Middle Ages can be explained by the disappearance of most of the non-domestic social uses. During the Modern era, domestic uses appear increasingly to the detriment of others (military and religious): the trend is clearly towards an exclusively residential occupation.

2.2.3. A chronographic representation of the dynamics

In historical topography studies, time is generally considered to be a reference aid and not a subject of study. The above paragraphs show that temporal analysis can be carried out along the same lines as spatial analysis. Due to the many parallels between these two dimensions, the

term "chronography" has been proposed for a time map allowing several pieces of information about time to be visualized, like a geographical map.

The chronographical representation should be able to provide a summary of the temporal and temporo-functional analyses which on their own provide only a partial view of the dynamics of the formation of the urban fabric. The chronographic representation thus corresponds to a global view of the temporal behavior of the historical objects. It helps describe the architecture of time, i.e. to represent the way time is constructed in a given space.

Figure 13 is a chronographic representation of the process of transformation of the Roman amphitheater in the canonical district.

The vertical bars represent each change of occupation, indicating the relative proportion of disappearance (in red), appearance (in orange) and stability (in white) of the historical objects. In addition to these bars which indicate the pace and character of the transformations, this type of chart also contains information which is specific to the functional and spatial dimension of the historical objects: between these bars, the grey rectangles represent the intensity of the way social uses were split up during periods of stability.

As in a map, this chronographic representation concerns a specific topic (in this case, the formation of urban fabric on the site of the Roman amphitheater). Moreover, this type of chart has a chronological range (in this instance, 350 to 1800 AD) and a scale (the year).

2.3. Current researches on the urban temporality

Following this work focuses on a district, the model has been adapted and tested at other scales. A similar study was also conducted from

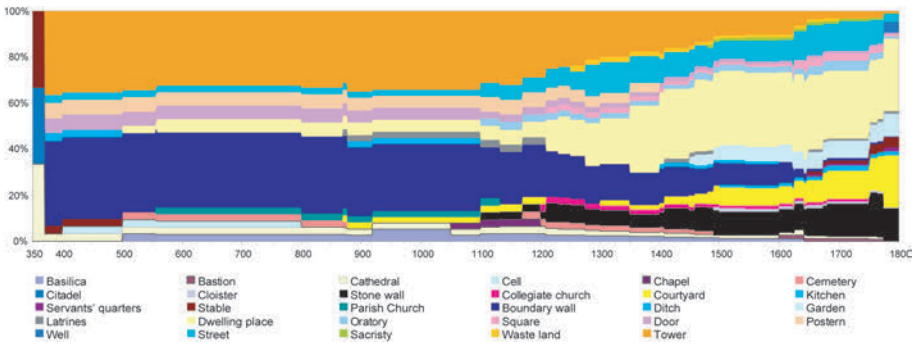

Fig. 12. Functional division graph.

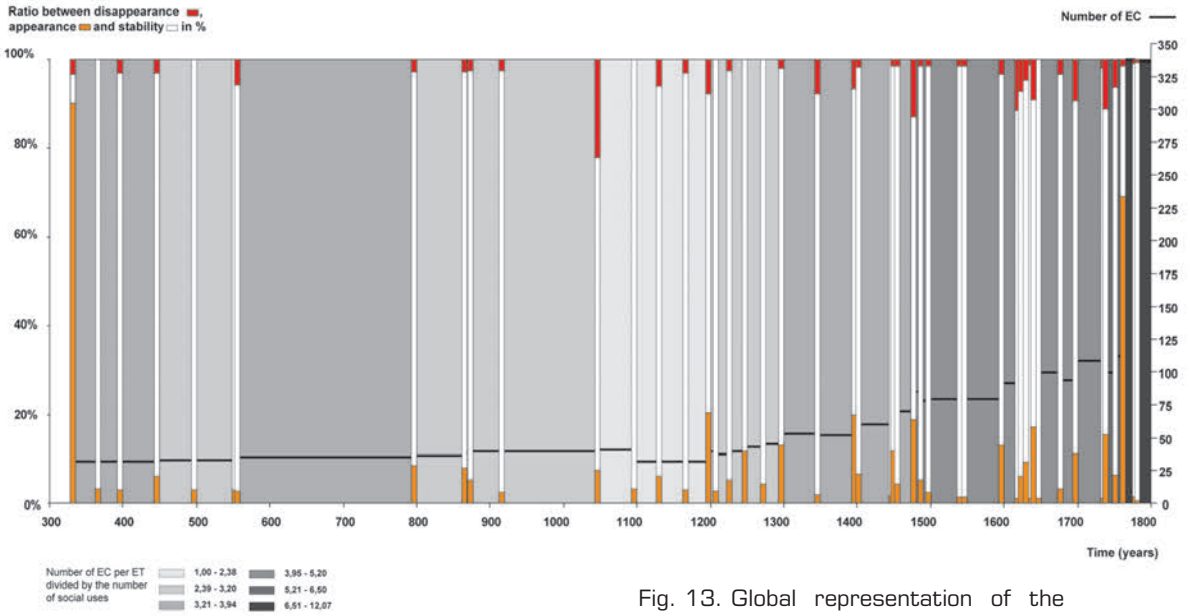

Fig. 13. Global representation of the architecture of time.

the archaeological knowledge of whole city of Tours (ToToPI) (Rodier *et alii* 2010). Several adjustments were made during the implementation of the model, especially about social uses that differ between these two levels of observation. On the scale of the city or the district, apart historical results, the analysis used to measure the effect of source, which is generally assumed, but here it is possible to reveal, quantify or even to analysis. Finally, a test was performed at the level of the excavation, using data from the site of Saint-Julien in Tours: reflections are still at an exploratory stage. The way of thinking is different, mainly because it is necessary to reflect from a relative chronology, and not dating (Lefebvre, Rodier, Saligny 2012).

If it is too early to validate the results of historical interpretation, on the scale of the excavation, to the district or the city, this model sheds new light on how we construct and analyze our own data, even on the very process of creation of archaeological analysis.

These initial experiments conducted exclusively in Tours have shown that the implementation of the model in a GIS and data processing are a heavy operation, mainly due to limited capacity of current software[2]. Needs have emerged in computer programming to integrate and manipu-

[2] It is also the report of Gaël Simon who works from this model in its current thesis "La fabrique urbaine de Vendôme du XI[e] au XVIII[e] siècle".

late data with more flexibly. Indeed, only while multiplying study case it can be possible, by comparison, to obtain among others temporal signatures and to propose one or several trajectories of the formation of cities. A research program[3] that focuses on time analysis was started this year to work in both directions. Focused on another case of research, the city of Albi, this program should end in the definition of specifications to develop tools of temporal analysis; the objective also is to set up a program of wider research on the rhythms of the urban factory.

3. Conclusion

In this work, which focused in first on the formation of urban fabric on the site of the Roman amphitheater in Tours, the dynamics are revealed by deconstructing historical information. Modeling the functional, spatial and temporal properties of the historical objects in a GIS allowed different analyses to be carried out, each one documenting a particular aspect of the dynamics. The result of these analyses provides substantial but partial information about the changes in the urban fabric. In spite of the originality and relevance of the results, the dynamics as a whole can only really be appreciated through the combined interpretation of the cartographic (centered on space) and chronographic (centered on time) representations.

Furthermore, the results highlight that, in spite of the differences between time and space, they can be understood, modeled and represented in a way which is not identical but analogous.

The modeling of time is a new approach which demands further investigations, discussions and improvements which are in progress: but this work already shows that history and archaeology can be sciences of time and not just of the past.

[3] A PE /PS funding from INSHS (CNRS) was obtained by the author in 2011 on the theme "Interroger les temporalités urbaines".

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research

It is all about location: GIS, property records and the role of space in shaping late medieval urban life. The case of Antwerp around 1400

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Urban historians have come to regard space as a key dimension of their areas of inquiry. Yet few apply GIS in question-driven research on pre-industrial cities. This is mainly due to the scarcity of accurate maps and spatially referenced data. This essay illustrates that locating large sets of textual data, constructing parcel maps, and linking both, is feasible even for medieval cities. Thus, medievalists too can apply GIS at the household-level and reach a spatial definition high enough to expose the roles played by space in shaping medieval urban life.
Keywords: real property, digital parcel maps, occupational topography, GIS, Antwerp

Per gli studiosi della città lo spazio è un concetto chiave dell'indagine, e tuttavia ancora pochi utilizzano i GIS nelle loro ricerche sulle città preindustriali, a causa della scarsità di mappe accurate e di dati georeferenziati. Questo contributo si concentra sulla georeferenziazione di dati testuali e il loro collegamento con le mappe parcellari. Anche i medievisti possono così usare questo strumento per poter mettere in luce il ruolo dello spazio della definizione della vita urbana medievale.
Parole chiave: *proprietà, mappe delle parcelle, topografia occupazionale, GIS, Anversa*

Over the last twenty years, many historians of both the modern and pre-modern city have come to regard space, physical space as well as social and cultural space, as an important dimension of their areas of inquiry. Inspired by the new cultural history or influenced by post-structural theory of space such as the work of social theorist Henri Lefebvre on the relationship of space to the capitalist process (Lefebvre 1974; 1991), urban historians have drifted away from the long-standing traditions of historiography that dealt with cities as mere containers of human activity. Their attention shifted from cities, and spaces of cities, as inert places lacking causal significance to spaces as socially produced

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and socially productive entities. Space, historians came to see, was an agent in its own right, playing a role in shaping economic, cultural, political and social city life and having the same significance as time in the unfolding of human affairs. In consequence, the geographical dimension of historical facts and events became an essential key to understanding how and why things had happened[1].

In the course of the 1990s did not only fresh theoretical impulses spur a renewed interest in the influence of geographical space on past human behaviour, the improvement of spatial technologies did too. A redevelopment for PC, a growing user-friendliness, and cheaper or even free software brought geographic information systems or GIS originating in the earth sciences within reach of historians, geographers, archaeologists, and other scientists who seek to answer questions about the past. A GIS, in short, is a database management system built around two linked components: a spatial database and an attribute database. The spatial database describes the location and shape of a selection of both physical and non-physical entities that exist or occur on earth, such as census districts, flood depths, or buildings. Spatial datasets take the form of layers of pixels or of layers of points, lines and/or polygons that have spatial coordinates. These georeferenced layers are the chief constituents of digital maps. The attribute database on the other hand, holds non-spatial facts about these spatial entities, for example their material qualities, or the personal data of their users. Thus, a GIS makes possible not only the combination of attribute data from various unrelated (historical) sources based upon their geographical location, they also allow the integration of familiar database operations such as querying and statistical analysis with the unique visualisation and geographic analysis benefits offered by maps. Owing to these specific qualities, GIS has become a popular addition to academic research in a wide range of historical endeavours.

Over the last ten years, for instance dozens of historical GIS (HGIS) infrastructure projects have sprouted whereas the number of scholars who apply spatial technologies to historical questions has also grown[2].

Yet, the number of historians using GIS to study the pre-industrial city remains relatively small, even though GIS-technology makes space

[1] For historians dealing with these changed concepts of space in regard to the Medieval and/or Early Modern city, see, for example, Maire Vigeur 1989; Hanawalt, Kobialka 2000; Boone, Stabel 2001; Harding 2002.

[2] Examples of application of GIS in history can be found, for instance, in Knowles 2002; Knowles, Hillier 2008; Boonstra, Schuurman 2010; and in special issues of "Social Science History" 24/3 (2000); "History and Computing" 13/1 (2001); "Historical Geography" 33 (2005); and "Social Science Computer Review" 27/3 (2009).

an explicit part of analysis. The lack of technical knowledge, the favouring of the word over the spatial image, and the historian's concern with 'time' rather than 'space' only partially account for this deficit. The limited temporal functionality of GIS software is an issue too; although by now solutions exist for effectively incorporating change over time in GIS (Gregory, Ell 2007, pp. 119-145; Goodchild 2008). The main obstacle in applying historical GIS to pre-industrial cities is the scarcity of ready-to-use maps and attribute information.

Very little historical information is available in a georeferenced or geocoded digital form, except for the often statistical and aggregated data already disclosed via infrastructure projects, such as the Great Britain Historical GIS. Urban historians eager to approach a particular historical problem by means of GIS usually face the laborious preparatory tasks of collating the required written texts into digital tables, of digitizing and georeferencing historical maps, and then somehow linking both. Most of the published GIS-based urban studies to date are therefore concerned with the modern city[3].

Archives favour the historian of the twentieth and nineteenth century city with geometric accurate maps and with a rich variety of sources that contain unambiguous geographic references. Such spatially referenced sources include household surveys, business censuses, and cadastral records, sometimes accompanied by plans. Preparing archival data of this kind for use in a GIS is rather straightforward. Moreover, the level of detail of the records is often that of the city dweller or the building unit. This allows one to move away from aggregate analyses on parishes, quarters or streets as a whole and to study complex city life with the individual actors as a starting point. Presenting and analysing data on the household-level allows a more inclusive form of history and leads to a better understanding of historical phenomena (Bisschops 2007, p. 138). In contrast, the historian of the early modern or medieval city has to deal with a lack of detailed and accurate city maps, with fewer and more partial records, and with strategies for describing precise locations that where once common but that are now since long disused, with numerous geographically meaningless references as a result. Yet these are surmountable obstacles.

This essay aims to illustrate that it is possible to locate large sets of non-spatial medieval urban data, to construct precise parcel maps of medieval cities, and to link both. Thus, historians of the medieval city too can apply GIS at the plot or household-level and reach a spatial definition

[3] Several successful case studies are discussed in Diamond, Bodenhamer 2001; Beveridge 2002; Hillier 2002; De Bats 2008; Lesger, Van Leeuwen, Buzing 2010.

high enough to expose some of the various roles played by space and place in the shaping of late medieval urban life. The methods and preliminary findings discussed in this text are drawn from an ongoing study of the property market in Antwerp around 1400[4].

Antwerp at that time was a flourishing inland port city of about 20.000, sited on the right bank of the river Scheldt and located on the border of the County of Flanders and the Duchy of Brabant. The body of source material described is similar in character to that for most of the larger cities in the Southern Low Countries. To these cities at least, the principles of the presented methodologies are transferable.

1. Containing medieval location: records of property-ownership

Records concerning the holding and use of property hardly need promotion as one of the best starting points for GIS-based studies of the late medieval city, even if real property is not the researcher's actual concern. Real property, which includes all interests arising out of property such as life estate or usufruct, logically has a fixed location on the earth surface. If one can establish the location of an individual medieval property, it follows that all information about this property automatically receives geographical meaning. Attribute data are obtainable from sources directly related to property such as deeds or material remains, but also from sources indirectly related via the users of property. Guild membership registers or militia payrolls, for example, may not include spatial references yet they become spatially meaningful if we can link the listed individuals to the street or house where they lived. Secondly, the documentation regarding rights and interests in property is not only profuse; it also starts at an earlier date than most other written record series. Real property was a valuable commodity that served various purposes ranging from the humble securing of housing to the raise of capital or the promotion of social advancement. The alienation of real property, therefore, became formalized in deeds or charters and enforceable at law at already an early stage. Twelfth-century deeds are relatively common. Thirdly, in addition to its power to authenticate the transfer of real property a local authority could systematically register changes in property ownership for fiscal or probative use. Of such predecessors of modern land registers many have survived and they are fruitful sources

[4] University of Antwerp (Belgium), Centre for Urban History, PhD study funded by the Flemish Research Foundation (FWO) for the period 10/2007-09/2012 under the working title "Broadening the spatial turn, Real Estate, annuities and the rise of the Antwerp market (ca 1390-1430)".

for tracing changes in for example the use of urban land or the distribution of wealth over the long term.

Antwerp was one of those cities that neatly kept track of its citizens' interests in land. Most of the land inside its walls was privately held and therefore transmittable, dividable, or chargeable at will. From around the middle of the fourteenth century any transfer of real property within the city's geographical jurisdiction had to be acknowledged by two local magistrates, known as *scabini* or aldermen, and entered in sum into official registers to be legally enforceable. A small fee was due for this service. Even in the sixteenth, seventeenth and eighteenth century when independent notaries controlled most of the writing of legal documents, the aldermen kept on recording an abstract of every change in interest in property. Only after the turn of the eighteenth century, the Napoleonic administration replaced the age-old land record system by the modern cadastre still in use today. Owing to its probative value, most of the old land register survived the French modernisations. Today the Antwerp City Archive preserves a series of aldermanic registers covering almost every year from 1394 to 1797 and containing the abstracts of more than half a million transfers of property. It follows that one can not only largely reconstruct Antwerp's property market at any given point in time since the Late Middle Ages; in theory one can also trace the succession of title ownership to a specific property from the present owner back to his medieval predecessor. The custom of legal registry by aldermen was widely spread in the Southern Low Countries and records series very similar to those in Antwerp survive for example in the cities of Ghent, Malines, and Louvain, starting 1339, 1345 and 1362, respectively (Dumon 1986).

The continuous series of aldermanic registers have already proven great value for the fields of economic and social history in the Low Countries. Seen as a perfect instrument to identify urban development trends in the pre-statistical era or to study social stratifications within pre-modern urban societies the series were very fashionable sources in the 1970s and 1980s[5]. Because of the strong scholarly emphasis on their value for quantitative analysis, the interest for the registers quickly faded when the cultural studies boosted in the 1990s. Nowadays urban historians consider the voluminous and non-indexed registers as rich yet highly unattractive research material. Nonetheless, their potential goes beyond the amassment of data to study urban economic trends or urban social geographies at ward or parish level.

[5] For example Soly 1974; Boone, Dumon, Reusens 1981; Degreve, Schoups 1983; Stabel 1989.

Beside the price and occupational information so much appreciated two decades ago, the registers contain a rich variety of data. In the Antwerp records a precise date and the names of the two attesters are always given. These attesters did not only witness changes in title to property. Debts, payments, marriage settlements, and other legal arrangements were entered in the registers as well, albeit less frequent. The aldermanic registers, therefore, also reveal personal details of the parties to a contract, for instance their marital status, their kin and acquaintances, or their political or religious offices. Particularly interesting is that nearly every reference to a property comes with a detailed description of its location.

The Antwerp magistrates used a particular discourse of space for accurately locating a building or piece of land. After having defined its typology, the aldermen approximately situated the property in terms of a place name or a landmark. Next, they specified the location of a property in relation to its abutments by giving a brief description of the neighbouring plots and quoting of the names of their owners or occupants. Sometimes the magistrates wrote down a house name as well. They also regularly relied on communal memory by referring to former owners or former use. Accounts such as 'The small house named The Salmon previously owned by our good bailiff, located at the Fish Market between the smoke house of John Stevens the fishmonger and the corner house of Peter the cooper, stretching at the back to the garden of the same Peter' were commonly used for defining the fixed location of houses or land. Today this system is no longer practicable as nearly all the references to individual plots and persons have lost their spatial connotation. Yet there are two generic ways to make these descriptions understandable in their historical context and to locate medieval property once again.

2. Determining medieval location: the 'cross-section method'

The first way to identify medieval property is via the 'regressive method' for historical investigation, a technique generally applied in house history research. The method involves the accumulation of as much property records as possible for a particular modern address in order to construct a successive chain of title from the present owner back to his medieval predecessor at best. To such a history of title, a researcher then attaches other archival information about the property and its users. As every title search is carried out for a geographically well-defined property, it follows that all historical attribute information automatically becomes spatially referenced and suitable for processing in

a GIS. Established histories of property ownership and use provide valuable information for the conservation, the excavation, or the promotion of specific historic sites. For locating large numbers of medieval urban property, however, working backwards from modern records is not always possible or practical. Even when serial records are at hand, as is the case in Antwerp, and no parts are missing, tracking the five- or six-hundred-year-old-histories of hundreds of modern parcels within a medieval urban area would require immense resources.

The second technique, the 'cross-section method', allows one to tackle the accurate spatial referencing of property over an entire medieval urban area without the construction of hundreds of property histories. The strategy of describing the location of a property by referring to its abutments was widespread in pre-industrial Western Europe. Particularly in the UK historians, archaeologists and historical geographers have drawn on abutment relationships to identify medieval and early modern urban property in order to reconstruct ancient plot or tenement patterns. Influential studies are those on late medieval Winchester and London by Derek Keen and Vanessa Harding[6]. The cross-section method is rather straightforward (fig. 1). Yet putting the procedure in effect can be quite a challenge.

The method requires a set of more or less consistent medieval records of property holding that geographically covers the entire area under examination. Preferably, the records also cover a substantial stretch of time. Several consecutive years are taken out of the available sources, and for every recorded property within this cross-section a (digital) filing card or abstract is made. Such an abstract contains at least the abutment clauses about the building or piece of land involved. Next, all filing cards are grouped according to the properties they refer to and according to the toponyms mentioned in relation to the properties (a street, square, landmark …). For each toponym are then traced as much 'reference properties' as possible. Most of the medieval street names and landmarks are still identifiable today, but this information alone does not allow one to locate individual plots or buildings accurately. Reference properties are locatable even today, for example because they adjoined a key medieval building, because they occupied a street corner, or because their medieval house name has survived. One can also try to create references using the regressive method. These locatable properties then serve as key stones for positioning numerous strings of properties with overlapping abutment relationships. If a sequence of properties includes at least one reference property then the block or

[6] Keene 1985; Harding 1985; Keene, Harding 1987.

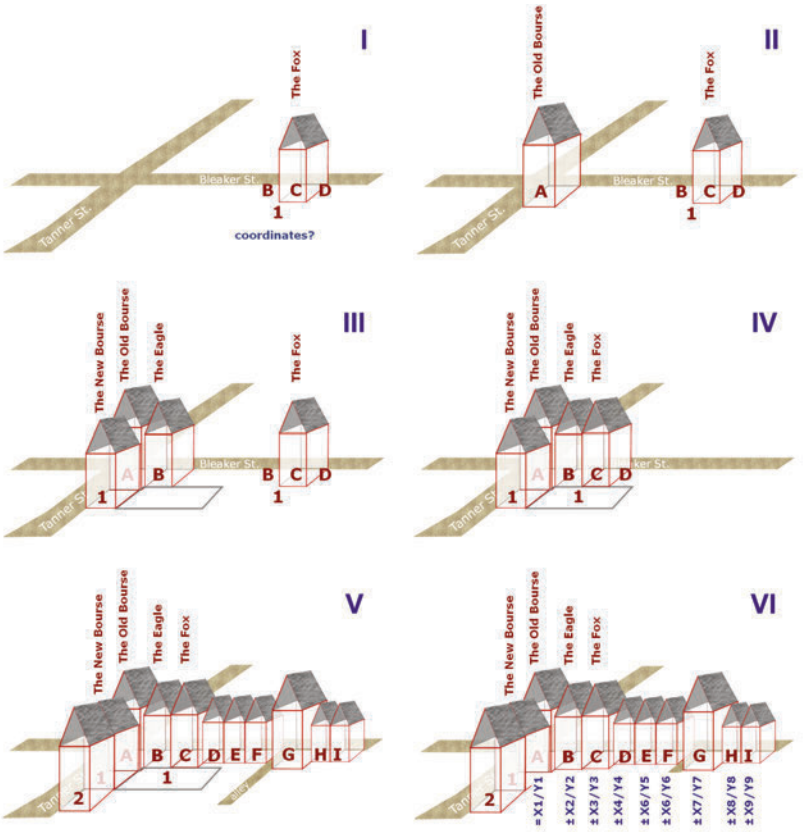

Fig. 1. Diagram of the 'cross-section method'.

street front along which the properties are located and the order of their progression along it can be determined with reasonable accuracy. Series without a reference property remain 'floating' inside a block or along a street until additional evidence makes it possible to establish the precise location of one of the string components[7].

The series of aldermanic registers that are available in a number of cities in the southern parts of the Low Countries evidently lend themselves for determining the location of large numbers of late medieval properties and their attribute data via the cross-section method. Despite their wealth of historical information the registers have been tested only once on a scale comparable to the Winchester and London sur-

[7] For a full discussion of the method see, for example Keene 1985, pp. 37-41; Asaert 1967-1968, pp. 5-12; Bisschops 2009.

veys. In the mid-1960s historian Gustaaf Asaert used the Antwerp registers of the years 1394-1403 to compose a 'repertory of houses and land in Antwerp around 1400'. By piecing together the abutment information of some 3.000 records he succeeded in identifying and locating, relatively accurate, about 85% of all privately owned property inside the city walls; exactly 1.688 units all together (Asaert 1967-1968).

Asaert published his vast topographical survey in 1967-1968 but the work failed to interest fellow historians. This was due partly because the author, mainly concerned with the topography of property ownership, barely included additional historical information apart from the names of successive proprietors. Asaert also put little effort into an actual reconstruction of the medieval plot pattern. The map supplements to the repertory are crude and do not contain plot boundaries. Forty years after its publication, however, the topographical survey turned out to be an excellent basis for a GIS-based study of Antwerp's late medieval real property market as it provides an almost ready-to-use gazetteer for linking spatial and non-spatial data on medieval property. The toponyms and properties identified by Asaert only needed digitising into database tables and next given unique street, block and property ID-numbers to create a gazetteer of disambiguated location references. The ID-numbers were then consistently added to all non-spatial research data regarding property (fig. 2), as well as to the spatial data representing streets, blocks and parcels. Properties and toponyms newly identified in the process of

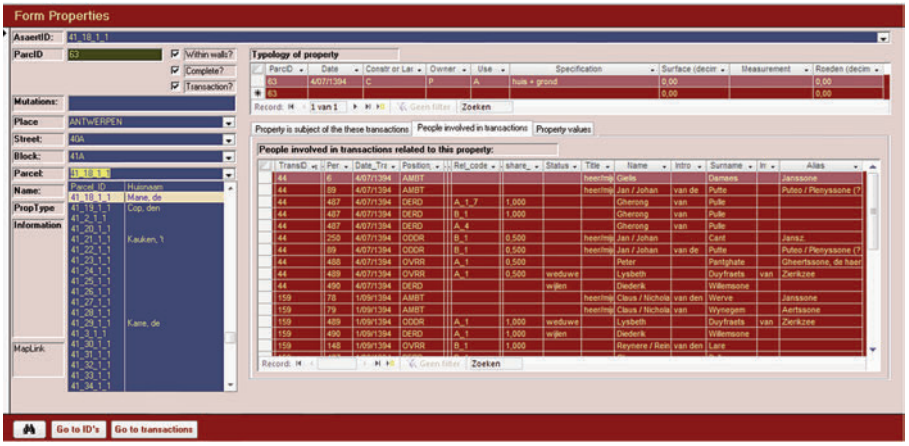

Fig. 2. A database record showing the attribute data of a plot/dwelling named 'De Mane'. The record holds information on the property's typology, value, users, transactions, etc. The three gazetteers containing the unique ID-codes of streets, blocks and parcels are integrated as dropdown lists (left).

data capturing received an ID too. With the ID-numbers acting as a key, a relational join can link together the two GIS-components: a multisource relational database of property and people, and a spatial database that stores the constituting parts of a large-scale base map. This enables the mapping and quantitative spatial analysis of data from various medieval written sources.

Alas, visualising and analysing medieval data with georeferenced modern large-scale city maps as a spatial basis is not an option. Modern maps, both in raster and vector geometry, include centuries of alterations of the medieval plan and are laden with non-relevant map elements. Using them as a backdrop for visualising medieval data addles research results. Moreover, the linkage of medieval attribute data to modern spatial units such as parcels and streets of which the shape, location and quantity is very likely to have changed over the past six hundred years is both problematic and pointless. On the other hand, in Antwerp no pre-modern cadastral maps or land register maps exist. Thus, it was necessary to construct a new, layered base map that consists of the fundamental features of Antwerp's medieval plan: plots, blocks, streets, waterways, key buildings…

3. Mapping medieval location: the legacy of 'town plan analysis'

The methodological principles of 'town-plan analysis' put to test by Michael Conzen in the 1960s and elaborated more recently by, for instance, Keith Lilley, underlie the creation of a detailed and reliable cartographic representation of late fourteenth-century Antwerp[8]. This methodology to analyse the process of physical change in an historical urban environment, especially a medieval urban environment, trusts in the fact that the form of streets and the property boundaries that define urban plots are extremely conservative. Hence, it is possible to trace medieval plan elements such as streets, plots and buildings on modern large-scale maps. In their *Mapping the Medieval Urban Landscape Project*, completed in 2005, Keith Lilley, Chris Lloyd, and Steve Trick proved that accurate and detailed medieval town plans can be constructed in a GIS-environment by combining plan elements with evidence from field-surveys, and historical and cartographic sources (Lilley, Lloyd, Trick 2007).

[8] Lilley 1998, 2000 provides and discusses a step-by-step methodology for performing town-plan analysis. On the original town-plan analysis techniques: Conzen 1960, 1968, evaluated in for instance Baker, Slater 1992.

Fig. 3. Vectorised and coded medieval streets with two 1823-1824 1:500 cadastral map sheets as a backdrop.

Digitally reconstructing Antwerp's medieval topography started with scanning at high resolution all 1:500 scale sheets of the 1823-1824 *Plan Primitif* which is the city's oldest, most accurately surveyed and detailed parcel plan. Through georeferencing and georectifying the digitized maps were then converted to raster layers fit for processing in a GIS. This was a procedure done visually by lining up features on the scanned historical maps with current GIS layers. A particular advantage of these 1823-1824 maps over more recent large-scale maps is that they show Antwerp's plot pattern before disruption by a range of major nineteenth century urban renewal projects. Once geocorrected the high-resolution scanned cadastre maps are usable for plucking off information to create new GIS vector layers.

With the cadastre maps displayed as a backdrop for visual reference, first the axes of all medieval streets were vectorised, uniquely coded, and stored as a new map layer (fig. 3). The previously created street-name gazetteer proved a valuable support. It provided an instant spatial overview of the now sometimes lost streets and squares that existed around 1400. Additional evidence from cartographic, iconographic, material and documentary sources assisted the refining or reconstruction of the shape and size of the medieval streets. Possibly some back lanes were omitted, but it is quite certain that no more than a tiny fraction of the city's fourteenth-century street pattern has been left out. After having constructed the medieval street plan, the outlines of most medieval house-blocks also became clear. The block contours were vectorised, corrected, coded and stored in the same way as the street-axes (fig. 4).

At the end of this first stage of mapping, 98 blocks and 111 streets, alleys and squares had been transformed into spatial objects linkable to attribute data.

The second stage of mapping involved the tracing of the medieval plots, a task more demanding than tracing and reconstructing the streets and blocks. At the end of the fourteenth century, extensive common fields and large pieces of non-built-up private land still represented a substantial part of all the land inside Antwerp's walls. It would take another two centuries and an additional 80.000 citizens to parcel out and

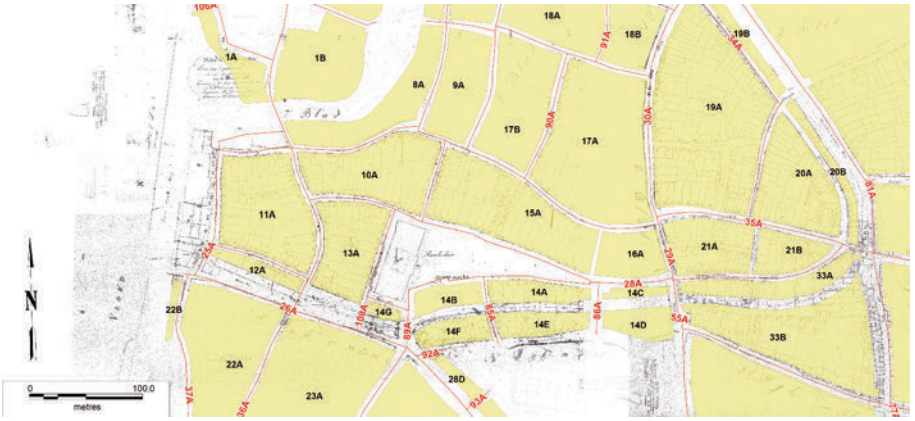

Fig. 4. Vectorised, corrected and coded medieval blocks with two 1823-1824 1:500 cadastral map sheets as a backdrop.

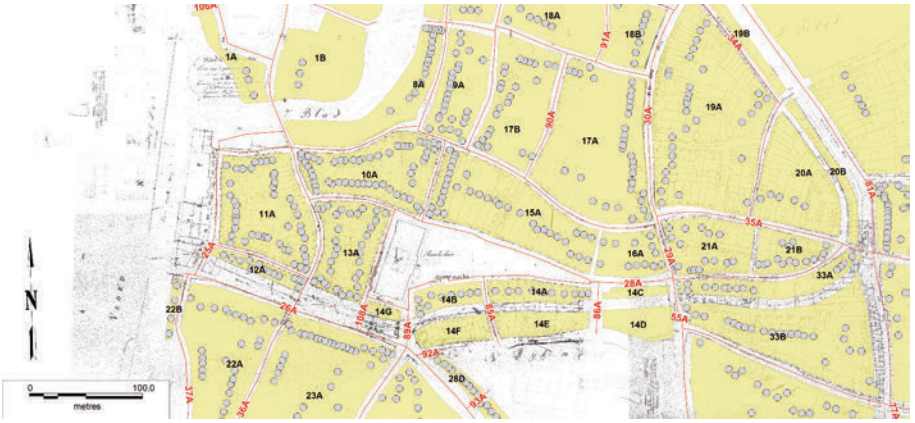

Fig. 5. Digitised 'property strings' from the Asaert survey; after their repositioning within the medieval blocks based on established primary plot boundaries.

consume these unoccupied lands as well. Filtering out these hundreds of post-medieval parcels inside the late medieval city walls would have been extremely time-consuming. Yet, again, the topographical survey already at hand proved its value. Instead of meticulously vectorising every parcel boundary on the cadastral maps and next deleting all fifteenth and sixteenth-century boundaries to create a map layer of exclusively medieval parcels, it sufficed to plot the property strings from the survey over the block-layer with the cadastre maps displayed as a backdrop (fig. 5). Then, of every the block or block front that held a sequence of medieval properties, the primary plot boundaries were traced in a temporary layer. While plots could be subdivided, amalgamated, or developed otherwise through time, their primary outer boundaries were unlikely to alter before the nineteenth century. This boundary stability is mainly due to the legal and practical difficulties of physically moving boundaries in densely built-up areas. As follows, a framework of principal boundaries was established to which the points of the property sequences could be repositioned with the reference properties from the survey serving as anchor points. Usually the strings matched the number of boundaries. If they did not, the problem could often be solved by re-evaluating those preliminary traced parcels of which the size exceeded the common medieval plot widths of 14 ft or 21 ft, ca 4,2 m and 6,3 m respectively. A parcel 28 ft wide for instance, may actually represent two parcels 14 ft wide. Most of the time such a missing boundary indeed stood out on the cadastral map as an anomaly in the shape of a building or parcel. After having defined the most likely location of every property, the prospective

Fig. 6. Located, vectorised, and coded medieval plots with two 1823-1824 1:500 cadastral map sheets as a backdrop.

plot outlines were vectorised in a new layer and each of the 1.688 plots was given its unique ID-code (fig. 6). In a final stage, spatial datasets were created for other features of the medieval plan: waterways, defences, ecclesiastical precincts and religious medieval buildings again by mapping them against historical evidence (fig. 7). The resulting digital parcel map of the medieval city (fig. 8) then made possible the visualisation, spatial querying and spatial analysis of a variety of data on urban land and urban land use on several levels of geographical detail.

It is evident that many of the mapped features do not fully correspond with medieval reality. Unavoidably assumptions had to be made while mapping, not in the least because the project resources only allowed the integration of a limited amount of historical evidence. However, distortions caused by adherence of these assumptions in the plotting of attribute data are relatively small. Wrongly assuming that the plot of a small house was only 14 ft wide, changes nothing to the fact that the house

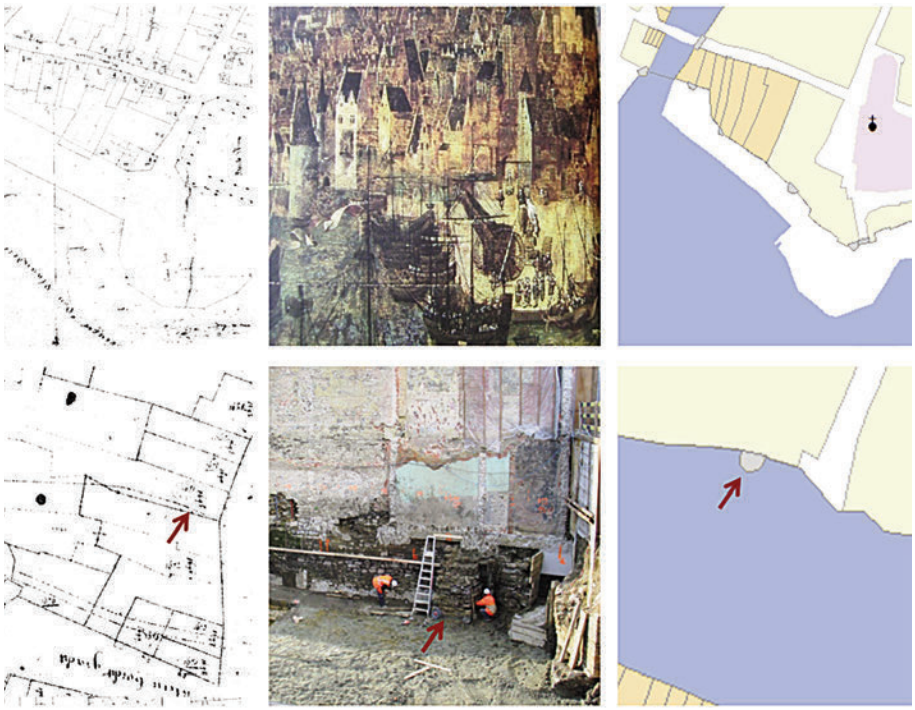

Fig. 7. Combining cartographic, iconographic, and archaeological evidence to locate and map medieval plan elements.

Fig. 8. Detail of the reconstructed parcel plan of Antwerp around 1400. The map-objects 'street' and 'parcel' are labelled with their unique ID-code.

was once named 'The Salmon'; located at the Fish Market; owned by 'the good Antwerp bailiff'; and abutted by the smoke house of John Stevens the fishmonger and the corner house of Peter the cooper. Moreover, spatial data are flexible and easily extendible in both space and time. Whenever new historical evidence or new research questions require it, one can resize, reshape, relocate, or add spatial objects. Spatial data-layers are also easily copied, making possible, for instance, the mapping year after year of changes in the layout of properties that can be constructed from the evidence of the abutment clauses. The unique match keys guarantee that the plots, streets and other objects remain linked to their attribute data.

4. It is all about location: Antwerp's medieval occupational topography

The ability to locate and map a wide range of documentary information regarding medieval urban land and its users at the plot or household level yet with the geographical scope of an entire city offers new perspectives for studying the attitude of medieval city-dwellers to real property and, accordingly, to urban space. This way for example we reach a spatial definition high enough and a spatial context large enough to gain original insights into the location decision processes of medieval urban land users, whether they be business, produce, or residential. The factors that made someone decide to live, work, trade, or invest in a particular property on a particular location were various. It is evident that considering each of

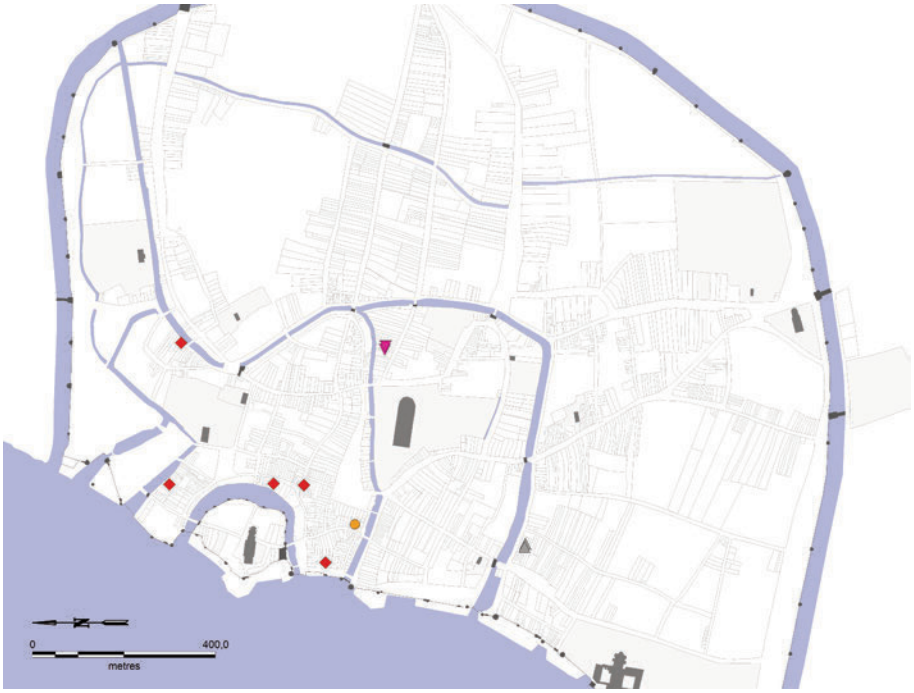

Fig. 9. Thematic map of a data query for land bought in Antwerp by butchers (♦), moneychangers (●), stonecutters (▼), and dyers (▲) in the year 1399.

them is not feasible in the context of a medieval city simply for lack of data. Yet with GIS, one can capitalize the evidence available.

At present, composing the attribute database regarding medieval Antwerp real property is a work in progress. Numerical datasets especially are still lacking. For that reason, the following brief discussion of preliminary results is based upon visual representations of rather simple data queries. The small set of thematic maps gives only an impression of the research potential. Among the attributes already usable are the occupations of about 60% of the ca 5.400 property-holders referred to in the registers covering the years 1391-1404. This sample, which comprises seventy different occupations and trades, is large enough to test if considerations about economies of agglomeration weighed on the location decision-making process of buyers of property and to what extent. The Antwerp GIS permits the isolation of a single occupational group out of the attribute dataset and the mapping of its activities on the property market within definite geographical and chronological boundaries.

A query for property *intra muros* acquired in the year 1399 by four non-related occupational groups, being butchers, moneychangers, stone-

Fig. 10. Four examples of discrete occupational clusters exposed via diachronic aggregation of a single attribute on the parcel level. Properties bought by butchers (♦), moneychangers (●), stonecutters (▼), and dyers (▲) between 1395 and 1404.

cutters and dyers, makes no trade concentration particularly noticeable when plotted on the base map (fig. 9). The query results are simply not sizeable enough. The picture changes drastically if the chronological scope of the same query is enlarged to the years 1395-1404. This diachronic aggregation of a single attribute on the parcel level brings to light four discrete occupational clusters (fig. 10). Even though the local land market was relatively fluid and no government regulations forced them to do so, most of the Antwerp butchers, moneychangers, stonecutters and dyers who were engaged in acquiring real property limited their investments to a small area of the city. In the case of the butchers, the proximity of the meat hall on the southeast bank of the castle moat played a key role in their spatial location process. On the other hand, as both slaughter and sale were restricted to the premises of the meat hall, there were few economic benefits for butchers to obtain by congregating close to the hall in a narrow street characterised by relatively small dwellings liable to flooding. The large number of conveyances of houses and land from one butcher to another through several gener-

Fig. 11. Occupational integration exposed via diachronic aggregation of a single attribute on the parcel level. Properties bought by cartwrights (♦), loggers (▼) and sawyers (▲) between 1395 and 1404.

ations, although not necessarily from the same family suggests that social ties, and territorial delineation of geographic space outweighed environmental inconveniences and limited economic benefits when butchers accounted for their residential needs and preferences.

A query similar to the previous one but now for the related occupational groups of loggers, sawyers and cartwrights reveals a different marked pattern of localisation: one of geographical occupational integration instead of spatial distinction (fig. 11). The Antwerp loggers or *houtbrekers* controlled the harvest, transportation, and local store and sale of inland wood. In an appropriate juxtaposition, sawyers and cartwrights lived alongside the loggers who brought them most of their trade. The location of these three occupations on both sides of the '*Meere*' correlates with the exceptional width of the public space they lined. Sized trunks, especially those for the building industry, could still measure up to 15 m in length and were heavy to handle. A street-width of 20 to 40 m instead of the usual 6 to 8 permitted an easier storing and processing of trunks in front of the houses instead of behind them. It is very like-

Fig. 12. The navigability of waterways as a structuring element in the clustering and spatial distribution of occupational groups. Properties bought by fishmongers (●), skippers (♦), stonecutters (▲), tanners (■), and dyers (▼) between 1395 and 1404.

ly that loggers and sawyers themselves are accountable for the rather uncommon dimensions of the '*Meere*' by first occupying the higher north side of the place and later building up the lower marshy south side at sufficient distance from the on-street lumber yards.

Location-specific advantages were also a steering element in the investments of occupational groups contingent on access to water. In fourteenth century Antwerp, the navigability of local waterways appears to have been a structuring element in the spatial distribution of fishmongers, shippers, stonecutters, tanners, and dyers among others (fig. 12). Trades depending on transport by sea-going vessels controlled most of the riverfront. The fishmongers clustered north and south of the castle. In the north, on the downwind side of the city and between two deep river inlets the fishmongers held nearly all herring smokehouses that could be located (fig. 13). In the south, they occupied most of the properties surrounding the fish market. The skippers of cargo-vessels congregated around the mouth of the canal that connected the river to the '*Markt*', the city's commercial heart. Shipwrights and fishermen are not

Fig. 13. A visualisation of spatial correlations within and between attribute-categories: clustering of smokehouses (highlighted in orange) and clustering of properties bought by fishmongers (●) and skippers (♦) between 1395 and 1404.

mapped but they too occupied a distinct part of the river bench, mainly the excentric river inlets in the north and south. For their supply of raw materials, especially limestone from the Tournai region upstream, the Antwerp stonecutters depended on the river as well. The fishmongers and skippers, however, outnumbered the stonecutters. As they needed less frequent access to navigable water, the stonecutters were therefore located somewhat inland on the south bank of an old moat that was navigable by vessels of limited draft only. Further inland along a non-navigable part of the same moat could be found the tanners and dyers who needed access to water solely for produce. Whereas other cities tended to relegate the noxious tanning and dyeing activities to the periphery, the Antwerp tanners and dyers concentrated close to the centre of the urban area. Customary activity, fixed industrial equipment, and most importantly, the fact that the brackish water of the river and moats was not suited for consumption anyway, probably made allowable the central location of these environmentally demanding trades.

Antwerp's late medieval occupational topography does not only provide

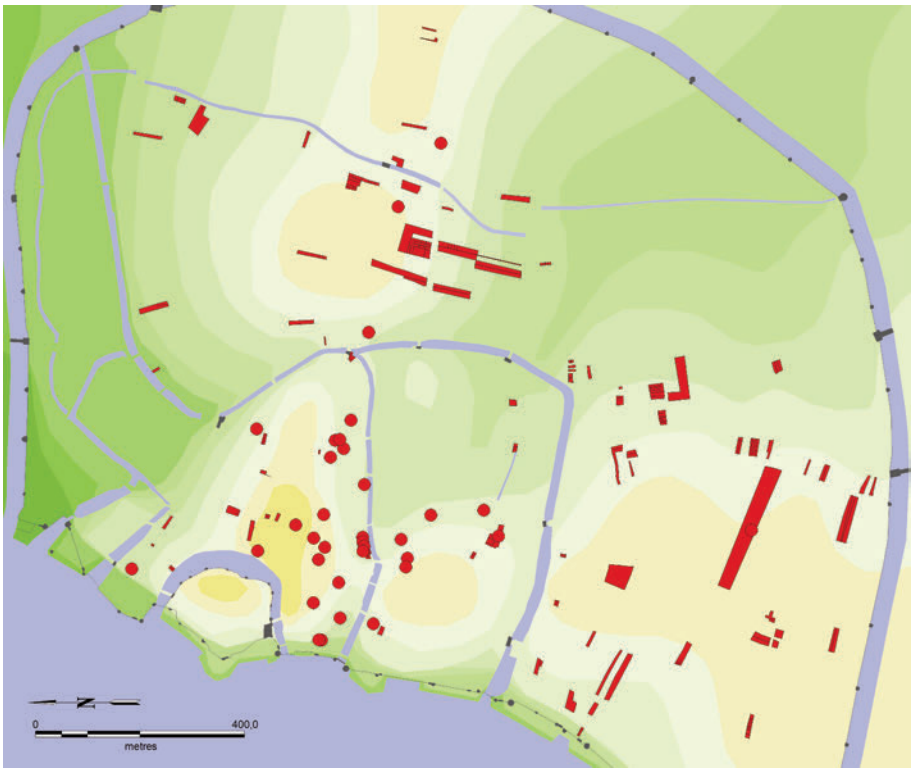

Fig. 14. An example of the complementarity of attribute-categories. One-room housing units (plots highlighted in red) were typical rental properties yet high turnover-rate and low prices made registering the rental agreements too costly. Valuable lease contracts on the other hand were frequently registered (•). When mapped together for the period 1395-1404 the attributes present an improved image of the topographies of Antwerp's medieval rental market.

examples of concentration. There certainly were trades with representatives scattered through the city such as shoemakers, tailors, blacksmiths and bakers. Still, the evidence suggests that while no individual occupation predominated to the exclusion of all the others in a specific area, most of the Antwerp trades did have a characteristic pattern of distribution. The thematic maps previously discussed are no doubt incomplete. They do not depict properties that tradesmen held but did not sell. Furthermore, records of property ownership do not always indicate where a citizen lived, so this is primarily a study ownership, not of property occupation, although it is possible to bring to light part of the hidden population of tenants by harvesting information from other datasets in the Antwerp GIS (fig. 14). In any case it is clear that thematic mapping of investments by members of the same trade can provide a relatively full pic-

ture of the medieval urban occupational topography when the sources traditionally used for this type of research, such as censuses or assessment rolls, are lacking.

5. Conclusion

It could be argued that this text has said little about the role of space in shaping medieval economic, cultural, political and social city life; except for a short discussion on the localisation of Antwerp trades that aimed to illustrate the potential of parcel-based GIS for recasting our understanding of urban life during the late medieval period. Rather this text has concentrated on demonstrating how historians can accurately locate large sets of non-spatial medieval textual data and how they can construct detailed and rather reliable digital maps of medieval cities using mainly archival sources. Using GIS for studying historical phenomena at the household level clearly does not have to be the prerogative of the historian of the modern city. Yet, even when able to conduct question-driven and fine scale GIS-based research to explore medieval urban life one cannot omit certain issues inherent to GIS and mapping. Maps often look more convincing than is justified by the ambiguity or incompleteness of the historical sources. Also, the ability to draw together distinct historical datasets by geographical location does not automatically imply a causational spatial relationship between the datasets. For such matters basic source criticism can and should be the treatment. The real issue with historical GIS is its cost. Although a historical GIS can have distinct cost advantages in terms of automation once created, actually building the GIS requires substantial investments in terms of time and money. The first question to ask when willing to use GIS for studying medieval city life, should therefore not be 'Can it be done?', but 'Will it be worth the effort?'

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