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How to Describe and Show Dynamics of Urban Fabric: Cartography and Chronometry?

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Abstract

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. To meet this dual objective, the historical data thus needs to be modeled by deconstructing their spatio-temporal properties.

The modeling proposed in this article takes a systemic approach and is based on the dual notion of simple objects and complex objects. On this principle, implementing this model in a GIS provides an original means of processing the information: the results of the different analyses – spatial and/or temporal – lead to a true interpretation of the urban dynamics. However, the specificity of the spatio-temporal framework requires appropriate representation, i.e. not only spatial but also covering the temporal dimension. But while cartography can represent the spatial context of geo-historical phenomena, no temporal equivalent exists. The term "chronography", expressing the framework of the architecture of time, has been formulated to fill this gap.

***Key words**: Spatio-temporal modeling, spatio-temporal analysis, urban fabric, GIS*

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. 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, 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)[1]. Through research into the transformation of a Roman building into mediaeval urban fabric (see fig.1), the aim of this thesis 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.

[1] Bastien Lefebvre, "*La formation d'un tissu urbain dans la Cité de Tours : du site de l'amphithéâtre antique au quartier canonial (5^{e}-18^{e} s.)*" (PhD, University of Tours, 2008). online: http://tel.archives-ouvertes.fr/tel-00349580/fr/

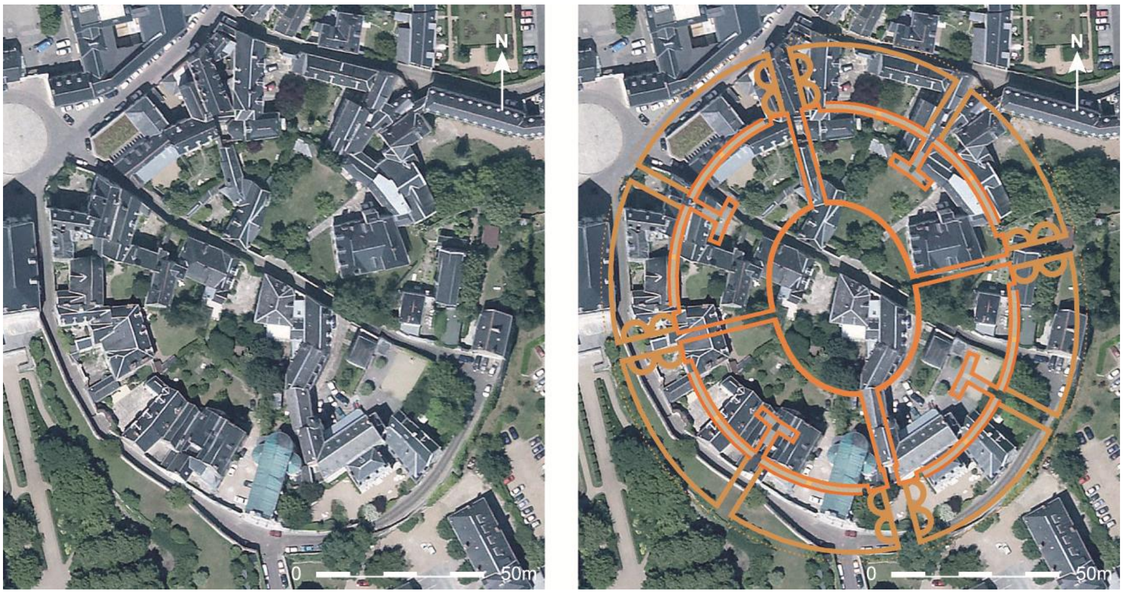

Figure 1. Aerial view of the current urban fabric covering the site of the Roman amphitheater in Tours. On the right, the overlay of the reconstituted plan of the Roman building.

This article describes the main methodological background of the thesis 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 implemented. 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.

1 Modeling the dynamics of the urban fabric

The methodological principle chosen to model historical information was largely inspired by the OH_FET model created to analyze the topography of the city of Tours (ToToPI)[2]. 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[3] in an essay about the town, Henri

[2] Bastien Lefebvre, Xavier Rodier and Laure Saligny, "Understanding Urban Fabric with the OH_FET model based on Social Use, Space and Time", *Archeologia e Calcolatori* 19 (2008): 195-214. online: http://soi.cnr.it/archcalc/indice/PDF19/16_Lefebvre.pdf

[3] Donna J. Peuquet, "It's about time; A conceptual framework for the representation of temporal dynamics in geographic information systems", *Annals of the Association of the American Geographers* 3 (1994): 441-461.

Galinié suggests that, to be valid, each of these historical objects must meet three fundamental criteria[4]:

- a location (where is it?)
- a date (when did it exist?)
- 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[5]. 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 schema called the Conceptual Data Model. Its formalization using the HBDS method (Hypergraph Base Data Structure)[6] 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

Marius Thériault and Christophe Claramunt, "La représentation du temps et des processus dans les SIG : une nécessité pour la recherche interdisciplinaire" *Revue internationale de Géomatique* 9 (1999): 67-99.

Thierry Saint-Gérand, "Comprendre pour mesurer... ou mesurer pour comprendre ? " In *Modélisations en géographie*, ed Y. Guermond (Paris: Hermès, 2005): 261-298.

[4] Henri Galinié, *Ville, espace urbain et archéologie* (Tours: Collection sciences de la ville, Maison des sciences de la ville, de l'urbanisme et des paysages, Université François-Rabelais de Tours, 2000).

[5] Henri Galinié., Xavier Rodier and Laure Saligny, "Entités fonctionnelles, entités spatiales et dynamique urbaine dans la longue durée", *Histoire et Mesure* 19, 3/4, (2004): 223-242.

[6] Françoise Pirot and Thierry Saint-Gérand, "La Géodatabase sous ArcGIS, des fondements conceptuels à l'implémentation logicielle", *Géomatique Expert* 41/42 (2005): 62-66.

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.

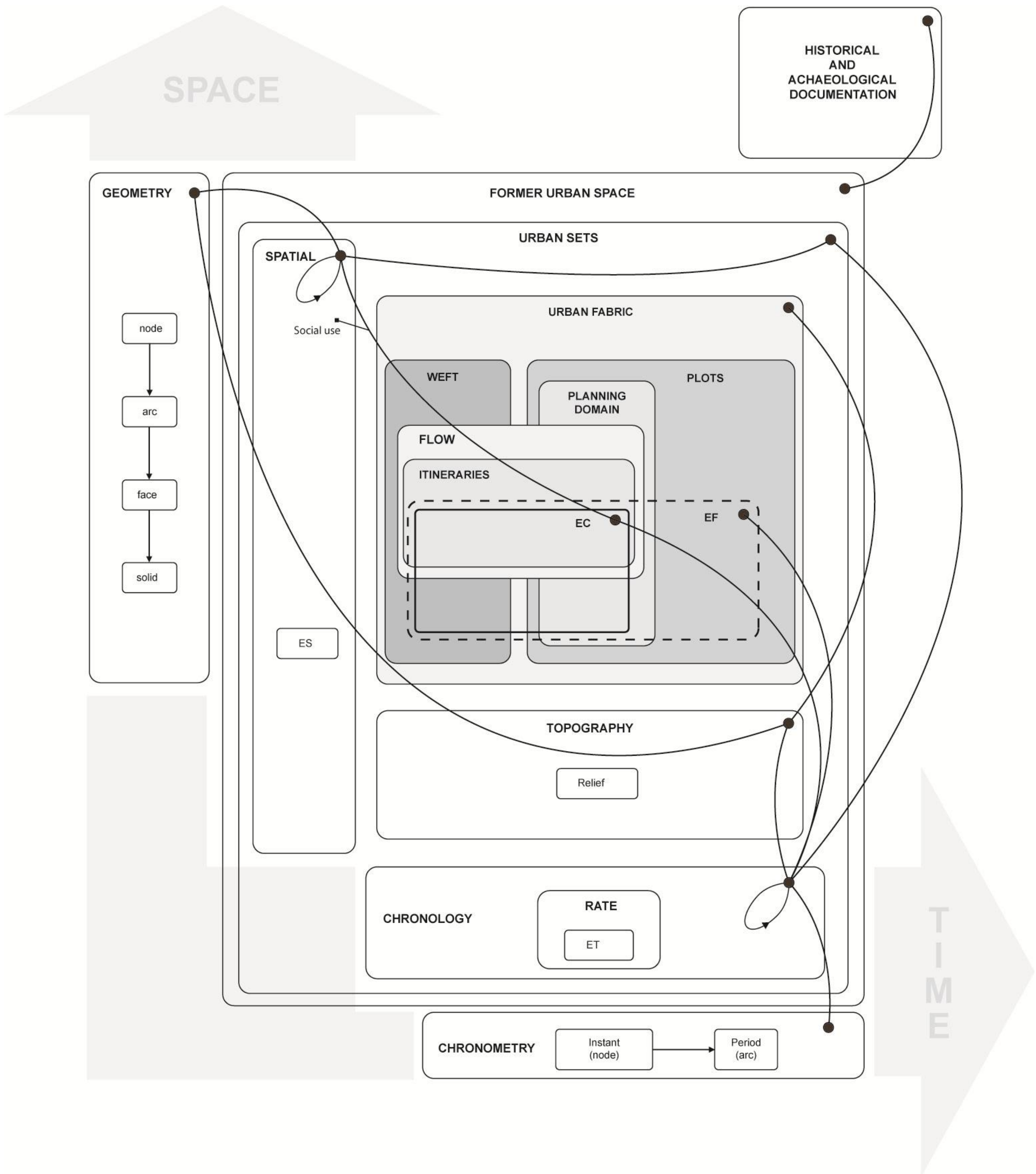

Figure 2. The conceptual data model.

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

Figure 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 (see fig.4).

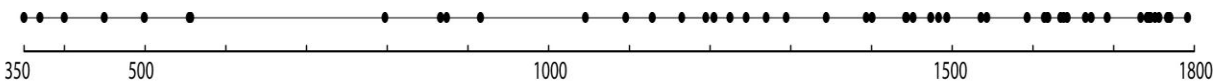

Figure 4. The division of time into Temporal Features (ET).

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.

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 (see 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).

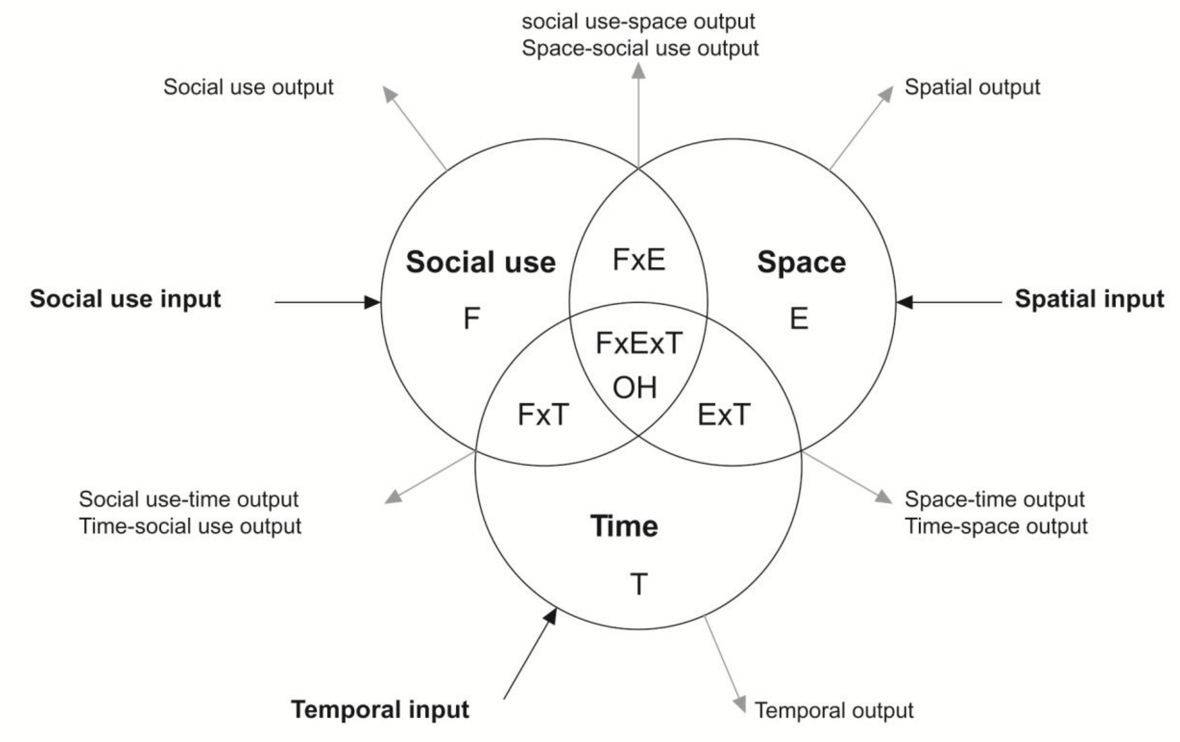

Figure 5. Diagram of the modeling, analyses (outputs) and inputs of the system.

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[7], 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.

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.

[7] Christian Grataloup, *Lieux d'Histoire. Essai de géohistoire systématique* (Montpellier: Collection Espaces mode d'emploi, GIP RECLUS, 1996).

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 (see fig.6).

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

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.

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.

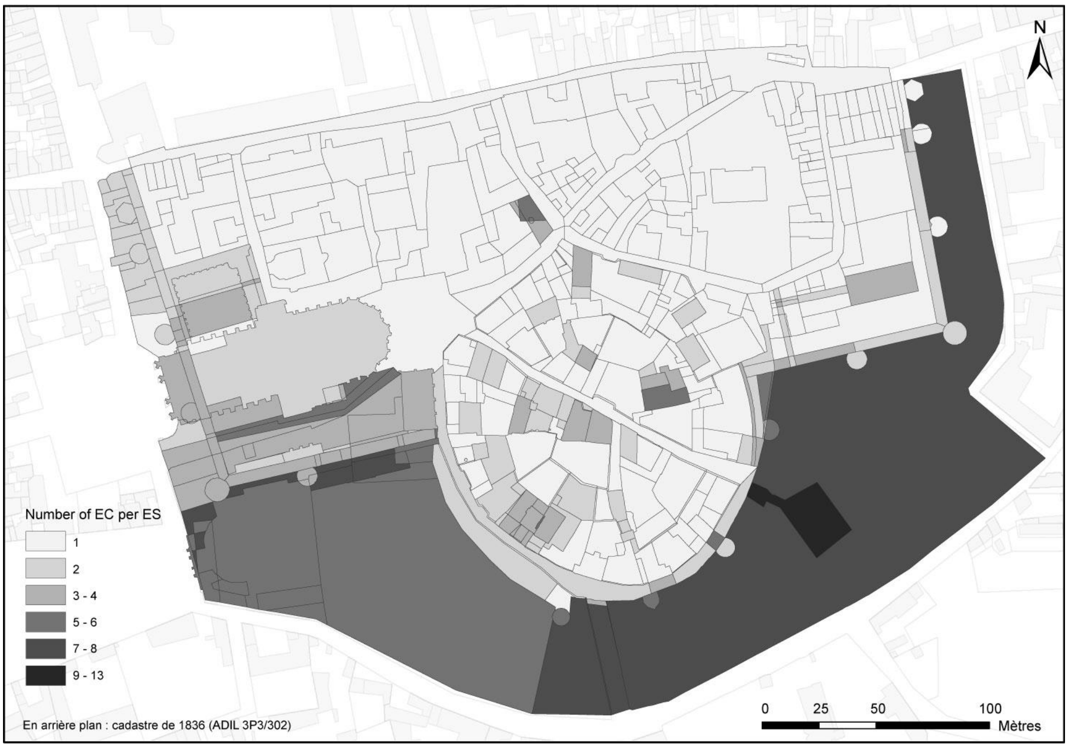

Figure 7. Map showing the incidence of spatial features.

This single map (see 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 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.

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

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

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 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.

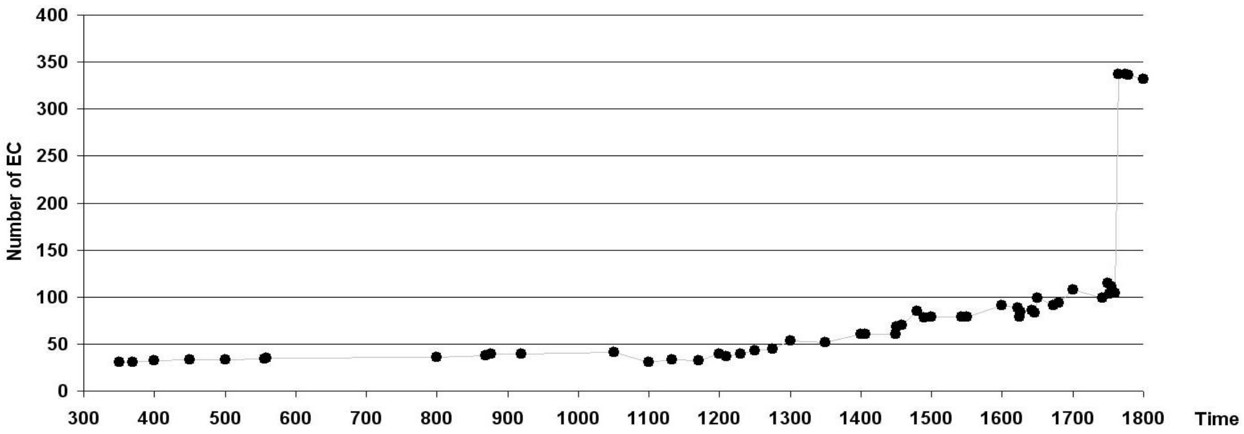

Figure 10. Graph of the occurrence of Temporal Entities.

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 (see 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.

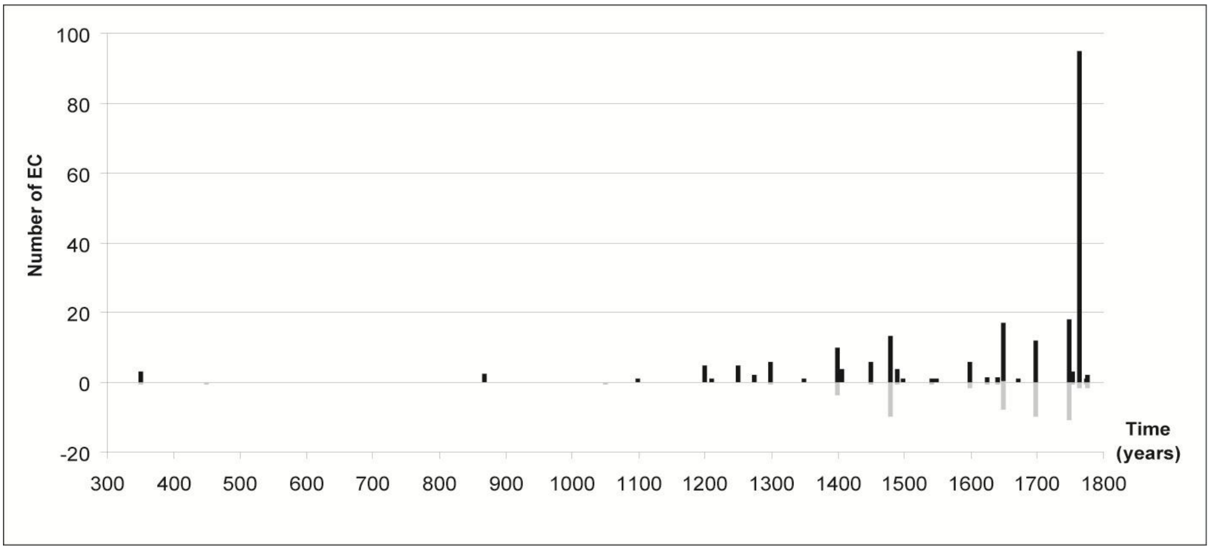

Figure 11. Chronology of the relationship between the appearance and disappearance of historical objects on the site of the Roman amphitheater.
The positive values in black refer to appearances; the negative values in grey refer to disappearances.

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.

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.

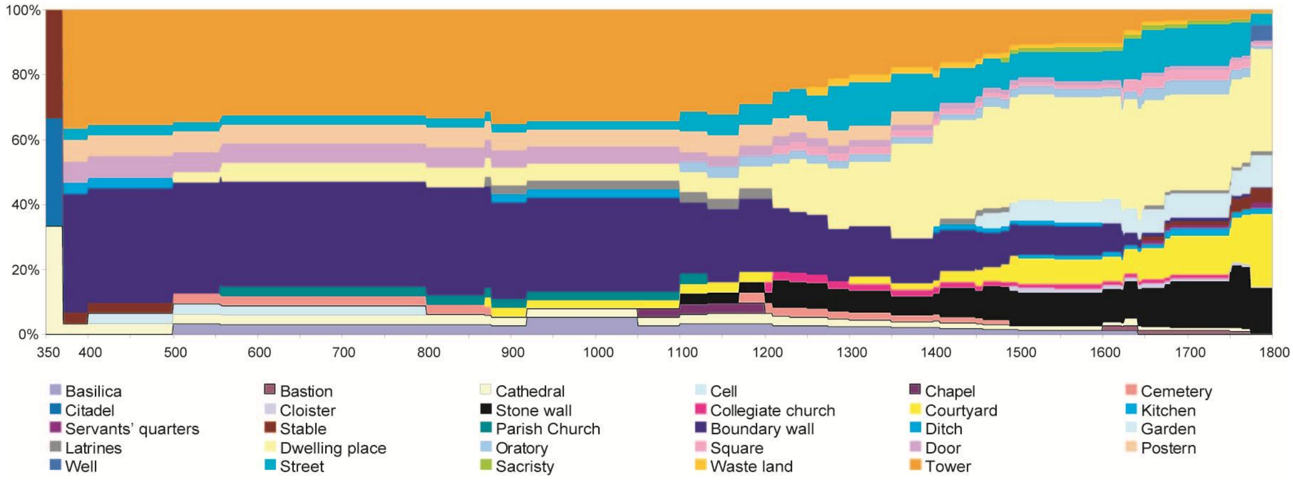

Figure 12. Functional division graph.

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.

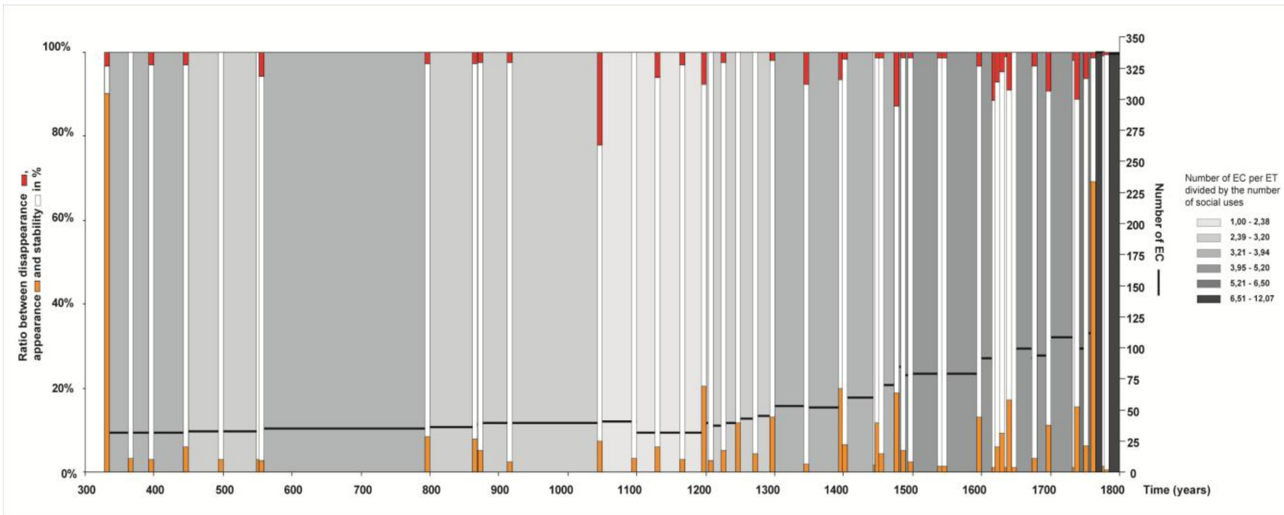

Figure 13. Global representation of the architecture of time.

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 A.D.) and a scale (the year).

Conclusion

In this work, which focused 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 merits further investigation, discussion and improvement: but it already shows that history and archaeology can be sciences of time and not just of the past.

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