

ToToPI (Topographie de Tours Pré-Industriel), a GIS for Understanding Urban Dynamics Based on the OH_FET Model (Social Use, Space, and Time)

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Abstract

ToToPI, for Topography of Tours Pre-Industrial, is a GIS for studying of the city of Tours (France) over a long time span. The concept for understanding the urban dynamic is based on considering the town as a set of complex objects, taking a systemic approach. The system used to study the urban fabric over long time spans is composed of three sub-systems relating to historical objects from the level of the excavation to that of the former urban space: function (social use), space (location, surface area, and morphology), and time (dating, duration, and chronology). The historical object is the analytical unit of the studied space. It is the Cartesian product of the three sets, Social use, Space, and Time, from which it stems. The OH_FET model is based on this process. The Historical Object (OH) is broken down into three types of simple object, functional (EF), spatial (ES), and temporal (ET).

The relationships between these three sets each characterize an interaction (social use-space, social use-time, time-space, or function-space-time). In addition to reconstructing the OH, they allow urban changes to be observed by analyzing the distributions and mapping of each of the entities singly or two-by-two.

The originality of this procedure lies in its approach, whereby it is possible to start not from the mapping of a phenomenon at a time t_1 and comparing it to that at a time t_2 , but to look at it in the same way whether its input is social use, space or time. The heuristic value of this modeling lies in the shift from description (what, where, when) to understanding the phenomena of change (how, why).

The implementation of the OH_FET model in ToToPI, with classical GIS software (ArcGIS from ESRI), makes possible on the one hand the analysis of data sets in long time spans and on the other hand the creation of new analyses (and of new products that result from it, such as the temporal mappings). The paper will explain how GIS is used for historical data processing to understand time-space dynamics.

Keywords: *Spatio-temporal modeling, town, urban functions, spatial dynamics, temporality, GIS*

INTRODUCTION

The study of a city in the *longue durée* is usually based on knowledge of the topographical elements and their relationships with each other from the beginning of human settlement to the present day. Archaeologists study the processes of change of the town. To that end, they must look at the heritage, inertia, trajectories, and dynamics of each object making up the town.¹ These can be considered under three headings:

- Social use;
- Location and surface area;
- Duration and chronology.

In order to assist such archeological studies, geo-historical databases can be viewed as valuable tools. This system could be used to:

- provide a vertical and horizontal perspective of the phenomena (What happened at a particular time? How did a particular place evolve?);

- produce as many inventories as possible;
- express the change of state (and thus the inherent process);
- preserve the specific nature of each place, i.e. its social, temporal and spatial mutations;
- avoid redundant information, in order to facilitate data analysis and management;
- represent a single reality in a variety of ways (depending on the accuracy and quality of information available).

This fundamental process of building geo-historical databases, which is part of a more global geographical information system (GIS), requires the use of procedure and spatio-temporal data modeling steps. Various methods of spatio-temporal modeling exist in the literature, such as the snapshot model,² the amendment

¹H. Galinié, *Ville, espace urbain et archéologie* (Tours: Coll. Sciences de la Ville n° 16, MSH Villes et territoires, 2000).

²M. P. Armstrong, "Temporality in Spatial Databases," in *Proceedings GIS/LIS '88: Accessing the World 2* (San Antonio, Texas, USA, 1988): 880–889.

vector model,¹ the spatio-temporal object model,² or the event-based model.³ Each presents valuable information and knowledge on how spatio-temporal databases could be used to manage spatio-temporal data.

Based on the framework proposed by Peuquet,⁴ we present in this paper a specific approach for modeling historical objects and creating geo-historical databases. The procedure is part of a conceptual approach, which concerns historical sciences, geomatics, and informatics, because of its simultaneous consideration of the *longue durée* and multiple temporalities. The proposed modeling is the result of three key steps. The first step involved formalizing the objects of the historical landscape.⁵ This consisted of a strictly social approach to the town.⁶ The main aim was to characterize the objects making up the urban landscape in the *espace support*.⁷ The methodology used is linked to the methods of archaeological classification and to the culture of relational data bases. The second step involved investigating the spatial properties of the urban objects. This involved a geographical modeling of the archaeological entities.⁸ It was based on a geographical approach to urban space, with a view to analyzing the

spatial dynamics. It corresponds to the appropriation by archaeologists of certain geographical concepts and the use of GIS. The third step involved isolating time within the time-space process so that it is no longer subject to space.⁹ This in some way involves the re-appropriation of time by archaeologists and historians in the analysis of spatial dynamics. The objective is to analyze time and space separately. The approach is based on an analogy between the modeling and treatment of space and time, to develop an independent approach to space and time in order to observe both time-space and space-time processes.

The paper is organized as follows. First, we propose an urban archaeological data-model (OH_FET) based on social use, space and time. Second, we implement this model in a GIS architecture. Finally, we discuss how this work contributes to the understanding of urban fabric. The outline of this paper results from research about town studies and improving GIS with regard to the city of Tours and urban archaeological data management in general.¹⁰

1 BUILDING A SPATIO-TEMPORAL DATA MODEL

1.1 HISTORICAL OBJECT AND SCALE

The Historical Object (OH, *objet historique*) is the basic unit for recording and analyzing urban organization and change in the *longue durée*. It can be defined as being unequivocally distinct from other items, based on the same criteria as the geographical object in relation to the scale, time frame, and materiality of the data brought together within the notion of time-space granularity.¹¹

To study the urban fabric over long time spans,¹² the historical object is the analytical unit of the former

¹G. Langran, "A Review of Temporal Database Research and its Sse in GIS Applications," *International Journal of Geographical Information Systems* 3 (1989): 215–32.

²M. F. Worboys, "A Model for Spatio-temporal Information," in *Proceedings of the 5th International Symposium on Spatial Data Handling* 2 (1992): 602–611.

³D. J. Peuquet and N. Duan, "An Event-Based Spatiotemporal Data Model (ESTDM) for Temporal Analysis of Geographical Data," *International Journal of Geographical Information Systems* 9 (1) (1995): 7–24.

⁴D. 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.

⁵H. Galinié and X. Rodier, "ToToPI, un outil d'analyse urbaine," *Les petits cahiers d'Anatole* 11 (2002). www.univ-tours.fr/lat/pdf/F2_11.pdf.

⁶Heighway C., *The Erosion of History* (London, 1972); M. Biddle and D. Hudson, *The Future of London's Past: A Survey of the Archaeological Implications of Planning and Development in the Nation's Capital*, Rescue Publication 4, 1973; H. Galinié (p. 329n1).

⁷Pumain D., "L'espace, le temps et la matérialité des villes", in *Temporalités urbaines*, ed. B. Lepetit and D. Pumain, coll. «Villes», Anthropos, Paris, 1993: 135–157.

⁸L. Saligny, "La modélisation des entités spatiales," in *Informatisation des documents d'évaluation du patrimoine archéologique des villes de France*, Ministère de la Culture et de la Communication, Centre National d'Archéologie Urbaine (Tours, 2004) 35–38; H. Galinié et al., "Entités fonctionnelles, entités spatiales et dynamique urbaine dans la longue durée," in *Histoire & Mesure* 19 (Paris: CNRS, 2004): 223–242.

⁹X. Rodier and L. Saligny, "Social Features, Spatial Features, Time Features: An Urban Archaeological Data Model," in *Layers of Perception. Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA) Berlin, Germany, April 2–6, 2007*, ed. A. Posluschny et al. (Bonn: Kolloquien zur Vor- und Frühgeschichte, vol.10, 2008); B. Lefebvre et al., "Understanding Urban Fabric with the OH_FET Model Based on Social Use, Space and Time" in *Archeologia e Calcolatori* 19 (2008):195–214. http://soi.cnr.it/archcalc/indice/PDF19/16_Lefebvre.pdf.

¹⁰CNAU, *Informatisation des documents d'évaluation du patrimoine archéologique des villes de France*, ed. Ministère de la Culture et de la Communication (Tours: Centre National d'Archéologie Urbaine, 2004).

¹¹P. Langlois, "Complexité et systèmes spatiaux," in *Modélisations Géographiques, Traité IGAT*, ed. Y. Guermond (Paris: Hermès, 2005); T. Saint-Gérard, "Comprendre pour mesurer...ou mesurer pour comprendre?" in *Modélisations Géographiques, Traité IGAT*, ed. Y. Guermond (Paris: Hermès, 2005).

¹²H. Galinié (p. 329 n1).

urban space, a church, a cemetery, a marketplace, etc. The use of GIS in order to study the spatial evolution of preindustrial cities requires a rigorous formalism of heterogeneous data from different sources as robust entities. Archaeologists are currently facing three main issues: social uses, spatial features, and chronology.

The historical object, as a complex object, will be determined by those three dimensions: attributive or social uses (what); spatial (where); and temporal (when). This definition corresponds to Pequet's three W's (What, Where, When)¹ which is frequently used in spatio-temporal modeling.²

The historical object is not simply characterized by attributing to it each of these three criteria; the object is defined on the basis of the three sets, Function, Space and Time, of which it is the Cartesian product (fig. 1). The combination of these three sets is a space-time analysis (how). The urban object, our study object, is in this intersection.

The principle used to understand the urban space involves a systemic approach whereby the town is seen as a set of complex objects. The town system used to study the urban fabric over long time spans is composed of three sub-systems relating to the historical objects from the level of excavation to that of the former urban space: function (social use), space (location, surface area and morphology), and time (dating and chronology). This systemic approach can be used to identify an historical object, each sub-system providing a possible key.

The first step usually requires defining a framework for study and time-space analysis. This framework will require the use of temporal, spatial and social resolution. This in fact corresponds to the choice of the scale of perception of the phenomenon to be studied.³

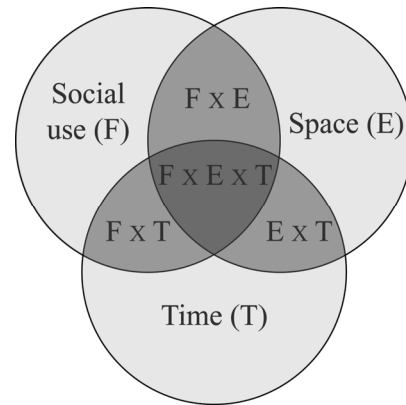


Figure 1. The three sets: social use, space, and time.

The reiteration in this process corresponds to a level of analysis that can overlap another, each time forming a similar model but at a higher or lower level, encompassing or encompassed by another level. Each of these overlapping levels leads to a specific definition of the object. Moving from one to another corresponds systematically to a change of resolution within each of the three sets: function, space, and time (fig. 2).⁴

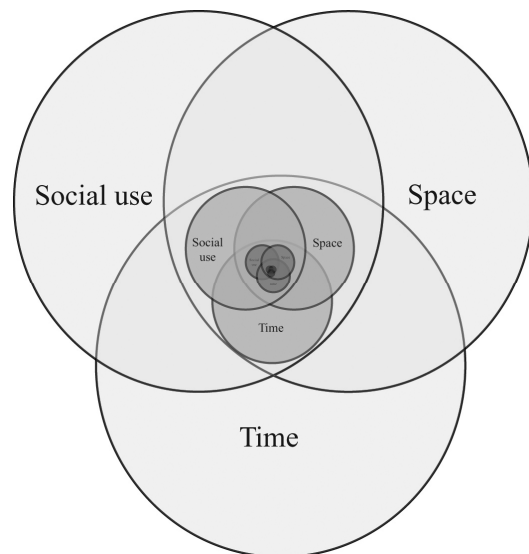


Figure 2. The overlapping system of analysis.

For each scale-change we must define a new historical object, because the scale is changed in each of the three dimensions. At each of these levels, which fit into each other like Russian dolls, there are corresponding descriptors for each system.

Each set (Function, Space, Time) is described according to its own model, and then incorporated into a global model, with the main objectives of:

¹D. J. Pequet (p. 330 n4).

²J. M. Egenhofer and G. R. Golledge, *Spatial and Temporal Reasoning in Geographic Information* (Oxford: Oxford University Press, 1998); S. Lardon et al., "Concevoir la dynamique des entités spatio-temporelles," *Représentation de l'espace et du temps dans les SIG, Revue internationale de géomatique* 9 (1999): 45–65; M. Thériault and C. Claramunt, "La représentation du temps et des processus dans les SIG: une nécessité pour la recherche interdisciplinaire," *Représentation de l'espace et du temps dans les SIG, Revue internationale de géomatique* 9 (1999): 67–99; T. Ott and F. Swiaczny, *Time-Integrative Geographic Information Systems, Management and Analysis of Spatio-Temporal Data* (Berlin: Springer, 2001); G. Panopoulos et al., "Spatio-temporal Generalization: the Chronograph Application," Acts of the 21st International Cartographic Conference, Durban, South Africa, 10–16 August, 2003. http://ontogeo.ntua.gr/publications/icc2003_panopoulos_etal.pdf.

³T. Saint-Gérard (p. 330n11).

⁴X. Rodier and L. Saligny (p. 330n9).

- formalizing data from multiple and heterogeneous sources;
- differentiating function and geometry: dissociating historically relevant social use and geographically relevant spatial features; and
- converting the chronology into time features.

1.2 SOCIAL FEATURES

Social use or function can also be modeled, thanks to various features. The model chosen for function is a hierarchical thesaurus (fig. 3). Its resolution, through a three-level hierarchy (urban value, use value, description), is based on the chosen scale of perception. The social feature is an item in the thesaurus. The function of the OH is defined by a single social feature. One social feature can be used by several OHs. The thesaurus is limited to the chrono-cultural area studied. Not all of the items of the thesaurus are necessarily used for describing the historical object. The thesaurus can be expanded by the creation of a new OH.

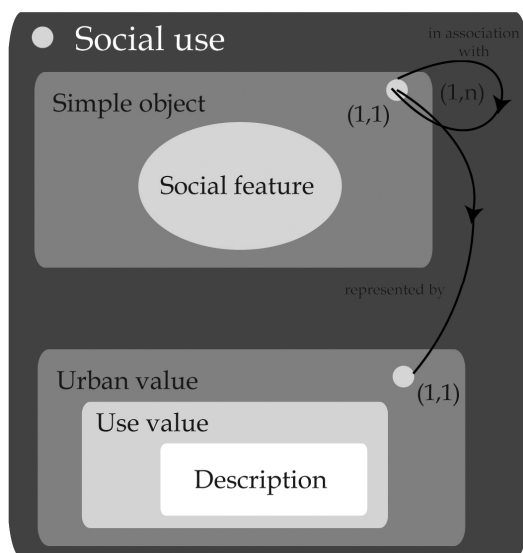


Figure 3. Social use model.¹

¹HBDS formalism is used for modeling. The HBDS method (F. Bouillé, “Un modèle universel de banque de données simultanément partageable, portable, répartie” (Thèse d’Etat en sciences, Université de Paris VI, 1977); T. Saint-Gérard, “Comprendre pour mesurer...ou mesurer pour comprendre?,” in *Modélisations Géographiques, Traité IGAT*, ed. Y. Guérmond (Paris: Hermès, 2005) is based on the theory of graphs and sets. This method groups together five fundamental elements: Class (a set of objects which have the same characteristics. These objects are said to be “simple”. It is represented by an ellipse); Hyper-class (a set of one or several classes. These objects are said to be “complex”. It is also represented by an ellipse); Attributes (they define the class or set of objects (e.g., dating). They are represented by squares linked to the class); Links (these involve the relationships between the object classes and are represented by arrows. They can be bearers of attributes); and Hyperlinks (a set of links of the same nature).

There are numerous examples of functional groups, stemming from urban geography, to be found in the contemporary archaeological or historical bibliography.² We use the hierarchical thesaurus that was drawn up and tested by the French National Centre of Urban Archaeology (CNAU) of the Ministry of Culture, which has been used successfully since 1990 to process topographical data of preindustrial towns.³ In the data model for social use, a simple object is a social feature built with urban value, use value, and description.

The thesaurus includes three hierarchical levels: Urban value, Use value, and Description (fig. 3). For example, a building is interpreted as a workshop (this is the use value). We infer the existence of a craft area and of a production and transformation activity (this is the urban value). Converting use value into urban value corresponds to a change in scale.

1.1 SPATIAL FEATURES

Space is currently the most formalized (by geographers) of the three sets. In GIS, space is structured on the model of a planar topological graph, without isthmi,⁴ into which spatial features are inserted. Spatial features are created according to the way the Historical Objects are defined. In our own modeling, Space is continuous, limited by the definition of a study area. It contains voids, i.e. empty spaces left when the ES have been removed.

Once the OH has been characterized by transforming the data into Social features, the spatialization must be expressed in ES. The proposed spatial modeling⁵ is based on the principle of the non-redundancy of features. On the one hand, it identifies the OH as archaeologically interpreted objects, which are

² C. Heighway, *The Erosion of History* (London, 1972).

³ See the directory of field operations in an urban environment 2005, online on the CNAU website, www.culture.gouv.fr/culture/cnau/fr/index.html.

⁴*Planar topological graph without isthmi*: A graph G is planar if it is possible to represent it on the plane in such a way that the vertices are distinct points and the vectors are simple and disjoint curves except on their extreme points. A planar topological graph is the representation of a planar graph G on the plane. In a planar topological graph, one face is by definition a part of the plane limited by the vectors in such a way that two points of the face can always be linked by a continuous line that meets neither the vertex nor the curve. Two faces are adjacent if they have a common vector. Two faces are opposed if they share a common vertex without being adjacent. A planar topological graph without isthmi is a planar topological graph without a *pendant vertex*. See F. Pirot, “Systèmes d’information géographique, archéologie et histoire,” *Histoire & Mesure* 19 (3/4) (2004), glossary; and C. Berge, *Théorie des graphes et ces applications. Collection universitaire de mathématiques* (Paris: Dunod, 1958).

⁵L. Saligny (p. 330 n8) 35–38; H. Galinié et al (p. 330 n8).

described as “complex”; on the other hand, the spatial features are designated “simple” objects (geometrical object). A simple object forms part or all of a complex object (see below). In this model, space is continuous; it can in some places be unoccupied. In a given place, there can be one and only one spatial feature, but this can play a role in as many OHs as necessary.

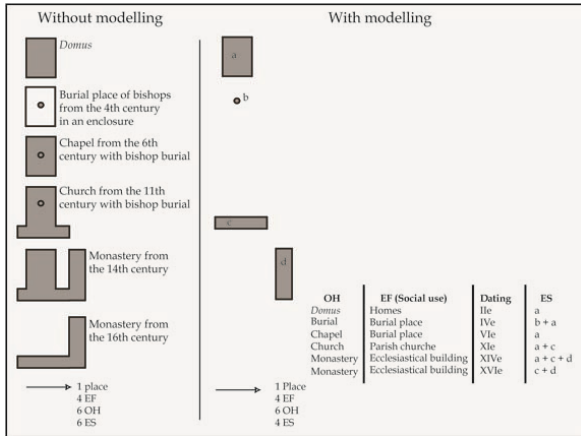


Figure 4. Example of converting an OH to spatial features.

Data modeling consists in deconstructing information, even if it means going counter to our global view of a place. It is the dividing up of space by the accumulation of OH that defines the spatial features. Figure 4 provides a detailed example showing the type of successive changes which can be found in many towns in France, based on a variety of modalities. To transform the historical object into a spatial feature, we have to identify the basic geometric unit, in order to be able to fully define or delimit the space. For example, if a *domus* is transformed into an enclosure and later into a funerary church, these are three different urban objects (fig. 4). The use is changing, the time is changing, but the shape is the same for all the urban objects. Therefore, we must create three urban objects, but if we also created three spatial objects, they would be redundant in the database. With the specific spatial data modeling, if there is no change of shape and no movement, we can use the same spatial features (geometry) for all urban objects. Thus, the spatial features do not have a social meaning. With this more complex example in the schema, we obtain four social uses and six urban objects for one place. Without modeling, there were six spatial features to manage, but only four with the proposed spatial data modeling. Therefore the geometry does not represent an historical fact or reality, but a part of these, in accordance with the observed spatial transformations.

The objective of the proposed spatial data modeling is to create spatial features on the basis of their morphological transformation, and not of their social definition. This means dividing up the place into entities (spatial features) that are not defined by a date and/or

social use. In our example, the ESs that have been created correspond to spatial realities, to materialized and well-localized forms, which take on a detailed historical meaning due to their successive time-space links in constructing OHs. It can thus be seen that creating a spatial feature is dependent on the temporal aspect of the elements characterizing a place; the latter is split up into as many ESs as there are identifiable “structures” that appear or disappear.

This division reflects a spatial reality (appearance, stability, disappearance) in time, and not a social reality. The latter is obtained from the play between the relationships and attributes of each of the spatial features, which will form complex objects—the OH. The difficulty linked to this destructuring of space is freeing oneself from the interpretative historical value when defining the spatial feature. The simple object is a spatial feature represented by a traditional geometric entity (fig. 5), built with node as point, arc as line, and face as area.

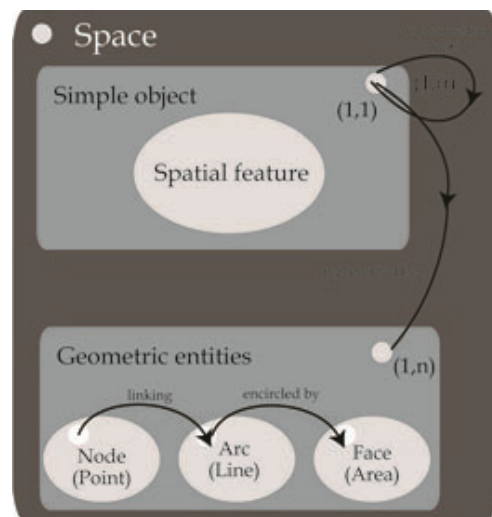


Figure 5. Model for Space.

1.2 TIME FEATURES

We propose modeling time by analogy with space, using the same type of simple object in order to free ourselves from the continuous and linear *temps support*, but above all so as to no longer make time subject to space. However, as long as time is confined to the role of attribute, it cannot be mobilized globally but only specifically to each feature class, and repeated for each of them. Time should therefore be considered as a feature class in its own right. This idea is based on the work of James Allen on artificial intelligence, which formalized the 13 topological relationships between time intervals, circumscribed by dates (fig. 6).¹

¹J. F. Allen, “Towards a General Theory of Action and Time,” *Artificial Intelligence* 23 (1984): 123–154.

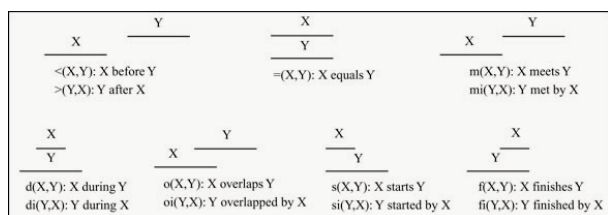


Figure 6. Allen's time relationships.

As for modeling of space, we eliminate all forms of intersection between two intervals from these 13 relationships, in order to retain only the ones which are non-redundant:

- <(X,Y): X before Y
- >(Y,X): Y after X
- m(X,Y): X meets Y
- mi(Y,X): Y met by X

With the observation of time features, such as the atoms of time, the aim is to analyze time pattern. In this way, each piece of time is used only once. When the redundancies have been eliminated, all notions of time span, century, and period can be reconstructed from this model. Like the spatial features, time feature modeling is done independently from the social and spatial interpretation. The time span and number of time features for a period of time determine a frequency. Observation of how these are distributed should allow time patterns to be analyzed.

As for space, to transform the urban object into a temporal feature, we have to break down the structure of time. We consider that no temporal redundancy should be seen here. Like space, time is continuous. Sometimes it may not be used. At any given moment, there can be only one time feature, but it can be used by as many OHs as necessary. The time resolution chosen for time features determines the dating of the historical objects. Continuous time is circumscribed by the chronological markers of the studied object. Time features thus belong to a set with a known number of elements. The time features used by historical objects constitute a sub-set which, when removed from the whole of the time features, reveals time gaps.

A temporal feature can be a date or an interval. Time features are defined by the division of time through the accumulation of historical objects. The time feature is neutral and defined by the smallest possible time unit for dating the phenomenon studied; it can be a date or an interval with which we create duration, span or century. Thus, there are as many time features as necessary to build historical objects. Time features are defined by the division of time through the accumulation of OHs (fig. 7).

The time model is linear and, like space, topological. Here, time is assimilated to a space with one dimension. This formalization of time into instants and intervals

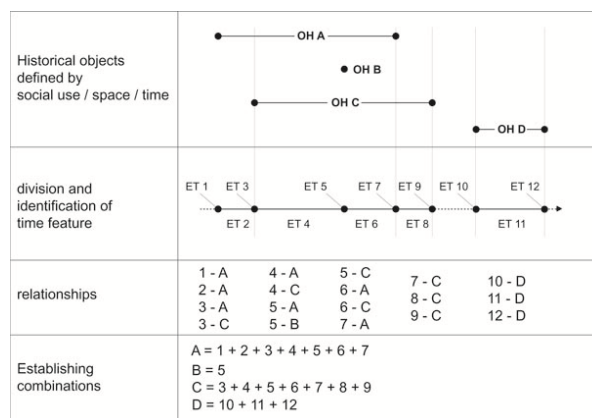


Figure 7. Deconstruction of the historical object and construction of Ets.

was described by Philippe Muller and Vincent Dugat.¹ By contrast, we propose deconstructing time into as many time features as necessary to constitute the historical objects (fig. 7). To this end, as for space, the historical object must be deconstructed in order to transform it into a time feature. In the model for time, the simple object is a temporal feature built with node as date and arc as interval (fig. 8).

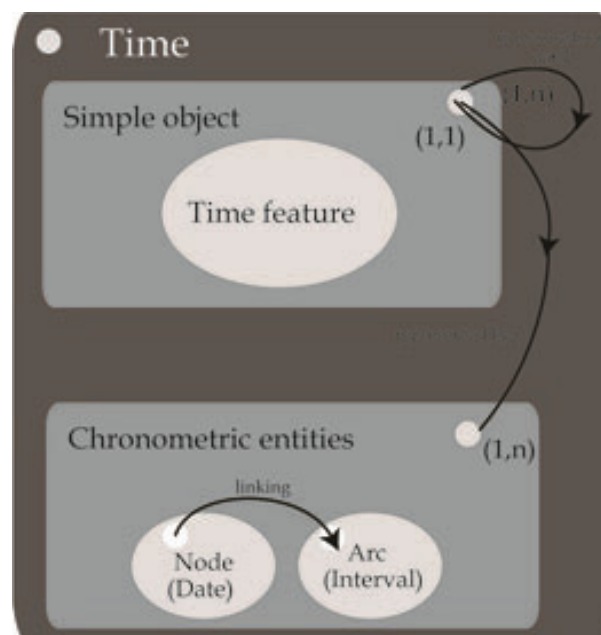


Figure 8. Time model.

¹P. Muller and V. Dugat, "Représentation en logique classique," in *Raisonnements sur l'espace et le temps : des modèles aux applications. Traité IGAT*, ed. F. Le Ber et al. (Paris: Hermès, 2007) 33–70.

1.3 OH_FET MODEL

The organization of these three features around the historical object makes up the general model OH_FET of former urban space for studying the town over long time spans (*dans la longue durée*).

The relationships between the social use, space and time sets, and the historical object determine respectively its interpretation, localization, and dating. These relationships are qualified by their attributes: reliability of the interpretation, accuracy of the localization, and the origin and accuracy of dating (fig. 9).

Even if, like time, there is no pre-determined resolution for space, and while the social use set is not finite (additionas can always be made to the thesaurus), the scale of perception selected for the phenomena studied does determine a scale for each set.

With this organization, it is possible to place the historical object in the center of the model, interacting with its three components, while making social use, space, and time independent of each other.

2 IMPLEMENTATION OF ToToPI

2.1 CONSTRAINTS AND CHOICES

The implementation of this model is constrained by four factors.

(1) The model itself

Indeed, if the organization of social use in the hierarchical thesaurus is not a difficulty, the model of deconstruction of space and time implies the creation of simple objects and of relationships that are needed to reconstruct the historical objects. The simple objects are defined by the accumulation of historical objects. Thus, for each new historical object, the piece of space and the piece of time will be recomposed. This involves recalculating the associations of the simple objects that make up the historical objects. Thus, for a data set, the simple objects are constructed by the division of space and time in as many elements as the superposition of the historical objects. However, the reiteration of the database when adding or editing an OH implies:

- identifying all the simple objects and all relations involved;
- reorganizing simple objects according to new data;
- transferring the properties of old simple objects to new ones;
- removing old simple objects; and
- rebuilding relations of simple objects-Historical Object necessary.

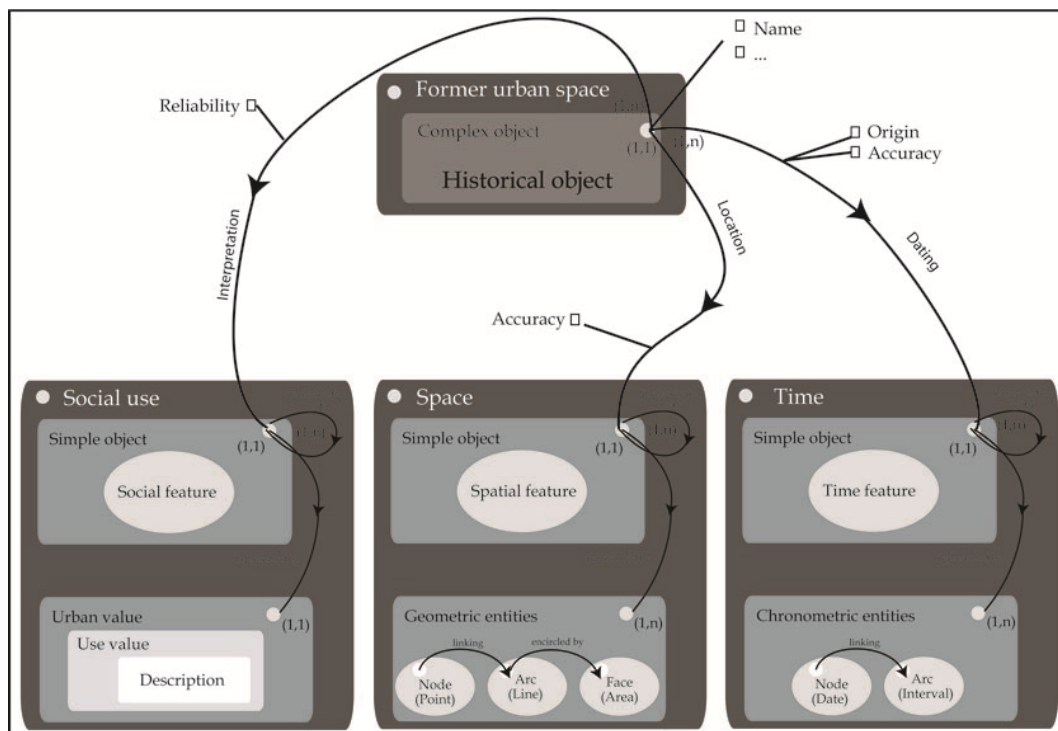


Figure 9. OH_FET Model.

(2) *The data set*

As usual, the archaeological data set is incomplete and heterogeneous. The historical objects used must be created on the basis of assumptions and sufficiently robust arguments. The archaeological information for which it lacks interpretation and/or location and/or dating is not integrated. The choices made in the three dimensions are based on the state of knowledge at a given time. They are intended to be questioned. Our aim is to develop a tool to analyze this state of knowledge.

For the case study of Tours, the former urban space is approximately one hundred and eighty hectares. The time span is from antiquity to the 18th century. The dataset contains eight hundred historical objects.

(3) *The scale analysis*

When we chose to implement the OH_FET model into ToToPI, we also decided to work at one scale of analysis—the scale of the city. When you look at the urban phenomenon as a whole, it is necessary to represent all data by points, in order to make them comparable and readable. Thus, all information has been generalized into points. This choice is conditioned not only by that of the scale of analysis but also by the nature of the documentation, which does not allow us to define the influence of each OH with acceptable and comparable accuracy. Then, the data used in the spatial analyses would not be homogeneous enough.

(4) *The software selection*

As we are not computer scientists, we decided to use ArcGIS because it provides all the functions necessary

to do this spatial analysis without any programming efforts. All information is managed in a geo-database. The construction of the geo-database is not a problem for spatial features because this is the foundation of GIS. Similarly, the hierarchical structure of the thesaurus of social features is easily constructed with some data tables. However, the tool is not designed to incorporate the temporal modeling that we proposed. In addition, we wanted to test the possibility of representation of functional and temporal analysis. We have therefore opted to exploit the capabilities of ArcGIS and give a spatiality at social use and time (see below). Thus, all requests—simple, multiple, or cross—will be made using the same method in the geodatabase.

2.2 GEODATABASE

The geodatabase ToToPI is built from this model (fig. 10). It consists of three feature classes for each type of simple objects corresponding to social features, spatial features, and time features, as well as another feature class for the historical objects. Each feature class of simple object has its own representation.

The time feature corresponds to a class feature in our OH_FET model, and we wanted to be able to visually represent this feature in the cartographic viewing tool available in ArcMap. To do this, we attached a graphic representation (a point) and a relative position to each time object. We used the same methodology to represent the social feature. In this case we used an encompassing triangle shape.

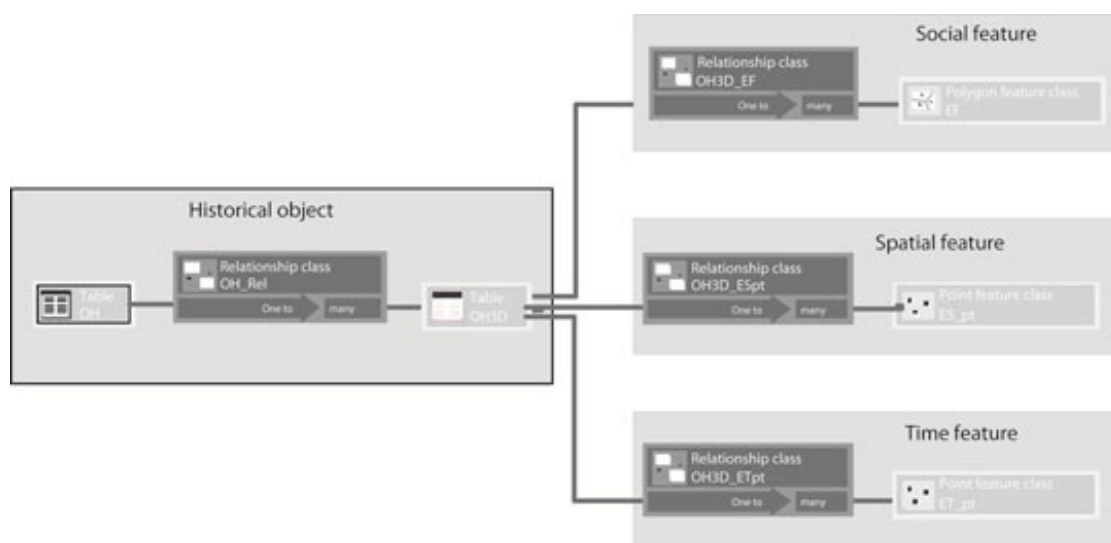


Figure 10. Schema of geodatabase.

The relationship between simple objects and historical objects takes place in two stages. The historical objects

are composed of three simple objects; the solution is to create a relationship class with three primary keys. This

three-key relationship class will contain a large number of records.

Each feature class of simple objects is linked with this relationship class. The feature class of historical object (as a complex object) is also linked to the same relationship class. With the urban scale chosen, the spatial feature is represented only by points. The spatial modeling is simpler than if they were areas. In this case one OH needs just one spatial feature, since a point is sufficient to represent it.

For the hierarchical thesaurus of the urban values, we chose a representation with encompassing triangles (see fig. 13). Each large triangle represents an urban value and the small triangles inside them represent the use values. Naturally, the triangles do not have spatial meaning. It is just one possibility, among others, for drawing the functional thesaurus. There is no relation in the order of the succession of urban value in the thesaurus, and no spatial logic in the arrangement of triangles. The time features are represented by chonometric entities like points on a line in one dimension (see fig. 15).

Only the position of the points on the line has a meaning, because it represents the position of the time feature in time. At this stage it is not necessary to indicate the duration of time by lines but it can be reconstructed from the points.

SQL queries in the geodatabase are performed in the same way for each dimension.

3 USING OF_FET MODEL

3.1 OUTPUT OF THE MODEL

By using the OF_FET Model, one is able to obtain new products and new kinds of analyses. Figure 11 summarizes the possible analyses. Three are one-dimensional—space (E), time (T), and social use (F); and three are bi-dimensional, which are the Cartesian products of social use and space (F x E), social use and time (F x T), and space and time (E x T).

The three dimensions are inseparable, and the six types of analysis that are proposed do not allow one part of the system to be studied independently of the rest; each result represents an aspect that helps understanding the whole. Each of these analyses provides different but complementary information to help understand the dynamics of the system.

The OH_FET model provides three distinct inputs, and six outputs, plus one: F x E x T. Among the six outputs, three (F, E, and T) show the distributions, and the other three show the variability. At the heart of the system, the additional output, F x E x T, does not indicate any process of change but rather the state of the historical object and the historical topography as a snapshot.

The dynamics can be studied by analyzing, singly or in pairs, the social, spatial, and time dimensions.

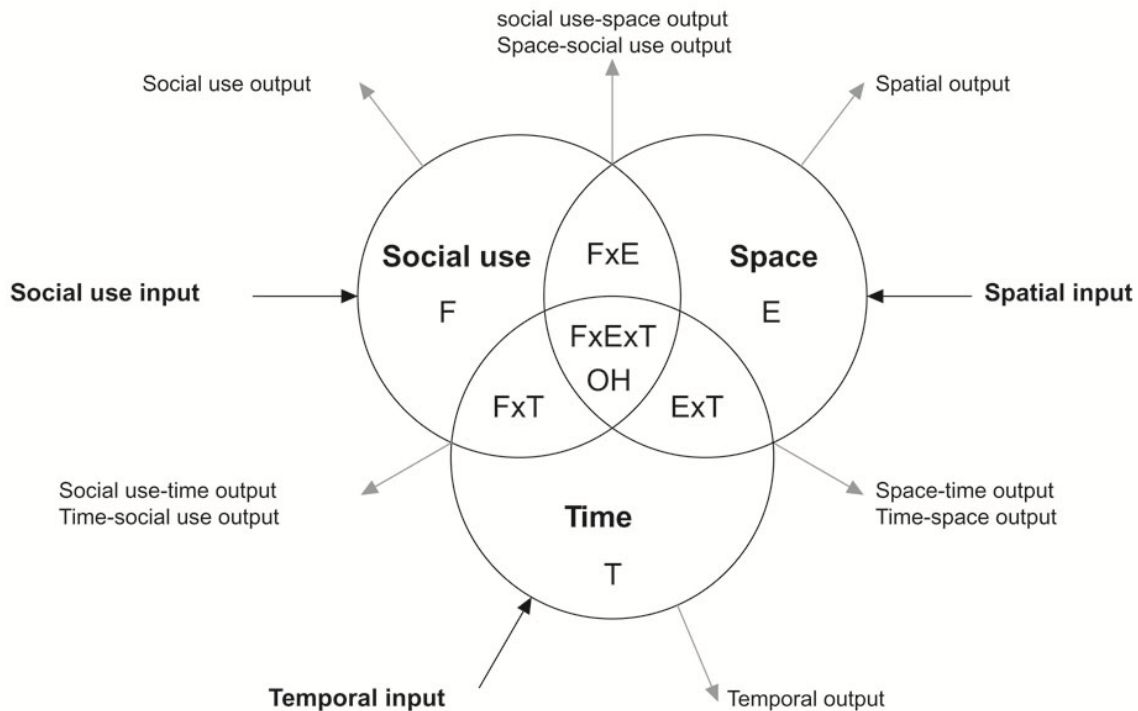


Figure 11. Diagram showing the model and inputs of the analysis of the dynamics.

3.2 SOCIAL, SPATIAL, AND TEMPORAL ANALYSIS

The aim of the conceptual formalization is to be able to analyze and model data in order to further our understanding of the observed phenomena. Modeling time by analogy with space implies that the analysis of time is based on similar concepts to that of space, with the following equivalences:

Spatial analysis	Temporal analysis
Localization	Dating
Distance	Time span
Relative position	Relative chronology
Spatial interaction	Temporal interaction

By temporal interaction, at present we understand the analysis of patterns and frequencies. While geographical models of spatial interactions have been used to process archaeological data,¹ there is no equivalent for analyzing time. And yet, analysis of these interactions provides a way of reading these patterns and indicating the accelerations and decelerations, the contractions and expansions of time, which are observed empirically by archaeologists.

To summarize the possibilities offered by the OH_FET model, we can distinguish three cases:

- a) $F \times E \times T =$ OH state, snapshot
- b) $State_2 - State_1 =$ change of state
- c) $F \times E =$
 $F \times T =$ process of transformation
 $E \times T =$

- a) The Cartesian product of the three sets provides a state or a snapshot. It is static. We can reproduce all the possible states, i.e. all the mappings at every possible date, instead of having pre-defined states, or “snapshots”, which inevitably lead to a bias in the way the phenomena are viewed (since part of the time span of the phenomena is not recorded in these cases). An example is the historical topography of Tours in c. 1250 (fig. 12). However, this is not a mapping tool, but as a research tool. The documents produced are intended to clarify the issues to be resolved.

- b) Analyse and observe all the possible changes of state. As usual in archaeological studies, after the creation of n snapshots at given times, the difference between two snapshots provides the change of state. The result is a map of the changes representing disappearance, stability, and appearance
- c) The process of the change(s) of state is revealed by the Cartesian products of pairs of sets—in other words, the transformations. It is this objective that is essential in order to understand the OH_FET system and model.

In this way, by modeling and working on each of the three aspects used to describe historical information, i.e. social use, space, and time, we can produce new elements of analysis with which to observe.

The one-dimensional products which show the distributions are as follows:

- (a) The distribution of functions: the number of times each social feature is used to form the historical objects. Figure 13 shows the distribution of use values and urban values, in other words, the number of times each social feature is used to build the historical objects.
- (b) The use of space: the number of times each spatial feature is used to form the historical objects (fig. 14).
- (c) The use of time: the number of times each time feature is used to form the historical objects (fig. 15).

Identification of these patterns is likely to convey the state of knowledge by highlighting the source effects. Beyond this, the analysis of these distributions provides new perceptions of the historical pattern and the possibility of focusing observations on the transition from one state to another, i.e. concentrating on the change of state rather than on the state itself.

Finally, the bi-dimensional analysis offers the opportunity to observe the variability of social use in space; of social use in time; of space in time; and of time in space.

Some examples for time pattern analysis are given by Lefebvre,² who developed new models of representation for this variability such as temporal mapping.

¹Laure Nuninger et al., “From *Archaeomedes* to *Archaedyn*,” in *Layers of Perception. Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA) Berlin, Germany, April 2–6, 2007*, ed. A. Posluschny et al. (Bonn: Kolloquien zur Vor- und Frühgeschichte, vol.10, 2008).

²Bastien Lefebvre, *La formation d’un tissu urbain dans la Cité de Tours: du site de l’amphithéâtre antique au quartier canonial (5e-18e s.)* (Ph.D. diss., University of Tours, 2008). <http://tel.archives-ouvertes.fr/tel-00349580/fr/>.

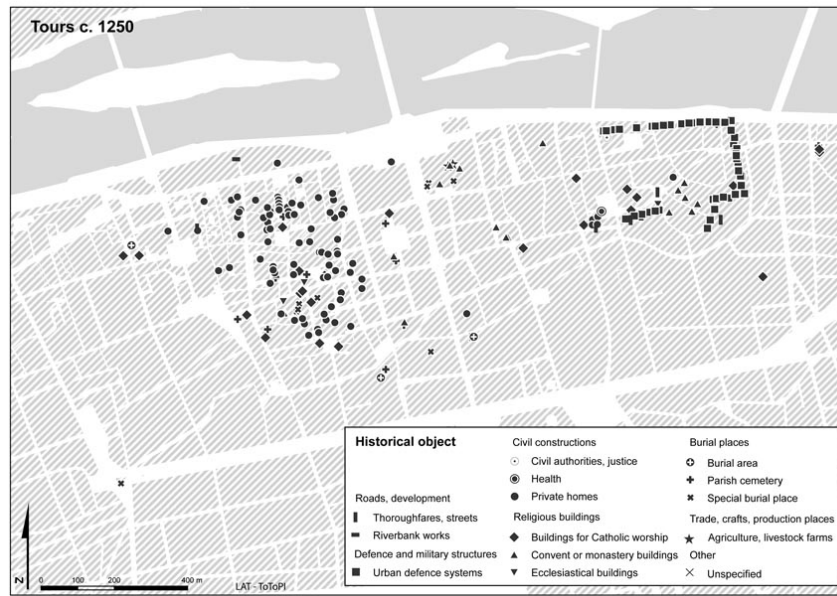


Figure 12. Maps of the historical topography of Tours in 1250.

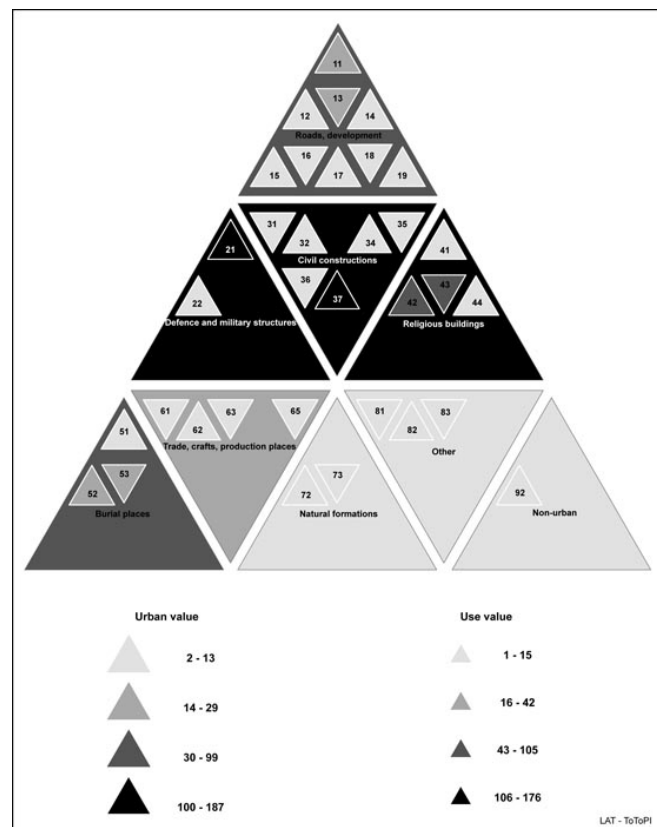


Figure 13. The distribution of functions: 11 thoroughfares, streets; 12 unoccupied spaces; 13 riverbank works; 14 landscape works; 15 crossing points; 16 water supply systems; 17 sewers/ drains; 18 monuments, vestiges; 19 unspecified monuments; 21 urban defence systems; 22 fortified structures; 31 public spaces; 32 civil authorities, justice; 34 health; 35 entertainment, sports; 36 baths, thermal baths; 37 private homes; 41. pagan worship; 42 Catholic worship; 43 convent or monastery buildings; 44 ecclesiastical buildings; 51 burial area; 52 parish cemetery; 53 special burial place; 61 trade, markets, shops; 62 crafts, workshops; 63 agriculture, livestock farms; 65 extraction, quarries; 72 rivers; 73 marshes; 81 unspecified; 82 no confirmed occupation; 83 abandoned; 92 peripheral structure.



Figure 14. *The use of space.*

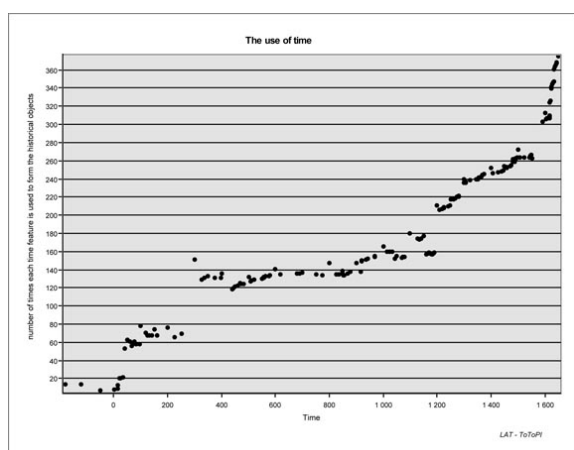


Figure 15. *The use of time*

4 CONCLUSION

Understanding the transformations, i.e. the process of change of state, is possible with the OH_FET system and model. The principle that the three intrinsic characteristics of the object studied-social use, space and time-are distinct entities makes it possible to group them two by two in order to observe the factors affecting change and to estimate the role or predominance of one over the other. This application is a good tool for data analysis. It offers many possibilities for data processing and it has great potential for urban analysis. It provides a formal approach for spatio-temporal modeling adapted to the historical study of urban dynamic, and new spatio-temporal analysis capabilities available on a standard GIS tool. Although the constraint of the software used is very strong, it nevertheless has the advantage of being able to handle all data in the same way. In addition, to our knowledge, no other tool allows us to implement temporal modeling that we have chosen and even less that of the three dimensions together. One of the drawbacks inherent to the model itself is the exponential growth of relationships based on three keys. But the biggest difficulty concerns the repetition of the system when adding or changing data. One must rebuild the simple objects for space and time and then recalculate the relationship.

The originality of the procedure lies in its impartial approach, which means that rather than starting from the mapping of a phenomenon it can be approached equally from a social, spatial or temporal standpoint. The heuristic value of this modeling lies in the shift from the description to the understanding of the phenomena.

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BIBLIOGRAPHY

- Allen, J. F. "Towards a General Theory of Action and Time." *Artificial Intelligence* 23 (2) (1984): 123–154.
- Armstrong, M. P. "Temporality in Spatial Databases." *Accessing the World: GIS/LIS '88 Proceedings*, vol. 2 (San Antonio, Texas, 1988): 880–889.
- Berge, C. *Théorie des graphes et ces applications*. Collection universitaire de mathématiques. Paris: Dunod, 1958.
- Biddle, M., and D. Hudson. *The Future of London's Past: A Survey of the Archaeological Implications of Planning and Development in the Nation's Capital*. London: Rescue publication 4, 1973.
- Bouillé, F. *Un modèle universel de banque de données simultanément partageable, portable, répartie*. Thèse d'Etat en sciences, Université de Paris VI, 1977.
- CNAU. *Informatisation des documents d'évaluation du patrimoine archéologique des villes de France*, ed. Ministère de la Culture et de la Communication. Tours: Centre National d'Archéologie Urbaine, 2004.
- Egenhofer, J. M., and G. R. Golledge. *Spatial and Temporal Reasoning in Geographic Information*. Oxford: Oxford University Press, 1998.
- Galinié, H. *Ville, espace urbain et archéologie*. Tours: Coll. Sciences de la Ville n° 16, MSH Villes et territoires, 2000.
- Galinié, H., and X. Rodier, X. "ToToPI, un outil d'analyse urbaine." *Les petits cahiers d'Anatole* 11 (2002) http://www.univ-tours.fr/lat/pdf/F2_11.pdf.

- Galinié, H., X. Rodier, and L. Saligny. "Entités fonctionnelles, entités spatiales et dynamique urbaine dans la longue durée." *Histoire & Mesure* 19 (2004): 223–242.
- Heighway, C., *The Erosion of History: Archaeology and Planning in Towns*. London: Council for British Archaeology, 1972.
- Langlois, P. "Complexité et systèmes spatiaux," in *Modélisations Géographiques*, Traité IGAT, edited by Y. Guermond (Paris: Hermès, 2005).
- Langran, G. "A Review of Temporal Database Research and its Use in GIS Applications." *International Journal of Geographical Information Systems* 3 (1989): 215–32.
- Lardon, S., T. Libourel, and J.-P. Cheylan. "Concevoir la dynamique des entités spatio-temporelles." *Représentation de l'espace et du temps dans les SIG, Revue internationale de géomatique* 9 (1999): 45–65.
- Le Ber, F., G. Ligozat, and O. Papini. *Raisonnements sur l'espace et le temps : des modèles aux applications*, Traité IGAT (Paris: Hermès, 2007).
- Lefebvre, B. "Construction et déconstruction de l'espace urbain : une modélisation en volume du bâti ancien." *MIA Journal* n°2 (VII 2006) <http://www.map.archi.fr/mia/journal/>.
- Lefebvre, B., X. Rodier, and L. Saligny. "Understanding Urban Fabric with the OH_FET Model Based on Social Use, Space and Time." *Archeologia e Calcolatori* 19 (2008): 195–214, http://soi.cnr.it/archcalc/indice/PDF19/16_Lefebvre.pdf.
- Muller, P., and V. Dugat. "Représentation en logique classique," in *Raisonnements sur l'espace et le temps*, edited by F. Le Ber, G. Ligozat, and O. Papini, 33–70. Traité IGAT, Paris: Hermès, 2007.
- Nuninger, L., F.-P. Tourneux, and F. Favory. "From Archaeomedes to Archaeodyn," in *Layers of Perception, Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA) Berlin, Germany, April 2–6, 2007*, edited by A. Posluschny, K. Lambers, and I. Hertog. Bonn: Kolloquien zur Vor- und Frühgeschichte, vol.10, 2008.
- Ott, T., and F. Swiaczny. *Time-Integrative Geographic Information Systems, Management and Analysis of Spatio-Temporal Data*. Berlin: Springer, 2001.
- Panopoulos, G., A. Stamatopoulos, and M. Kavouras. "Spatio-temporal Generalization: The Chronograph Application." Acts of the 21st International Cartographic Conference, Durban, South Africa, 10–16 August 2003. http://ontogeo.ntua.gr/publications/icc2003_panopoulos_etal.pdf.
- Pelle, S. *Modéliser des données géographiques grâce à la méthode HBDS*. Ecole Nationale des Sciences Géographiques; Institut Géographique National, 2001. <http://pelle.stephane.free.fr/HBDSConseils.htm>.
- Peuquet, D. J. "It's about Time: A Conceptual Framework for the Representation of Temporal Dynamics in Geographic Information System." *Annals of the Association of American Geographers* 3 (1994): 441–461.
- Peuquet, D. J., and N. Duan. "An Event-Based Spatiotemporal Data Model (ESTDM) for Temporal Analysis of Geographical Data." *International Journal of Geographical Information Systems* 9 (1) (1995): 7–24.
- Pumain, D. "L'espace, le temps et la matérialité des villes," in *Temporalités urbaines*, coll. « Villes », 135–157, edited by B. Lepetit and D. Pumain (Paris: Anthropos, 1993).
- Rodier, X., and L. Saligny. "Modélisation des objets urbains pour l'étude des dynamiques urbaines dans la longue durée." *SAGEO 2007, Rencontres internationales Géomatique et territoire*, 2007. www.emse.fr/site/SAGEO2007/CDROM/index.html.
- Rodier, X., and L. Saligny. "Social features, Spatial features, Time features: An Urban Archaeological Data Model," in *Layers of Perception, Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA) Berlin, Germany, April 2–6, 2007*, edited by A. Posluschny, K. Lambers, and I. Hertog. Bonn: Kolloquien zur Vor- und Frühgeschichte, vol.10, 2008.
- Saint-Gérard, T. "Comprendre pour mesurer...ou mesurer pour comprendre?" In *Modélisations Géographiques*, edited by Y. Guermond. Traité IGAT (Paris: Hermès, 2005).
- Saligny, L. "La modélisation des entités spatiales," in *Informatisation des documents d'évaluation du patrimoine archéologique des villes de France*. Tours: Ministère de la Culture et de la Communication, Centre National d'Archéologie Urbaine, 2004: 35–38.
- Thériault, M., and C. Claramunt. "La représentation du temps et des processus dans les SIG : une nécessité pour la recherche interdisciplinaire." In *Représentation de l'espace et du temps dans les SIG. Revue internationale de géomatique* 9 (1999): 67–99.
- Worboys, M. F. "A Model for Spatio-temporal Information," in *Proceedings of the 5th International Symposium on Spatial Data Handling* 2 (1992): 602–611.