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OH_FET: A Computer Application for Analysing Urban Dynamics Over Long Time Spans

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OH_FET formalism has been designed to analyse urban fabric over long time spans (Lefebvre et al., 2008; Rodier and Saligny, 2010; Rodier et al., 2010). The conceptual model is founded on the idea of historical object (OH – objet historique) which is defined as the Cartesian product of three elementary dimensions: social use (what), space (where) and time (when). Processes are performed in Python programming language and data are stored in various kinds of spatial database. With a minimum of required data from archaeologists' observations, the application allows users to automate the calculation of standardised indicators about urban transformations and to generate graphical and cartographic representations. As an example, it is possible to query the database about functional transformations over time and across space either quantitatively (How many social uses for a given date in a given place?) or qualitatively (What changes occurred in social uses over time for a particular place?).

Keywords: Urban Dynamics, Space-Time Modelling, Software Development, Temporal Analyses

Urban fabric (Galinié, 2000) designates the interactions between a space, an environment and social and human activities. The city is the outcome of 'interactive dynamics between the evolving structure of social groups and the development of space' (Galinié *et al.*, 2007). Based on documentation describing chronological and evidential surveys, the study examines the formation and the transformations of urbanised space over long time periods, from the origins of the urban settlement to the present day. The snapshot character of the chronological states described is a stumbling block that prevents the perception and restitution of changes between states and examination of the transformation processes.

After describing the OH_FET model (Rodier *et al.*, 2010), we explain how the model is implemented and the data structured for software development. Finally, we present the analysis module grounded specifically on the time dimension using the the city of Vendôme as an example.

1. The OH_FET conceptual model

1.1 Historical Objects (OH) as the result of functions (F), space (E) and time (T)

The idea of historical object (OH) is the crux of the model. It is defined as the basic unit of analysis, unequivocally distinct from others by the same criteria as the geographical object 'relative to a scale, time-frame and material character of data' brought together in 'the idea of space-time granularity' (Langlois, 2005: 311; Saint-Gérand, 2005). It may be, say, a church, a market or a workshop. The historical object is determined by its interpretation or its function, its location and spatial extent, its date and its duration. A new historical object is created whenever its function changes or moves in space or whenever its spatial extent evolves.

Accordingly, the model is based on interpreted knowledge and is not a solution for a documentary system of comparison of historical sources.

The second specificity of the model is that it deals with urban space as a system composed of three functional (social use), spatial (location, extent and morphology) and temporal (date and chronology) dimensions meaning that the historical object is the Cartesian product of the Function, Space and Time sets (Fig. 1). This principle is consistent with the logic of the three Ws (What, Where, When) of Peuquet (1994: 447-451) which is often used (Egenhofer *et al.*, 1998; Lardon *et al.*,1999 ; Thériault *et al.*, 1999; Ott *et al.*, 2001).

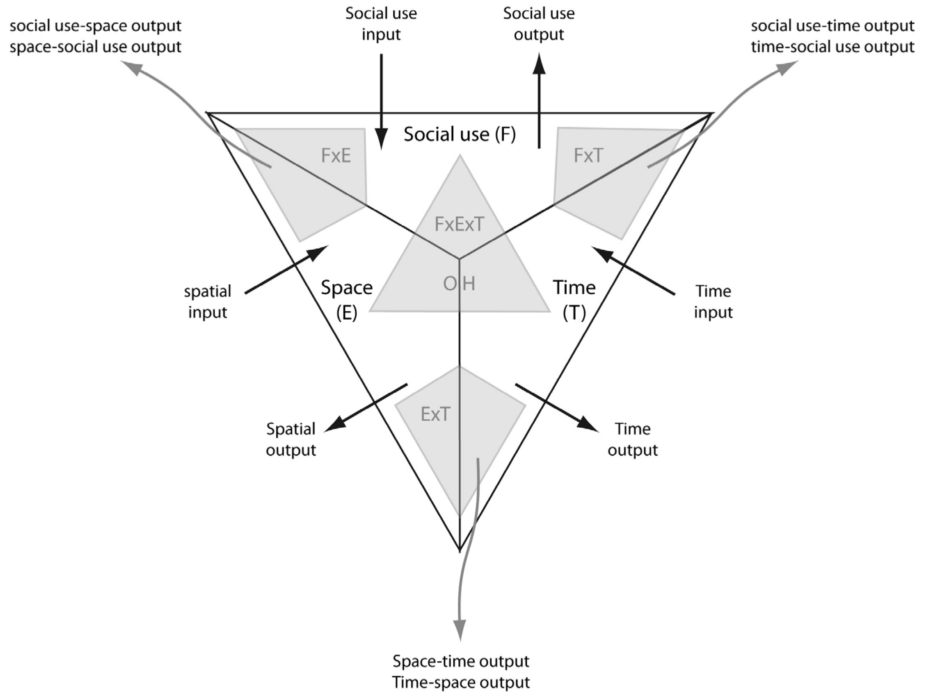

Figure 1: Conceptual model: historical model included in the three dimensions (Rodier and Saligny, 2010)

The combination of the three sets implies that each process is determined by the other two as explained by Donna Peuquet (1994: 448):

The triad framework permits the user to pose three basic kinds of questions:

(1) when + where -> what: Describe the objects or set of objects (what) that are present at a given location or set of locations (where) at a given time or set of times (when).

(2) when +what -> where: Describe the location or set of locations (where) occupied by a given object or set of objects (what) at a given at a given time or set of times (when).

(3) where + what -> when: Describe the times or set of times (when) that a given object or set of objects (what) occupied a given location or set of locations (where).

- The functional interpretation of a historical object is made by selecting a function from a thesaurus. The dating of the historical object (or rather its inclusion within a time-frame) and its location (or rather its inclusion within a space) directly influence this choice. Some items in the thesaurus are functions determined by a particular space (canonical cloister, burial area, etc.) and/or chronology (*domus*, parish churches).

- The location and shape of a historical object are determined by the function (necropolises, entertainment edifices) and chronology (necropolises, defensive systems). In addition, the subdivision of space into spatial entities is determined by the successive construction of historical objects depending on their temporal and functional definition (there is no prior matrix subdivision of the space under study).

- The dating of a historical object is characterised by its dates of appearance and disappearance. Even when the temporal continuity of a function is ensured, a change of place (movement) or a significant change of shape imply the transition from one historical object to another.

1.2 Social Use

Functions identifying a social use of space over a certain span of time. To be efficient for their study, functions must be selected from a thesaurus. It is essential to use a common thesaurus to standardise function interpretations so as to make comparison possible. We use the thesaurus drawn up and tested by the *Centre national d'archéologie urbaine* (CNAU) of the French Ministry of Culture which since 1990 has proved its worth for the processing of topographic data of pre-industrial cities.[1]

The function in the model is defined by the functional entity (EF) corresponding to a term from the thesaurus.

1.3 Space

The spatial modelling is based on the principle of non redundancy of entities. We postulate that space is continuous, bounded by the definition of a study zone and that in the absence of a spatial entity (ES) it contains voids, that is, unoccupied spaces. There can be only one spatial entity in any one place. Accordingly a historical object can be composed of one or more spatial entities and a spatial entity may serve one or more historical objects.

[1] http://www2.culture.gouv.fr/culture/cnau/fr/doc_3.html

1. Roads, development
11.thoroughfares, streets
12. unoccupied spaces
13. riverbank works
14. landscapes works
15. crossing points
16. water supply systems
17. sewers/ drains
18. monuments, vestiges
19. unspecified monuments
2. Defence and military structures
21. urban defence systems
22. fortified structures
23. garrisons, barrack buildings
3. Civil constructions
31. public spaces
32. civil authorities, justice
33. education, culture
34. health
35. entertainment, sports
36. baths, thermal baths
37. private homes
4. Religious buildings
41. pagan worship
42. Buildings for Catholic worship
43. convent or monastery buildings
44. ecclesiastical buildings
45. worship other than catholic
46. parish churches
5. Burial places
51. burial area
52. parish cemetery
53. special burial place
6. Trade, crafts, production places
61. trade, markets, shops
62.crafts, workshops
63. agriculture, livestock farms
64. manufacture, industrial premises
65. extraction, quarries
7. Natural formations
71. coast lines
72. rivers (alluvions)
73. marshes
74. colluvial events
8. Other
81. unspecified
82. no confirmed occupation
83. abandoned
9. Non-urban
91. complex settlement of a non-urban character
92. peripheral structure

Figure 2: Urban values (1 to 9) and use values (11 to 92) according to the CNAU thesaurus

We obtain the spatial entity by subdividing the space arising from the superimposition of archaeological observations that provide input for the model. The shape of the spatial entity has no functional or interpretative meaning; it results solely from spatial changes observed in a place.

Modelling therefore consists in deconstructing the information, even if this means countering the synthetic perception we have of a place (Fig. 3).

For example, in the illustration above, Observation 1 is composed by ES_0, ES_2 and ES_4.

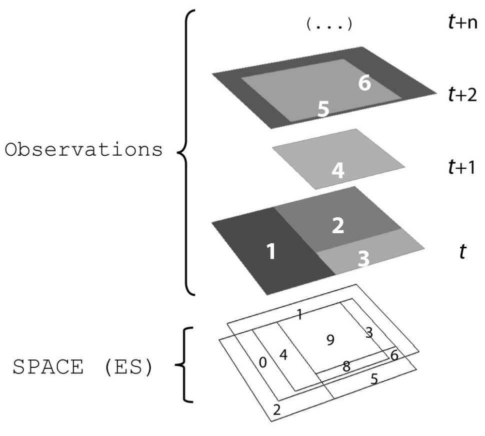

Figure 3: Example of calculation of ES resulting from the spatial subdivision of various Observations

2.4 Time

Time is modelled by analogy with space so that it is not confined to the role of an attribute. So that it can be mobilised and queried globally, it is necessary to define a temporal entity (ET) that is neutral and defined by the smallest unit of time that is meaningful in dating the phenomenon under study.

To this end, the modelling is based on the formalisation of topological relations among time intervals in artificial intelligence by J.F. Allen (Fig. 4: Allen 1984).

Relations between two entities (A and B) can be written as an equation. For example, the relation A *before* B respects the equation $A^+ < B^-$, where X^- is the start date and X^+ is the end date of the duration.[2] A duration (an interval) is strictly positive ($A^+ < A^-$). Equivalence can be found in the modelling of spatial topological relations.[3]

We eliminate all forms of intersection between two intervals so that our temporal entities have non-redundant relations only. All notions of duration (centuries, years, periods) can then be recomposed from the model. Like spatial entities, temporal entities are disconnected from the functional and spatial interpretation. The duration and number of temporal entities for a time period determine a frequency.

Time, like space, is continuous, bounded by the chronological boundaries of the study object. The temporal resolution selected for time entities determines the dating of historical objects. The creation of time entities depends on the prior definition of observations. There is no a priori subdivision of time. At any given time, there can be one and only one time entity but it may serve as many historical objects as necessary. It is the subdivision of time by the accumulation of historical objects and with time that defines time entities.

There are two types of time entity: dates and durations. For example, in Fig. 5, dates are: 150 (ET_1), 200 (ET_3), 250 (ET_5), 350 (ET_7) and durations: [150–200] (ET_2), [200–250] (ET_4), [250–350] (ET_6).

[2] By transitivity: $A^- < B^-$; $A^+ < B^+$ and $A^- < B^+$.
[3] Where the temporal *before* or *after* is equivalent to the spatial *disjoint*; *meets* or *met-by* is equivalent to *touches*; *overlaps* or *overlapped-by* is equivalent to *intersects*; *starts* or *ends* or *during* or *contains* or *finishes* or *finished-by* is equivalent to *contains*; *equals* is equivalent to *equals.*

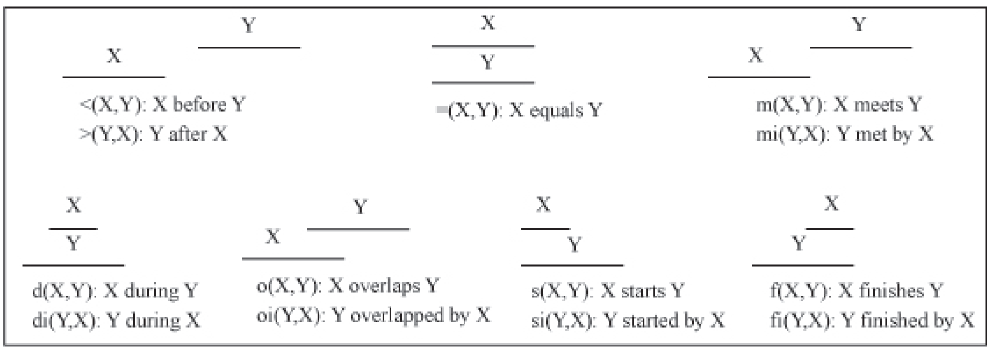

Figure 4: Allen's time relationships

After being applied to the study of the cities of Tours and Vendôme (Lefebvre, 2012; Rodier *et al.*, 2010; Simon, 2012) this model has proved effective in analysing urban change. But the exploratory works also showed that the constraints of data integration, structuring and manipulation imposed by the model were too stringent with the software available for it to be diffused and used in the archaeological community. This is why we undertook the design and development of ad hoc software.

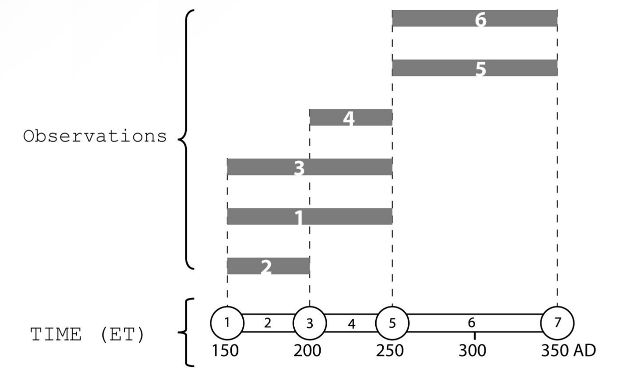

Figure 5: Example of calculation of ET resulting from the temporal subdivision of various Observations

2. OH_FET computer application

2.1 Principles and technical criteria for software development

Two fundamental principles have been applied. First, the development concerns only the processing and analysis implementations that are new or that could not be performed automatically with the tools available. This is why all aspects of the display, management and interrogation of semantic and spatial data is done on existing software. Second, the OH_FET application must be composed of independent modules that can be used separately.

Four modules have been developed (Fig. 6). The first is for integration (cf. section 2.2), the second for deconstructing data into the three dimensions (cf. section 2.3), the third is for storage in DBMS (cf. section 2.4) and the fourth handles analyses and graph production over the time dimension (cf. section 3).

The principle is that the user may integrate a set of vector data in the *shapefile* format together with a file describing the projection system (*SRID*) and a tabular file (*csv*) containing the values and levels of the hierarchical thesaurus. From these input files, the modules integrate rules to check the compatibility of the data sets and then rules for constructing the functional (EF), spatial (ES) and temporal (ET) entity classes and their relations. These are stored in a relational and spatial data base system. Lastly, the display module proposes to restore them in the form of graphs and diagrams and as output files in *shapefile* and *comma-separated values* from the processing of the data.

We opted to develop software independently of any platform because the archaeological community uses several GIS software packages and we chose to develop it in Python, which is a simple, expressive, multi-paradigm and multi-platform programming language widely used by the scientific community. Python offers a large range of libraries for passing from one application to another. For example, the Python module pyshp can read *shapefiles* as if they were simple lists (both for column names and series of values); the Python psycopg module can execute SQL queries on a spatial database (such as *Postgre/PostGIS* or *SpatiaLite*) from a Python script. Python is also used for programming into leading GIS applications: *QGIS* and more recently *ArcGIS*.

For the database, we chose *Postgre/PostGIS* and *SpatiaLite*. Both were selected because they are fully compatible with current GIS, they comply with international standards such as the WKT format[4] and OGC recommendations,[5] they have features for exporting/importing shapefiles (the common format of geographical data) and they can be interrogated with procedural language such as PL/SQL or PL/Python.

2.2 The graphical user interface and integration module

The software is installed from an executable file that launches a graphic interface designed to be as simple as

[4] *Well-Known Text* (WKT) is a text markup language (human readable) representation of geometry, spatial reference systems, spatial transformation, etc. It is also used by various Python geometric modules such as Shapely.

[5] *Open Geospatial Consortium* (OGC) is an international consortium that makes recommendations (formats WKT, WKB, WMS, etc.) to ensure interoperability of contents and services in geomatic and spatial information fields.

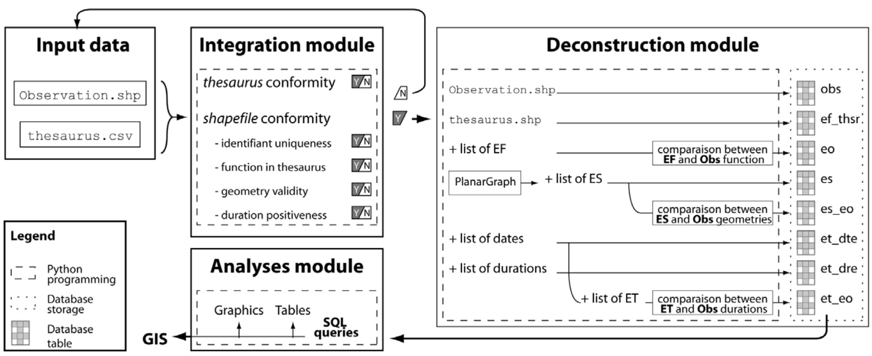

Figure 6: OH_FET application diagram

can be. It prompts the user to open a shapefile containing all the data of the urban space under study. These data are termed 'observations'. It is mandatory for these observations to have a function among the terms of the hierarchical thesaurus, plus a start and end date. Accordingly, the shapefile must have at least four fields that cannot be left blank: ID, Function, Start date, End date. Fields names are not important, although an explicit label is recommended. Besides these four mandatory fields, the shapefile may have any number of fields for 'attribute data'. The ID field must be a unique integer, the Function field a function value that must be referenced in the thesaurus, and the duration must be strictly positive (Start date < End date).

The user also uploads a thesaurus and may specify the projection system. The user also indicates the output folder where the results are to be stored. The results are created

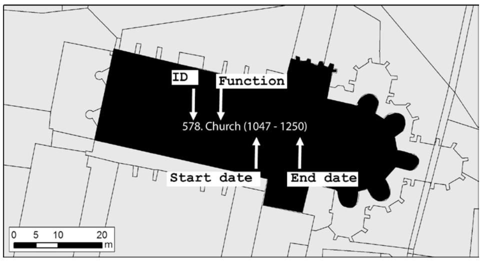

Figure 7: Example of an Observation with the mandatory fields

by default in a *SpatiaLite* data base and possibly also in *PostgreSQL/PostGIS* DBMS. The default base, *SpatiaLite*, is included in the executable file whereas *PostgreSQL/PostGIS* must be pre-installed locally or on a server with PostGis activated (Fig. 8).

The graphical user interface also proposes the types of graphical output the user may choose. These outputs are those executed in the display module. Currently, the executable file proposes just a single output, the chronograph for two types of object classes (functional entities and historical objects, cf. section 3).

The integration module is the interface between the user and the deconstruction module. Its purpose is to control the coherence of values and types of data when the user clicks the 'OK' button. For example, a procedure of the integration module will verify that all OH durations are strictly positive (Start date < End date, where Start date and End date are respectively the lower limit and the upper limit of a duration) (cf. Fig. 6).

2.3 Deconstruction module

The deconstruction module groups all processes starting from the data source and results in the recording in the spatial database. The result of on-the-fly deconstruction is the creation of four classes in the OH_FET data base: the Function class of functional entities (EF), the geometry of the spatial class with spatial entities (ES) and the time dimensions classes (ET), date and duration.

Deconstruction is performed with just one logical constraint (Fig. 9) which can be formulated: 'if A.duration crosses B.duration then A.location does not cross B.location'. The reciprocal is true: 'if A.duration does not cross B.duration then A.location may cross B.location'.

a. Social use, EF

The OH_FET model has been designed on the basis of the CNAU thesaurus but the application can import and use any thesaurus.

Figure 9: Logical constraint for Observation recording

The identifier of a functional entity is the concatenation of its path from the highest level of generalisation to its own definition. For example, the key of the EF 'unoccupied spaces' is '12' where '1' refers to 'Roads, development' (highest level of generalisation) and '2' is its own key. So, the identifier of the 'unoccupied spaces' function is eF_12.

b. Space, ES

As said, after the deconstruction operation, each Observation is divided into its most elementary part for either the geographical (Fig. 10) or the temporal dimension.

We can observe from the illustration below that Observation 578 is composed of two spatial entities: ES_3226 and

Figure 10: Space deconstruction (ES)

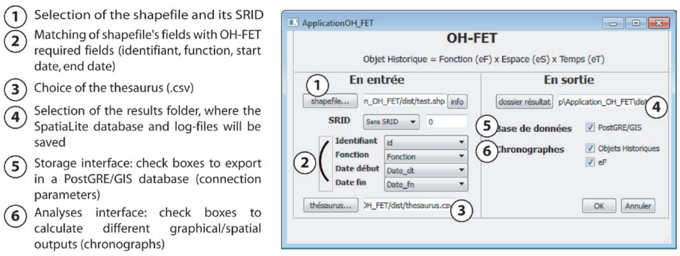

Figure 8: OH_FET graphical user interface

ES_3365. Relations between Observation and spatial entity are recorded in the database.

This first step is performed with the PlanarGraph Python module.[6] The PlanarGraph module can be used to obtain ES, the vertices and arcs of ES, but without recovering the initial attributes of observations. Attributes are recovered by spatial queries and stored in the data base to link a spatial entity and a historical object (cf. Fig. 6).

The initial data tested often exhibit problems with geometrical capture, seldom obeying strict topological rules. The polygons which should have common boundaries are not always properly captured. This results in overlapping of polygons.

If these data sets are processed directly, the deconstruction engenders far too many spatial entities and so skews the analyses. Several approaches have been contemplated to overcome this.

First, so as to work with existing data, two data cleaning protocols have been proposed (one under *Arcgis* based on topological coverage and the other on *QGIS* by using the topological properties of *GRASS GIS*). These two protocols are based on a system of tolerances, the parameters of which are to be defined. Unfortunately, this raises other problems. Specifying too low a threshold entails redundant spatial entities; specifying too high a threshold eliminates spatial entities that go to constitute historical objects.

We plan eventually to propose a good practice guide so as to avoid these errors at the time of data capture. After the subdivision, no geometric entities should overlap.

c. Time, ET

Deconstruction of time consists in coding the creations of temporal entities in a Python script so that the 4 out of 13 Allen's relations used here are validated (Fig. 11).

The duplicates are eliminated and the list is ordered from the most ancient to the most recent date. The process then consists in parsing this list and identifying whether a date lies between two durations or just touches one duration. In the latter case, the date is a *terminus*. Respecting predicates of the OH_FET model, the list of temporal entities is constructed (Fig. 11 and cf. Fig. 6).

The list of ETs starts/ends necessarily with this sequence:	[■],[■$^-$,■$^+$],[■]
A duration has necessarily two dates touching it	[■],[■$^-$,■$^+$],[■]
A date has, at least, one duration touching it	[■$^-$,■$^+$],[■] or [■],[■$^-$,■$^+$]
There cannot be two consecutive durations	~~[■$^-$,■$^+$],[■$^-$,■$^+$]~~
There cannot be three consecutive dates	~~[■],[■],[■]~~

Figure 11: Predicates for constructing the ET list

The following sequence of tests ('a' to 'g') can be used to calculate a variable for each ET/Observation. Initially the variable value is 0 (Fig. 12).

All tests, 'a' to 'g', are performed for each Observation and ET. After 'g', if the index >= 1 then the ET is recorded in the list of ETs. In other words, this ET is one component of the Observation duration.

All ETs composing an OH must necessarily follow each other without interruption (e.g.: …, ET_6, ET_7, Et_8,…)

Remember that temporal entities result from a topological deconstruction in the time dimension and there is no overlap between two durations. In other words, for a given duration there is no creation and no destruction of Observations.

2.4 Storage (spatial DB)

For storage, two kinds of spatial database have been chosen to export the result of the deconstruction process: *SpatiaLite* and *PostgreSQL* (with its spatial extension *PostGIS*). These two databases (DB) serve two different purposes. *SpatiaLite* is a simple, easily transportable DB file. *PostgreSQL/PostGIS* has been designed for DB administrators. It enables more complex management of data and supports multi-user access. Furthermore, *PostgreSQL/PostGIS* has a topological extension with topology whereas topology is not yet completely implemented in *SpatiaLite*.

Data are integrated within data bases by the conceptual model below (MERISE formalism) (Fig. 13). A table

[6] Developed by Pascal Leroux https://github.com/paleroux/PlanarGraph

	Relations between Obs durations and ET	Logical test	variable
a	eT *contains* Obs	Obs$^-$ >= eT$^-$ and Obs$^+$ <= eT$^+$	variable =variable +1
b	Obs *contains* eT	Obs$^-$ <= eT$^-$ and Obs$^+$ >= eT$^+$	variable =variable +1
c	Obs (older) *overlaps* eT	Obs$^-$ <= eT$^-$ and Obs$^+$ <= eT$^+$ and Obs$^+$ >= eT$^-$	variable =variable +1
d	eT (older) *overlaps* Obs	Obs$^-$ >= eT$^-$ and Obs$^+$ >= eT$^+$ and Obs$^-$ <= eT$^+$	variable =variable +1
e	Obs *meets* eT	Obs$^+$ = eT$^-$ and Obs$^-$ < eT$^+$	variable =0
f	eT *meets* Obs	Obs$^-$ = eT$^+$ and Obs$^+$ > eT$^-$	variable =0
g	eT *equals* Obs	Obs$^-$ = eT$^-$ and Obs$^+$ = eT$^+$	variable =variable +1

Figure 12: Sequence of tests to match Observations and ETs.

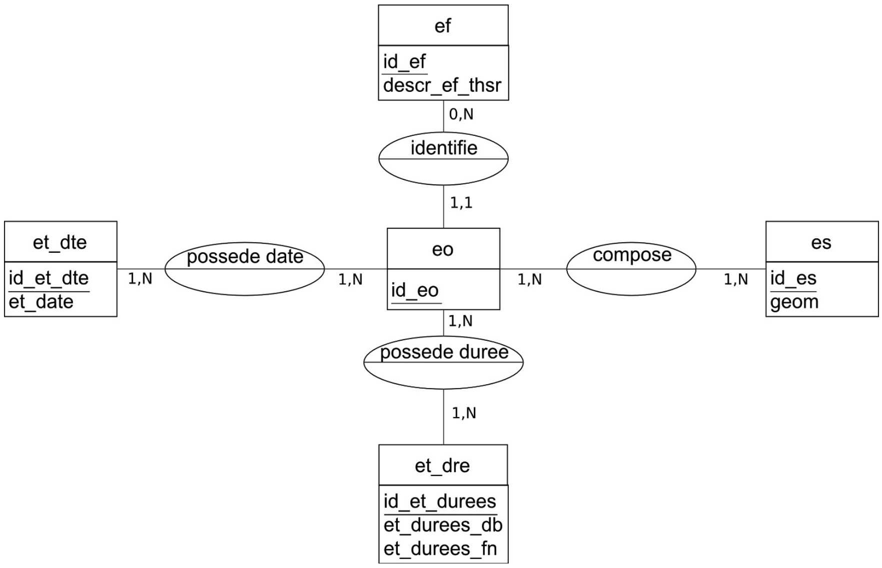

Figure 13: Data base conceptual model

stores the durations to improve performances, but they could be calcualted on-the-fly.

Physically, tables are created and then populated with the data from the deconstruction module.

The historical objects are the crossover of the ES, EF, ET_dte tables grouped by the identifier of the initial observations. To reconstruct the historical objects, we recover the function of the historical object, the 'lowest' date of the historical object as the date of appearance and the 'highest' date of the historical object as the date of disappearance. The geometry of the historical object may take on two forms, either by merging spatial entities into a simple geometry or by aggregating spatial entities into a multi-polygon.

3. Analysis modules

The principle of the OH_FET model is to provide output from which to observe on the one hand the distributions of function, space or time and on the other hand functiono-spatial or spatio-functional (F x E), functiono-temporal or temporo-functional (F x T), spatio-temporal or temporo-spatial (E x T) variabilities (See Fig. 1, section 1.1). The crossover of the three dimensions at the core of the model corresponds to the state of the historical objects at a given time. The aim of this approach (Rodier and Saligny, 2010; Lefebvre *et al.*, 2012) is to:

- restore all possible states, that is, all maps at all possible dates or intervals;
- analyse and observe all possible state changes by the difference between two states;
- understand transformations, that is, the state-change process by questioning the dimensions two-by-two in order to observe the factors affecting the change and to estimate the role or preponderance of one relative to the other.

The OH_FET model is designed to produce new elements of analysis for observing:

- the functional distributions (F): the number of times each functional entity is used to form historical objects;
- the spatial distribution or solicitation of space (E): the number of times each spatial entity is used to form historical objects;
- the temporal distribution or solicitation of time (T); the number of times each temporal entity is employed to form historical objects;
- the functional variability in space (FxE) based on the frequency of demand for functions by spatial entity and the number of different functions per spatial entity;
- the functional variability in time (FxT) based on demand for functions by temporal entity and the number of different functions per temporal entity;
- the spatial variability in time (ExT) based on the demand for temporal entity by spatial entity and the temporal variability in space (ExT) based on the demand for spatial entities per temporal entity.

Each result represents an aspect involved in understanding the whole by supplying various complementary information for comprehending the dynamics of the system.

3.1 Development

In order that the various modules can eventually be included in a single software package, the analysis module is also developed in Python language.

The analysis module connects to the data base created by the integration module from a Python, SQLAlchemy module.[7] This module can be used to connect to various types of DBMS and to query them with the same code. SQLAlchemy is an Object Relational Mapper and will allow us

[7] http://www.sqlalchemy.org/

to process all of the tables of the relational base as classes of computer objects. A Python (OH_FET) class is created with which to connect to the data base. As many methods are created as queries are needed for the analyses. The result is formatted to the corresponding output. We obtain either a graph (through the *matplotlib* module[8]) that can be safeguarded, or a csv file containing the data recovered which can then be used in GIS software to produce further analyses (cf. Fig. 6).

Only analyses bearing on the time dimension can be restored in graph form. The OH_FET application is currently oriented mainly to processing the time dimension so as to automate analyses and restorations that are difficult to implement in other software packages.

The DBMS structure can be used to recover the crude data required for the analyses implemented by Bastien Lefebvre in his thesis (Lefebvre, 2008). The analyses are currently in the form of Python scripts and shall soon be integrated in the OH_FET graphic interface so that users can produce them automatically, as is already the case for chronographs (cf. below).

3.2 Specimen analyses

The analyses proposed below are from data in a PhD thesis currently being written on the town of Vendôme (France) which was a castle-city that developed in the Middle Ages (1000 years occupation). Only one district of the town is studied, the abbey district (Simon, 2012).

a - The demand for time, the distribution of historical objects over time

It is a question on the one hand of the distribution of historical objects over time and on the other hand of the number of times each temporal entity is solicited by the formation of historical objects. This indicator can be used to evaluate source effects in part and to observe urban transformations (Lefebvre *et al.*, 2012).

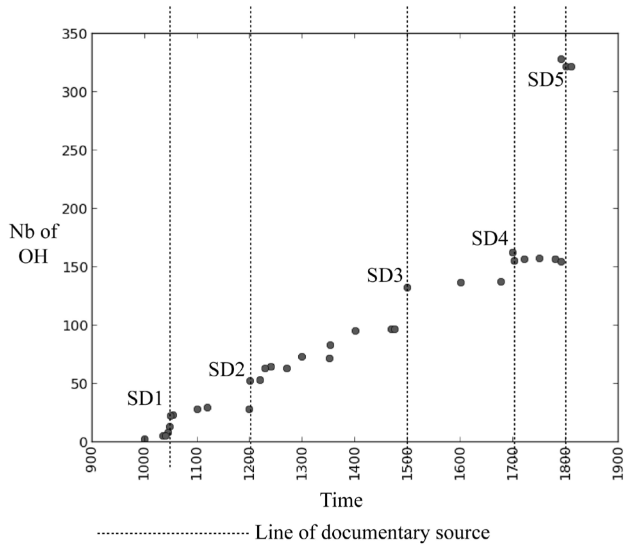

FIGURE 14: DISTRIBUTION OF OH OVER TIME

For the abbey district of Vendôme, the graph (Fig. 14) displays five documentary lines corresponding to the founding of the abbey in the mid 11th century (SD1), the increase in the number of medieval charters in the 13th century (SD2), the multiplication of texts and the improved conservation of the built environment between the end of the 15th and the 16th centuries (SD3), the Maurist plans and engravings at the very end of the 17th century (SD4) and lastly the old land registry in 1811 (SD5).

The OH_FET application proposes to supplement this indicator with a graph compiling the distribution of historical objects on a time line. This chronograph shows the number and duration of historical objects over time (Fig. 15).

[8] http://matplotlib.org/

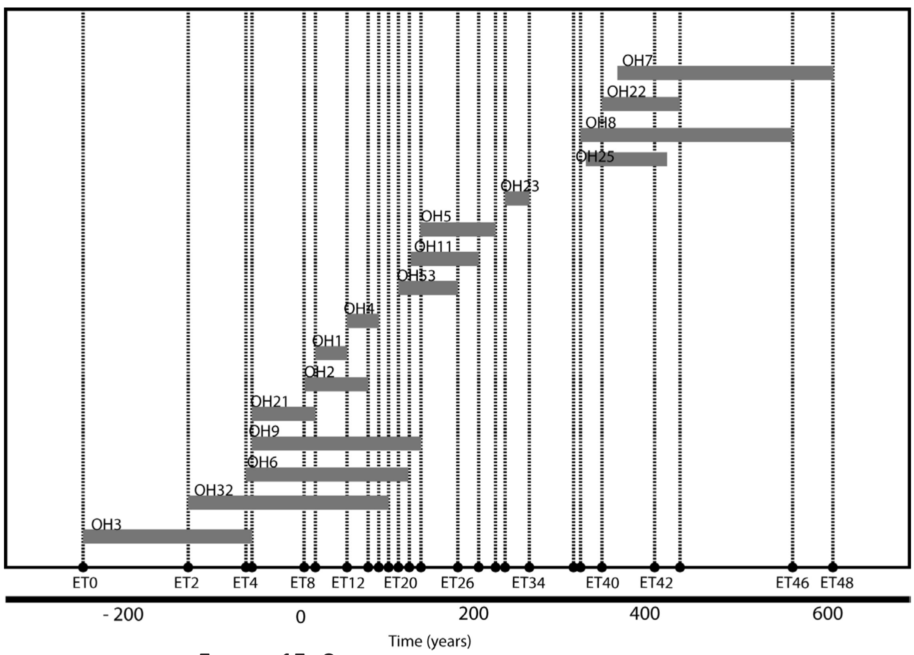

FIGURE 15: CHRONOGRAPH OF HISTORICAL OBJECTS

A query made of the class of temporal entities can identify the proportion of historical objects appearing and disappearing on the time line, highlighting the period of urban transformation and renewal but also the source effect (Fig. 16).

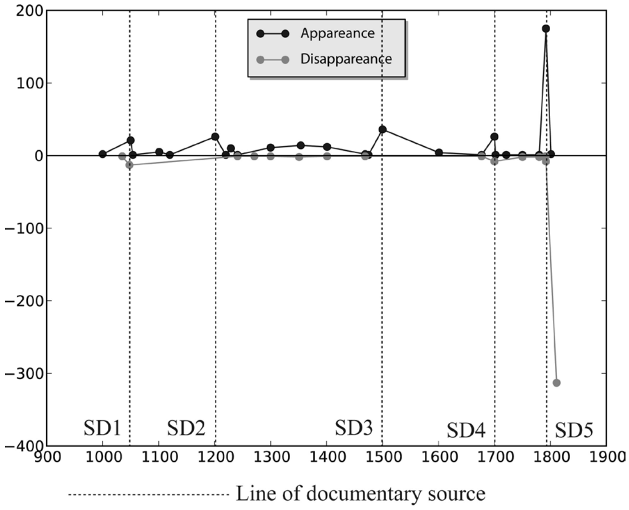

FIGURE 16: NUMBER OF HISTORICAL OBJECTS PER TEMPORAL ENTITY ACCORDING TO THEIR APPEARANCE AND DISAPPEARANCE

Again in the case of Vendôme, the appearance curve shows the five source effects observed before (Fig. 15) while the disappearance curve shows a strong propensity for historical objects to be conserved since on average never more than ten or so disappear at the same time and appearances greatly outnumber disappearances. The two peaks of disappearance around 1050 and 1700 nuance the effects of sources SD1 and SD 5 and reflect real transformations in the urban space.

b - The distribution of functions over time

We have implemented a series of representations based on combined queries of functional entities and temporal entities.

This time plot of function represents the times at which functions were present. It shows that some were permanent, others lasted for part of the total duration and other functions were discontinuous, appearing, disappearing then reappearing.

The plot below (Fig. 18) shows the percentage of functions present over time.

In this example for the town of Vendôme, the plot shows the variations in the functional fractionation of historical objects over time. This can only be interpreted by bearing in mind the substantial source effect. Two periods must be isolated in the documentation, the hinge point of which lies between the mid 14th century and the mid 15th century. The first period is characterised by sporadic documents which, by chance effect of the texts conserved of archaeological operations conducted, provide information about one or more historical objects but never over a long stretch. The second period is that of serial sources (land tax records and plans, land registry) which by nature provide information in one go about much or all of the space. These two stages of documentation are particularly apparent in this figure in which the general shape of the curves for dwellings, gardens and courtyards that must have made up most of the urban space surged during the 15th century because of the conservation of several land tax registers describing the town plot by plot. Although the appearances result mostly from the source effect, disappearances can be more readily interpreted. The number of defensive features declined markedly in the late 18th century as did the number of religious buildings, graveyards and water courses. These disappearances or marked reductions are the first signs of the transition from the pre-industrial to the industrial town under the influence, among other things, of concern for hygiene that sought to push the dead out of cities, to backfill open sewers that were sources of disease and to open up the city by tearing down the surrounding walls.

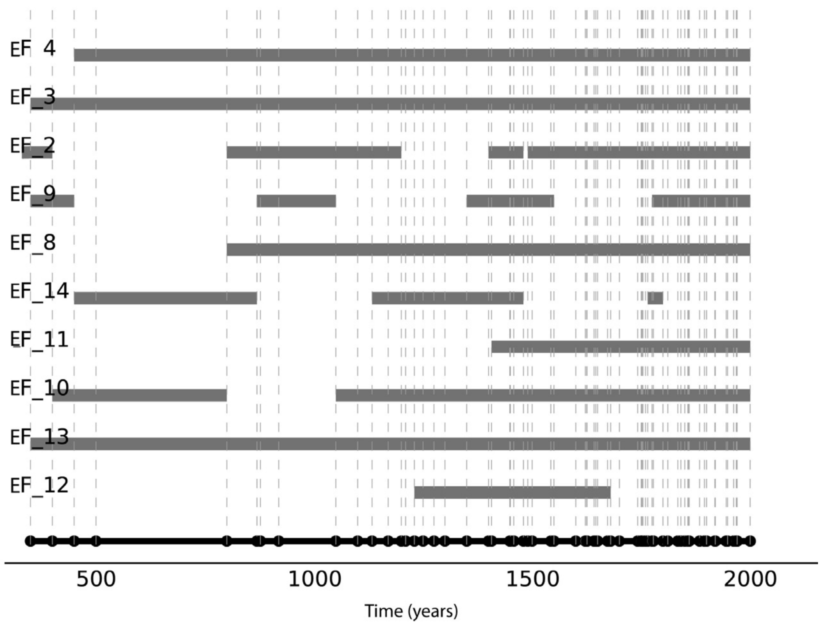

FIGURE 17: CHRONOGRAPH OF FUNCTIONS

c - The demand for space over time

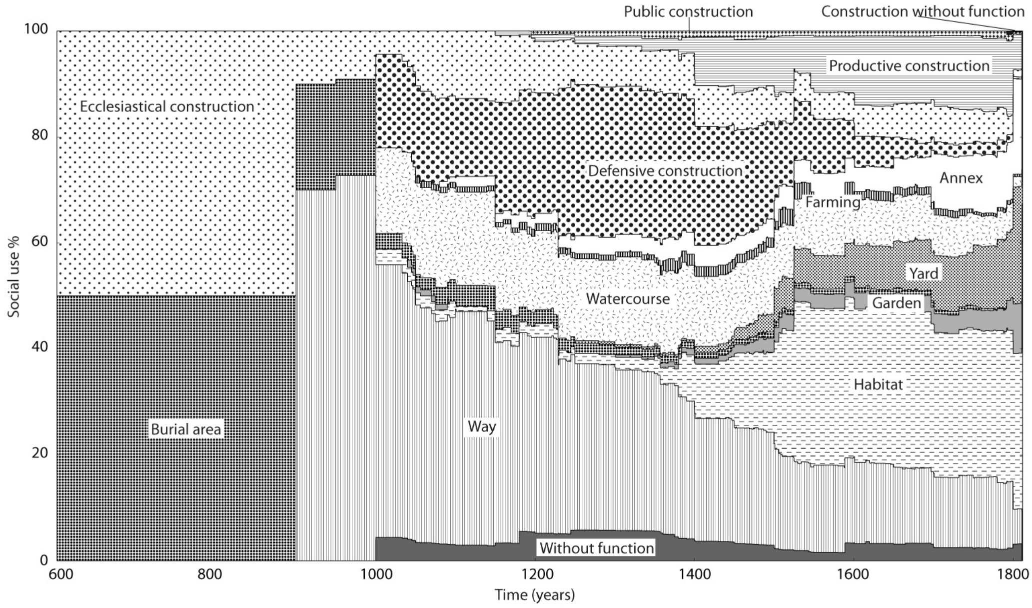

FIGURE 18: DISTRIBUTION OF FUNCTIONS OVER TIME

Figure 19 is a bar chart showing the number of spatial entities per temporal entity. It would be an indicator of spatial subdivision and its development over the course of time if it ware paired with the same plot showing not the number of spatial entities but their surface areas. This plot alone shows the steady increase in the number of spatial entities over time, except for two dips in the mid 11th and late 13th centuries, indicating a slight decline in the extent for which information is available for the space in question.

d- Temporal synthesis

The temporal synthesis proposed takes up the results of several plots and can be used to describe the architecture of time that B. Lefebvre referred to as a temporal 'map' (Lefebvre, 2008).

Fig. 20 Temporal map

The rhythm of appearances and disappearances is represented by a bar indicating for each event-type temporal entity the proportion of historical objects that appear, disappear or are maintained. Between two event-type temporal entities, the duration-type temporal entities are characterised by two items of information: the functional variation (the light values show a reduction in the ratio, the ratio is low when there are more historical objects than functional entities) and the number of historical objects during this phase (Fig. 20).

This plot for the Trinity Abbey district of Vendôme alone reveals several phenomena that can explain the urban fabric.

1. As few historical objects disappear over the whole of the study period, the focus is on appearances. The second half of the 11th century, the period when the abbey was founded, saw many creations at a sustained pace. The 13th century, although the apogee for the Trinity, appears to have been a period when constructions stagnated. Creations of historical objects accelerated from the 14th to the 16th centuries, although they were times of crisis. The 17th and 18th centuries, which are relatively well documented times, appear to have been a stable phase with few objects being created or transformed.
2. Although the state of knowledge greatly affects this representation, the functional diversification of space is very real over the long term.
3. This functional diversification seems to have ended in the 15th century, with later urban space retaining the same structure; even if buildings were regularly updated, their functions changed little. The Maurists who greatly transformed the abbey architecturally from the 17th century onwards did not change its function as indicated by the functional variability index which remains low in this period.

Conclusion

The development of the OH_FET application supplies the extension to the model that was missing. It renders accessible analytical tools for studying cities based on a set of input data complying with a loosely restrictive structure. It can be used for any urban space on the basis of a set of historical objects described by an item in a thesaurus, a geometry (area or point) and a chronology in the form of an appearance date and a disappearance date. On this basis, the application performs the spatial and temporal deconstructions recommended by the OH_FET model and produces the outputs, focused mainly on the time dimension in the form of documents to support interpretation of the data set.

Prospects for exploiting the OH_FET application are of several orders. First, the application can be used to multiply the number of study cases essential to test the model's robustness. In addition, comparison of examples will make it possible to envision the initial objective of the modelling of comparing urban trajectories. The aim is not to compare cities term for term but to identify types of transformation of the urban space over the long term and so trajectories.

Next, it is envisaged to use the application on different scales, that of the city, a district or an excavation. Exploratory tests (Lefebvre, Rodier and Saligny, 2012) have shown the model is relevant to all three scales. However, only the scale of the district or a portion of the urban space offering areal and continuous spatial information has been the subject of more advanced studies (Lefebvre, 2008, 2009 ; Simon, 2012). Other sites are currently being studied on this scale.

Lastly, the structure of the data base can be used to propose outputs from the model such as the lines of force of the plan as Bastien Lefebvre contemplated in his thesis, analysis of networks or graphs, and even dynamic representations, the heuristic representations of which are to be found in the various explorations of a data set.

Beyond these possibilities for the application, other avenues for further development lie open especially for managing hypotheses and taking account of uncertainty.

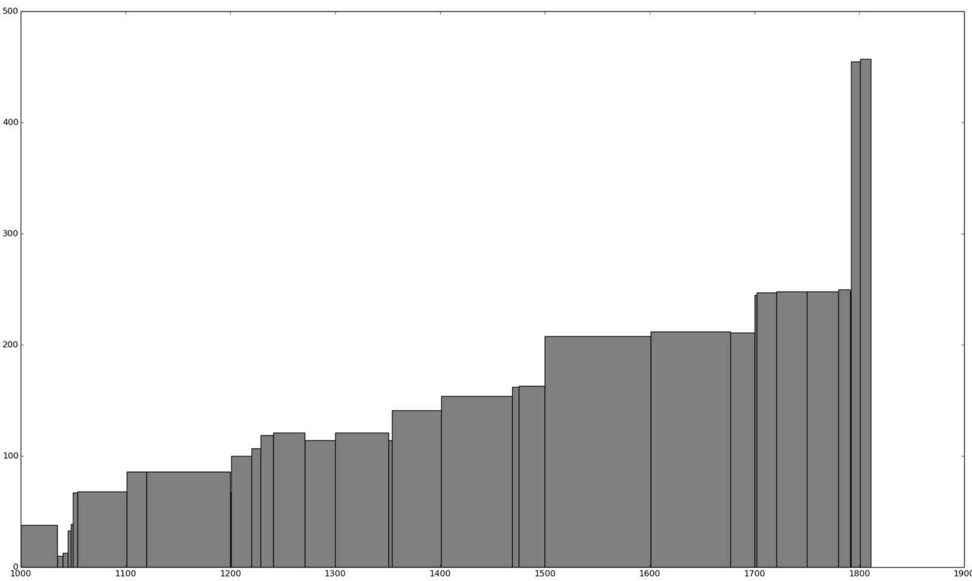

Figure 19: Use of space

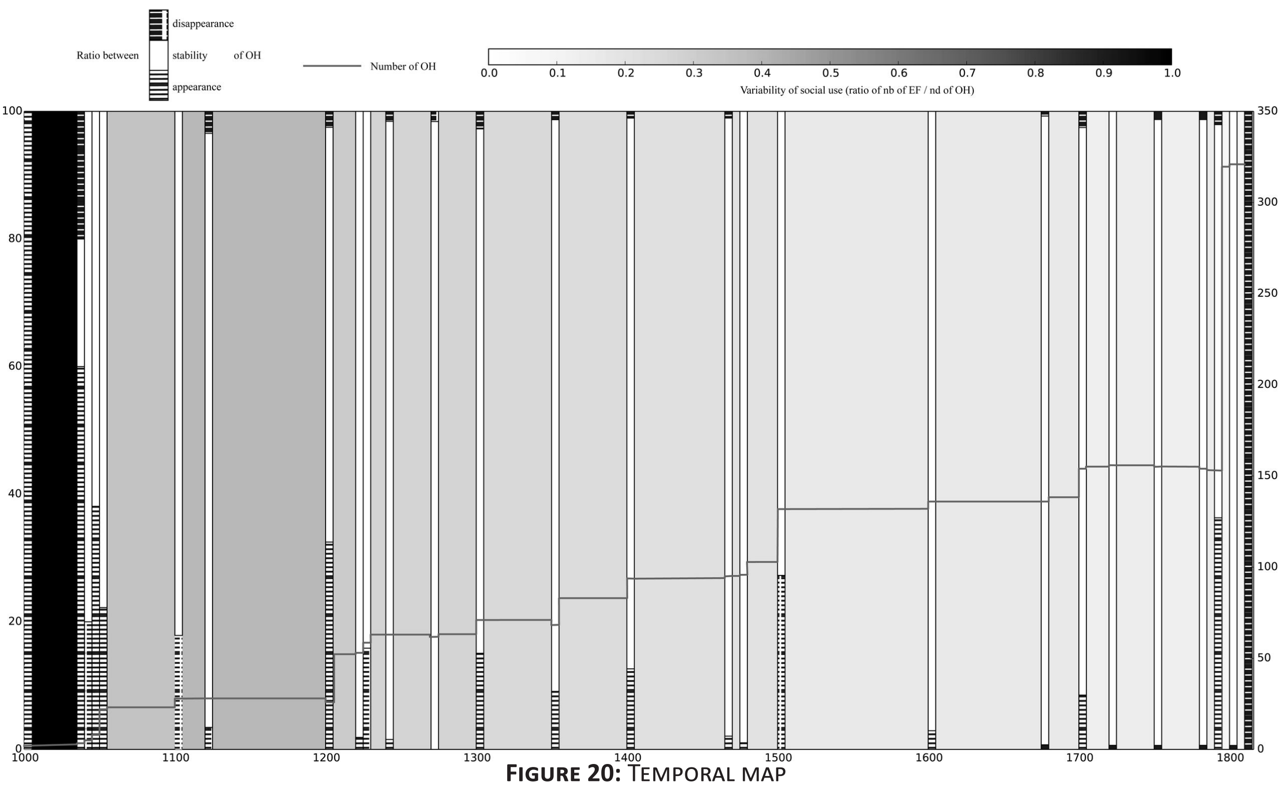

Figure 20: Temporal map

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