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### THE IMPACT OF URBAN TRANSFORMATIONS ON THE MORPHOLOGY OF STREETS NETWORKS.

A study on Paris between 1300 and 1871

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#### ABSTRACT

This research takes place in the field of quantitative analysis of historical streets networks. During the last decades, many studies have used network analysis or space syntax approach in a diachronic perspective, either to observe the interdependence between network configurations and land-use, or to explore the link between network configurations and known urban phenomena, such as densification, dispersal or expansion. These researches often focus on one single transformation rather than on the long time evolution of networks. In this work, we will explore the evolution of the street network of Paris, between 1300 and 1871, and link this evolution to all the transformations that occurred in the city during this period. The general question we are trying to address is **what is the impact of urban transformations on the form (the morphology) of streets networks?**

Our methodology is the following; we first describe the history of the city, by focusing on moments that have had an impact of the form of its street network. We then analyse this form, using graph theory, and compare it through time, so as to identify change and permanence. We finally face the evolution this form with the transformations in the city.

Our results revealed that the street network of Paris was subject to two kinds of interventions: spontaneous ones, which usually led to its expansion and densification, and planned ones, which led to its restructuration. We showed that the form of the network was thus differently impacted by these two kinds of processes.

#### KEYWORDS

Network Morphogenesis, Urban History, Graph Theory.

#### 1. INTRODUCTION

Roads are necessary to reach a human establishment and enable its development, but they are in turn deeply impacted by this *development*. For instance, the emergence of a market in a certain establishment may redraw the road network, since most roads will probably converge to it (Caniggia, 1994; Dicks, 1972; Douady, 2016). In the same vein, streets are, at a local level, strongly impacted by social, cultural, economical or political transformations. Indeed, many studies revealed the impact of transformations in a city on the *form* of its street network, namely the length of roads, their width, direction, position in relation to one another, etc.

These researches spread recently because of the increasing use of quantitative tools in social sciences. Indeed, architects, urban planners and geographers mix their knowledge about cities with quantitative analyses, with the aim of describing the evolution of networks' form in regard with various transformations in a city.

For instance, authors have tried to explore the link between transformations in land-use and the evolution of networks, either using modelling (Achibet, Balev, Dutot, & Olivier, 2014), or space syntax approach (Griffiths *et al.*, 2013; Psarra, Kickert, & Pluviano, 2013; Vaughan, Dhanani, & Griffiths, 2013).

Other authors focused on the impact of a particular transformation in the city— such as expansion (Strano, Nicosia, Latora, Porta, & Barthélemy, 2012), densification (Barthelemy, Bordin, Berestycki, & Gribaudo, 2013), or dispersal and spreading (Gudmundsson & Mohajeri, 2013)— on the form of the street network. For instance, Barthelemy and colleagues (*ibid*) revealed, using graph theory, that the densification of Paris between 1789 and 1836 led to an increase in the number of intersections and the length of streets. For their part, Strano and colleagues (*ibid*) revealed that the expansion of Groane (in Milan) between 1833 and 2007 provoked an expansion and reinforcement of pre-existing structures in the network.

Our work represents a continuation of the latter, since we use quantitative tools so as to identify **the impact of various transformations in a city on the form of its streets network**. We will take as case study the city of Paris, **compare its street network between 1300, 1652, 1790 and 1871, and put its evolution in relationship with the urban transformations** occurring during this period of time, so as to reveal their impact.

These four dates will allow us to explore the impact of many kinds of transformations. Indeed, Paris grows a lot between 1300 and 1871 (see figure 1), and passed through periods of "self-organisation" as well as periods of "top-down planning" (notably during the Haussmann period).



Figure 1 - The four graphs of Paris' street network. Top left: 1300; top right: 1652; bottom left: 1790; bottom right: 1871.

More generally, the results of this research will allow us to put forward hypotheses about the way a certain urban transformation impacts streets networks in general. Indeed, this will be a big step forward in answering the question: is the impact of a certain transformation – such as urban sprawl – on the network of Paris similar to its impact on other networks? If we compare our results to the ones obtained on other cities, will they be the same? Can we bring out generic conclusions about the way this or that urban transformation impacts streets networks in general? These questions will be addressed in further researches.

Our work requires many precautions. We first have to define precisely what urban transformations are we talking about. It is important to notice that urban transformations do not systematically have an impact on the network, partly because of the *resistance* of streets networks to “change” and their ability to adapt to various urban contexts.

Considering that, it would be more appropriate to focus on urban transformations that have actually had an impact on the street network. That is what Hanson did in her thesis (Hanson, 1989), since she explored the link between “morphological history” i.e. the evolution of the street plan (namely the form of the network), and “event history”, which refers to myriad localised interventions in the network, such as road widening or encroachments (Vaughan, 2015). Thus, when she studied the history of the city of London since the Roman period, she focused on “events” that have actually had a demonstrable effect on the network. She then put this “history of events” in relationship with the formal analysis of the street network (Vaughan, *ibid*), so as to explore the link between “morphological history” and “event history”.

Based on this approach, we will focus in the history of Paris **on moments that have actually provoked interventions on the street network of the city**. Besides, by focusing on interventions rather than transformations in general, we will be able to overcome the temporal lag between a transformation in the city (a new need, problem, ...) and its actual *effect* on the network.

Hanson’s work also helps us conceptualising our approach, since she treated separately the “morphological history” of the network and its “event history”. Caniggia and his colleagues (2000) help us going further in the definition of the “event history”, namely the history of “interventions” on the street network. According to them, the urban form – and thus the street network’s form, is subject to two kinds of interventions: the spontaneous (self-organised) ones and the planned ones. The former comes from little modifications made locally in the network, without “top-down” decision. These interventions are made according to the socio-economic forces and the urban practices of each context, so as to address punctual issues (carving out a road to build new houses, parcel out an agricultural land...). We can put in this category *unplanned* expansion and densification of the network.

For their part, planned interventions are usually more significant. They are decided by urban planners, public authorities, etc., usually to address a particular problem in the city, a new need, or to adapt the road network to a new context that transcends the city<sup>1</sup>. For instance, when a city sprawls, the centre becomes too far and urban planners may be asked to restructure the street network, so as to ease the traffic. Later, when a second centre emerges in the city, they may be asked again to carve out roads so as to connect the two centres. We can put in this category of interventions planning operations such as Haussmann’s one in Paris.

These two kinds of interventions have different paces; the spontaneous ones are almost continuous in time while the planned ones are rather punctual. It means that these interventions can be concurrent: while public authorities plan something in the network, spontaneous interventions are still occurring, in agreement or not with the planned one. Hence, planned interventions often speed, halt, reorient or reverse completely the spontaneous evolution of the road network.

In the light of the above, we decided to refine our general question: what is the impact of each one of these interventions on the street network? **Is it possible, based on the form of the street network, to distinguish moments of spontaneous interventions, and moments of planned ones? Put it another way, is the “morphological history” of the street network**

<sup>1</sup> Such as a War.

## of Paris different during moments of spontaneous interventions than during moments of planned ones?

To answer the questions above, we chose to treat separately the two kinds of “histories” mentioned by Hanson. Indeed, we will first focus (on section 2) on the “event history” of the street network of Paris between 1300 and 1871, and distinguish, in this history, moments of spontaneous interventions and moments of planned ones. After that, we will explore the “morphological history” of the network during this period (section 3). Thereafter, we will put these two histories in relationship, and try to put forward hypotheses about the impact of each intervention on the form of the street network (section 4). We will finally verify if each kind of intervention—the spontaneous and the planned ones—has had a specific impact on the street network of Paris.

## 2. THE “EVENT HISTORY” OF PARIS’ STREET NETWORK

Here we will try to highlight the urban transformations through which Paris passes during the four studied years, by focusing on the interventions made on its street network. The purpose is therefore to answer the question: what happened in the street network of Paris between 1300 and 1652, 1652 and 1790, 1790 and 1871?

Note that this “event history” of Paris’ street network is based on researches made by historians, archaeologists and architects (Bove, 2012, Gherdevich & Noizet, 2014; Huard, ND; Salat, 2011).

### 2.1 PARIS BETWEEN 1300 AND 1652:

In 1300, Paris was conserving some ancient parts such as the « *Cardo maximus* » of Gallo-Roman Lutetia (rue Saint-Martin to the north, rue Saint-Jacques to the south). More recent townhouses such as Les Halles (Huard, N.D) also existed at that time. These townhouses were composed of lots, organised either around impasses, or as a little city in the city. **Spontaneous urbanisation** was often taking place nearby these townhouses, all along the rural ways.

Thus, between 1300 and 1652, Paris was expanding, absorbing the Charles V’s enclosure and reaching the Louis XIII’s one at the end of the 16th century. During this period, ways—except the « *Cardo maximus* »—were mostly narrow and forming a maze.

### 2.2 PARIS BETWEEN 1652 AND 1790:

In the second part of the 17th century, Louis XIV decided the destruction of Paris’ enclosures, and the construction of the actual Grands Boulevards upon the Louis XIII’s enclosure.

Some planning rules also appeared in the late 17th century: new roads had to be large and as straight as possible. This said, except for the construction of the boulevards, no major urban project has been planned.

During this “no-wall” period, Paris passed through a classical process of centre-periphery expansion. Indeed, as mentioned in (Gherdevich & Noizet, 2014) the urban expansion of Paris before the 18th century followed a *suburbanisation* process: urbanisation took place on the access roads of the city, particularly in the left bank, but many areas remained empty between the new built up areas, creating a centre-periphery gradient. This urbanisation on rural ways was at the origin of the *faubourgs*.

Other townhouses appeared during this period, as well as many « ways of prestige » (Huard, *ibid*) at the entry of the city. Though, these ways were not a generator of urbanisation.

During the 18th century, only **few operations of access and circulation’s improvement** were planned. The intervention of the royal or municipal authority mostly consists in alignment or straightening of rural ways, and in fixing limits to the expansion of the city. This led to an urbanism of *accumulation*, with no planned urban project. Thus, the maze of narrow streets remained unchanged, as well as the plots.

Between 1784 and 1791, a new wall is constructed, the Wall of General Farmers, so as to establish a new tax territory in the city. The end of the 18th century also corresponds to the beginning of the French Revolution.

### 2.3 PARIS BETWEEN 1790 AND 1871:

After the Revolution, the clergy and aristocracy wealth were nationalised. Many buildings belonging to local and central government took on new functions (museum, schools, etc.). Other ones were demolished, freeing up land for new buildings and roads.

With the disappearance of the king and the urban hierarchy, urban planning was transformed. The *Artistic Commission* put forward refurbishment plans for the city, with majestic avenues linking the various squares and monuments.

Besides, at the beginning of the 19th century, laws about properties' expropriation for *Public utility* were established (Huard, *ibid*). The aim of these laws was partly to wind up the urbanism of accumulation occurring so far. However, the pressure of demography was still squeezing, agricultural areas grew in value, and densification increased in new townhouses. At the same time, major infrastructures shaped the city such as the eastern railway (1840), and the Thiers' enclosure (1844).

The Second Empire (1851, 1870), namely the *Hausmann period*, witnessed an important modification of Paris' street network, with the creation of 175 km of new streets, representing one fifth of the total network of 845 km in 1869<sup>2</sup>. Note that these new streets were superimposed on the former network, since no major expansion of the city has been planned during this period. This said, according to Salat (2011), this network deeply transformed the shape of the city while providing continuity to the existing roadway system. Indeed, the North-South and East-West crossroad was supplemented by a second network of concentric roadways, built using the remains of earlier road networks such as the actual *Grands Boulevards* and the Wall of General Farmers. On the left bank, the very irregular network along this Wall was straightened, reinforcing the concentric system.

Thereafter, we will analyse what happened in the **form** of the street network during each one of these interventions.

## 3. THE "MORPHOLOGICAL HISTORY"

Here we will first describe the datasets used to explore the "morphological history" of Paris' street network. Then we will present the method used to analyse them and finally the results of this analysis.

### 3.1 DATASETS:

Note that the choice of Paris as case study was due to the abundance of digitalised old maps of this city.

Our analysis was based on two main datasets. The first stem from the research programme ALPAGE<sup>3</sup>, which purpose was to create a GIS platform containing data about the pre-industrial Parisian space. This platform contains the 1300 street network we used for the analysis, as well as a GIS file of the 1652's blocks, which has been exploited as a background to digitalise the street network of this year.

The second dataset is the GeoHistoricalData platform<sup>4</sup>, a collaborative platform of digitalisation of historical maps. This platform contains the 1790 and 1871 street networks exploited in the analysis.

<sup>2</sup> Source: Exposition "Paris Haussmann" in the Pavillon de l'Arsenal, Paris, 31 January- 7 May 2017.

<sup>3</sup> URL: <http://alpage.huma-num.fr/fr/>

<sup>4</sup> URL : <https://www.geohistoricaldata.org>

Being based on the same process of construction, namely the georeferencing and the manual digitalisation of old maps, then the data conflation and the use of matching tools; the two datasets were mainly matching.

Furthermore, except for the 1300's network, the chosen maps are known to be reliable: the 1652's map is the first geometric map of Paris (Gherdevich and Noizet, *ibid*), and the reliability of the 1790 and 1871's maps was at the centre of many works (Dumenieu, 2015).

### 3.2 METHODS:

Based on previous researches, we chose to use network analysis so as to describe the form of the network of each date. It basically consists of turning the road network into a graph, i.e. a set of nodes linked by edges.

In the work presented here, a new geographical object, developed in (Lagesse, 2015), is used. This geographical object is named the *way*. It is built according to the angle between each couple of edges of the road network graph. The process considers iteratively each node, coupling the edges according to their deviation angle (cf. figure 2). Doing so, the two edges with the minimal angle of deviation will be paired and removed from the comparison. The remaining edges are considered in the next iteration. This association is made with respect of a threshold angle fixed at 60°: if the angle of deviation is superior to 60°, the edges will remain single.

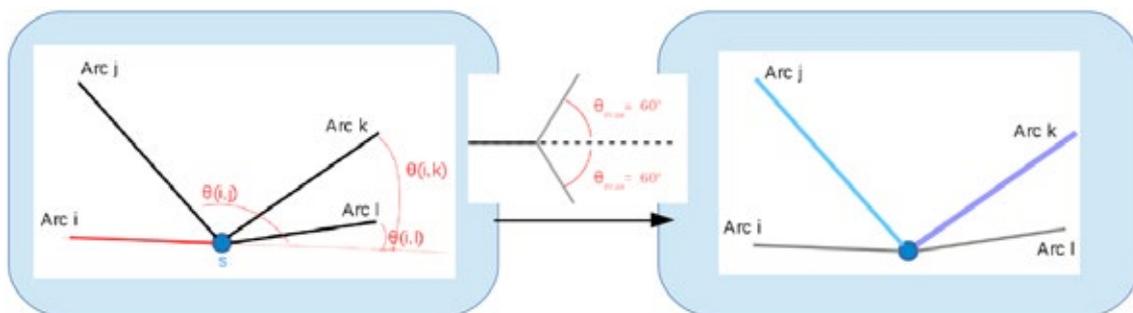


Figure 2 - Pairing process. In this configuration, arc (or edge) i and arc l are paired, arc j and arc k remain a single as they draw a deviation of more than 60°.

Once these pairing made, ways can be built using the examination of the list of paired edges. The resulting geographical object is multiscale: it can be equivalent to one edge or be composed of a large amount of edges, and cross the whole network. This construction is independent from the way the network is read. Its parametrisation has been extensively studied by (Lagesse, Bordin, & Douady, 2015).

The way is an association of continuous and aligned edges. It can be compared to the axial map defined by Hillier (1984), except that the axes are not straight and have the actual geometry of the road network. Following space syntax work, it is so possible to draw the *dual graph* of the primal road network graph. In this graph, a way will be a node and an intersection between ways will become the edges.

This dual graph will complete the primal one to elaborate indicators, based on topological and geometrical properties of the network. Classical indicators of graph theory as well as new ones, and their combination has been studied in a systematic way by Lagesse (2015). This Ph. D. thesis shows that it is not possible to elaborate an infinity of indicators to characterize a spatial network, some of them rapidly becoming redundant. It proposes a *grammar* of spatial characterization, for edges as well as for ways, based on the study of road networks of four cities, morphologically very different: Paris, Avignon, Manhattan and Barcelona.

This paper will focus on four particular indicators. Three of them are local (computed with the properties of the way itself and of its direct neighborhood):

- the degree: given by the number of other ways intersected by a way.
- the linear density: given by the relation between the length of a way and its number of connections (other ways' edges intersected). A high linear density means that the number of connection is high while the length of the way is low.
- the orthogonality: given by the sum of the sinus of the intersected edges, divided by its number of connections. This indicator has been introduced by Lagesse (2015) and characterizes the geometrical inclusion of a way in the city road network. A high orthogonality means that ways are intersecting orthogonally.

One of the indicators considered here is global (computed using all the network):

- the closeness : given by the relation of the number of ways and the sum of topological distances from the considered way towards the whole network.

These four indicators are not redundant and bring very specific information on the spatial graph. Furthermore, they are robust to border effect and to small changes into the network geometry (Lagesse, 2015b). The information they highlight is thus independent of the chosen borders and to the small imprecisions linked to old maps digitalisation.

Once the indicators computed<sup>5</sup>, our primary focus is to **analyse their statistical distribution**. Indeed, we consider the distribution of these indicators as good proxies to describe precisely the form of each network. Furthermore, this focus on the statistical distribution of indicators enables us to convert a "way level" measure (e.g. the degree of a way) into a "city level" one (the distribution of degrees in the whole city, its deviation comparing to a certain statistical law, etc.). This distribution is then compared from a period to another so as to identify change and permanence.

After that, we summarize, for each time frame, the evolution of the different indicators. We thus obtain a very accurate description of how the form of the network evolves during each time frame, and more generally throughout the 4 studied years. By doing so we will have revealed the "morphological history" of the network.

### 3.3 RESULTS:

The statistical distribution of the 4 indicators has been analysed following the same process: we first discretised it into classes, by choosing, for each indicator, bounds that suit each one of the studied years. This enables us to build the 4 years' graphs with the same key, which is essential to make them comparable.

We systematically used the « nested averages » method so as to discretise each indicator, and each period. This method consists in using the average of the indicator (called  $m_2$ ), in 1300 for instance, so as to cut the distribution into two pieces. We then compute the average of each one of these pieces, to obtain  $m_1$  and  $m_3$ .

We do the same thing with the other years. After that, we compute  $M_1$ ,  $M_2$ ,  $M_3$ , which are respectively the averages of  $m_1$ ,  $m_2$  and  $m_3$  of the four years. We finally discretise all the distributions following the same bounds: 0- $M_1$  ;  $M_1$ - $M_2$  ;  $M_2$ - $M_3$  ;  $M_3$ -max.

#### 3.3.1 LINEAR DENSITY:

The linear density distribution has been discretised into 4 classes. In 1300, most ways have a linear density in the two classes around the average. In 1652 in contrast, most ways have a very low linear density (between 0 and  $M_1$ ) and this phenomenon is strengthening in 1790, before slightly decreasing in 1871 (see figure 3).

<sup>5</sup> Using a GIS Plugin named ©MORPHEO (Lagesse, 2015).

This distribution reminds us an inverse power law: huge number of low values, medium number of mean values, and small number of high values. Indeed, when we try to approximate this distribution with an inverse power law, the deviation indicator passes from 0,06 in 1300 to 0,002 in 1790, before increasing to 0,02 in 1871. This result may indicate that the linear density is converging, at least between 1300 and 1790, to an inverse power law distribution, which means that ways are getting longer and *proportionally* less connected.

Inverse power laws are typical of very hierarchized (unequal) structures: values are concentrated in one extreme, quite far from the average. Such structures have already been revealed in various traditional urban fabrics. For instance, Salat (*ibid*) demonstrated that the distribution of streets' width, in historical cities, follows an inverse power law, with a big number of very narrow streets, and only few large avenues and boulevards.

A different phenomenon is occurring between 1790 and 1871. We will explore it in section 3.4.

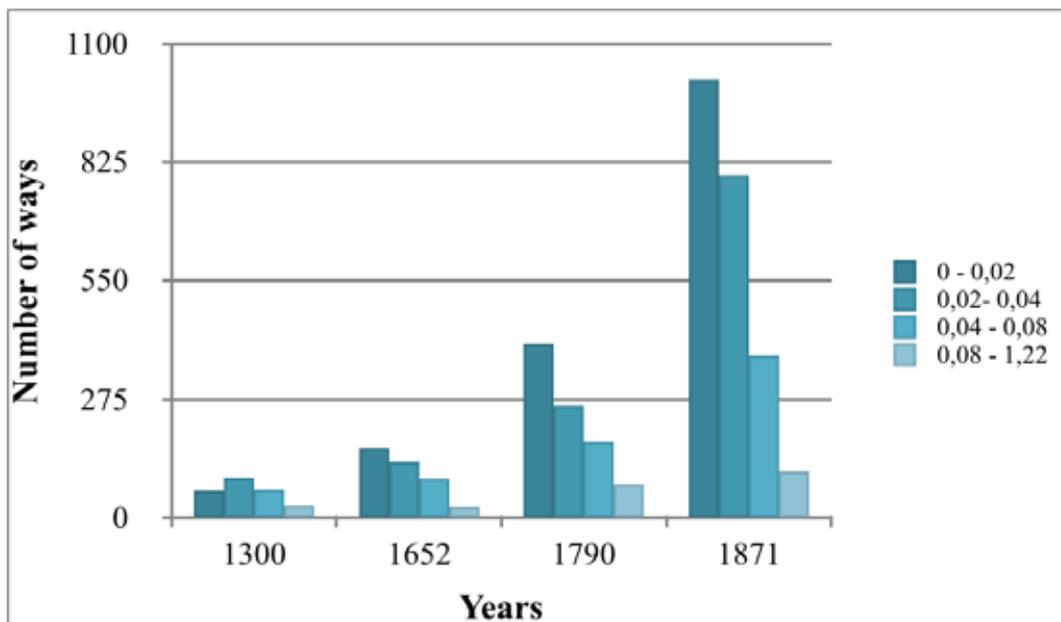


Figure 3 - Distribution of the linear density discretised in four classes (nested averages). The average (M<sub>2</sub>) upon which the discretisation was based is 0,04.

The distribution of the degree in 1300 is also close to an inverse power law, due to the big number of ways with a degree of 2 (figure 5). This is increasing with time, since the deviation indicator passed from 0,02 in 1300 to 0,0001 in 1871. This result means that the distribution of the degree is being more and more unequal and that new ways are less connected (they mostly have a low degree).

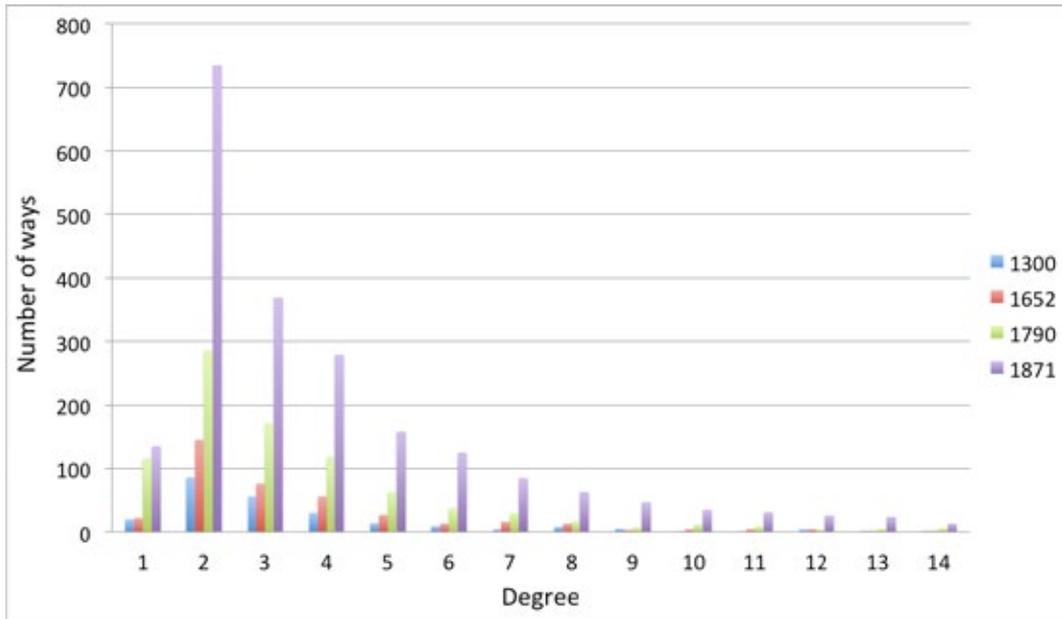


Figure 4 - Distribution of the degrees without discretisation. We can observe the huge number of ways with degree 2, in the four years.

To make the figure clearer, we only represented the degrees from 1 to 14 (actually the maximum degree in 1871 is 116, against 40 in 1300).

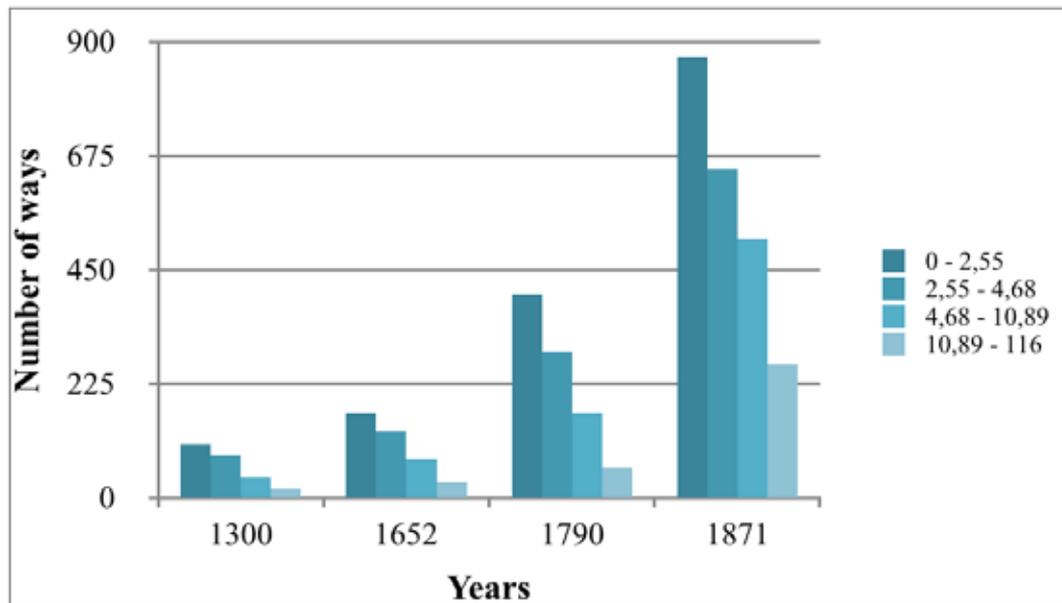


Figure 5 - Distribution of the degree discretised in four classes (nested averages). The average (M2) upon which the discretisation was based is 4,68.

### 3.3.3. ORTHOGONALITY:

In 1300, most ways have a very high orthogonality, and only a few have a low one. The distribution changes in 1652 with a slight catch up of ways with average and low orthogonality. In 1790, the orthogonality is once again quite high, before changing radically in 1871, with a very equal distribution of the orthogonality, and no over-represented class. The tendency is thus towards variable kinds of orientations.

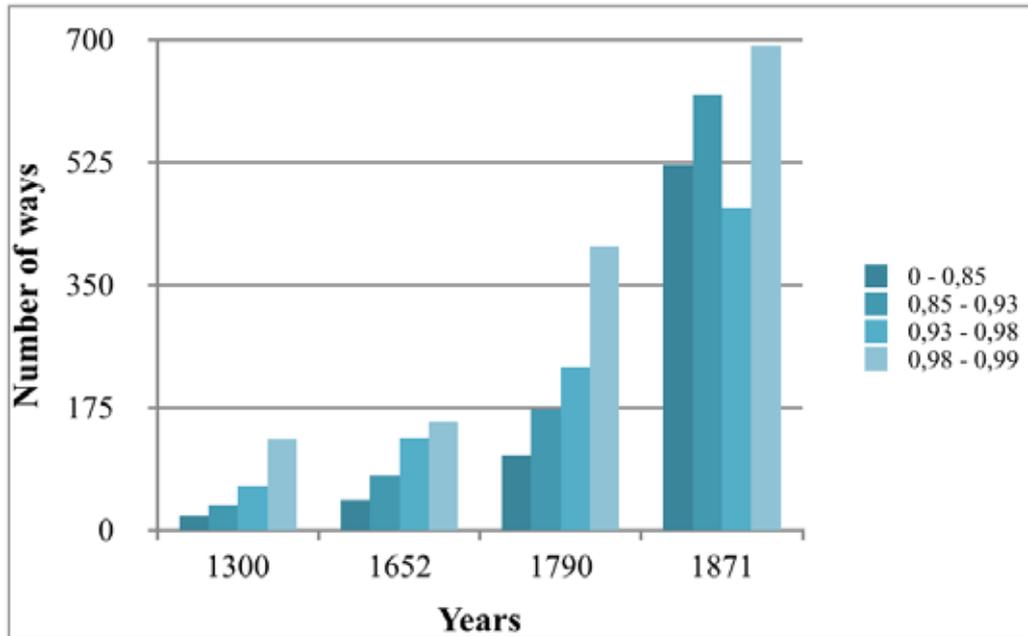


Figure 6 - Distribution of the orthogonality discretised in four classes (nested averages). The average (M<sub>2</sub>) upon which the discretisation was based is 0,93.

### 3.3.4. CLOSENESS CENTRALITY :

Being a global indicator, the closeness is strongly influenced by the size of the network. We therefore chose to weight it with the Napierian logarithm of the number of ways, at each period.

In 1300, the closeness seems pretty equal, but most ways are in the two classes under the average. This starts changing in 1652 and 1790, with an increase of the part of ways above the average. In 1871, the distribution has radically changed, with a predominance of medium and high closeness' ways.

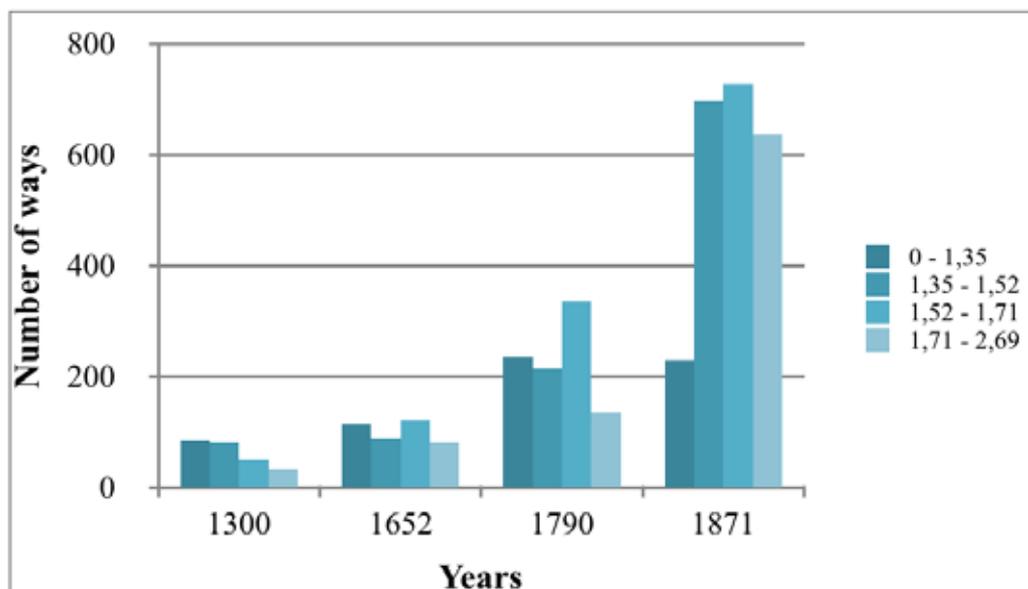


Figure 7 - Distribution of the "closeness x log (number of ways)", discretised in four classes (nested averages). The average (M<sub>2</sub>) upon which the discretisation was based is 1,52.

### 3.4 WHAT THE RESULTS MEAN:

In what follows, we will summarize, for each time frame, the evolution of the different indicators so as to describe the evolution of the network's form.

Between 1300 and 1652, the linear density and the degree are proportionally getting lower (closer to an inverse power law). This can be due to two phenomena: either ways are getting longer, or they are getting less connected, or both. Anyhow, it seems that the tendency in Paris is not towards adding intersections on short ways (which would increase the linear density), but rather absorbing longer and/or low connected ways. If we face this "morphological history" with the "event history" of Paris between 1300 and 1652, we can assume that this decrease in the linear density is due to the absorption by the city of rural sparsely populated (and thus low connected) ways during this period.

For its part, the orthogonality became more variable during this period, which means that various orientations appeared. This can be partly explained by the absorption of Charles V's enclosure, and thus the appearance of non-orthogonal ways.

Lastly, a lot of ways got topologically closer during this period (cf. closeness). We can assume that this is due to the combination of longer and variably oriented ways described before.

Between 1652 and 1790, the "morphological history" of the network is mostly the same. Ways are getting longer and proportionally less connected, probably due to the suburbanisation process on the rural roads. We can however notice that the orthogonality and the closeness are highly increasing during this period. Indeed, many ways are getting more orthogonal and topologically closer. We will explore this aspect in the next section.

Between 1790 and 1871, the degree is once more getting closer to an inverse power law, but it is not the case of the linear density. Indeed, the number of ways with a "medium" linear density is increasing, and the global distribution is further from the inverse power law. It means that ways are either getting a little shorter, or a little more connected, or both. This can be the sign that the expansion process occurring so far in Paris was partly replaced by a **densification** process. If we face this result with the "event history" of the city, we can assume that it was the impact of the pressure of demography and the densification of new townhouses in the first part of the 19th century. Furthermore, the Haussmann's plan provoked a high increase in the number of streets (175 km of new streets) *inside* of the Thiers' enclosure.

For its part, the orthogonality became much more variable, probably because of the concentric system of roads (made up of the *Grands Boulevards* and the former wall of General Farmers), and the refurbishment plans that aimed to link the various squares and monuments of the city. For its part, the increase in high closeness' ways was probably due to the concentric system, as well as to densification of the network.

## 4. DISCUSSION

By facing the "morphological" and the "event" histories of Paris' street network, we can identify two main processes: an expansion of the network between 1300 and 1790 (suburbanisation, ...), and a densification between 1790 and 1871.

The expansion process consists of carving out streets on the access roads to the city. The streets length thus increases, and (or) low connected roads are included in the city. This was highlighted by the decrease of the linear density. Furthermore, our results revealed that these moments of expansion correspond to a high orthogonality of the network. It means that the streets carved out during the expansion of the network are usually orthogonal. Concerning the closeness, it is usually in the average during these moments of expansion.

The second process is the densification of Paris, which occurred mostly between 1790 and 1871. Indeed, during this period, Paris did not expand much, but the density of its network highly increased. This was highlighted by the slight increase of its linear density.

On introduction, we considered the expansion and densification processes as *spontaneous* interventions as long as they are *unplanned*. The “event history” of Paris’ street network confirms that these two processes were mostly unplanned.

This said, Paris’ street network also passed through moments of planned interventions, mostly between 1790 and 1871. Indeed, the refurbishment plans of the Artistic Commission, then the Haussmann intervention clearly aimed at restructuring the street network, the former to link the various squares and monuments, and the latter to provide continuity to the existing network. It thus appears that the unprecedented densification of Paris between 1790 and 1871, as well as other factors such as the introduction of railways stations and, more globally, the Industrial Revolution, led to a pressing need for restructuring the network of Paris, and easing the circulation in the city. This was highlighted by the indicator of orthogonality, since ways of access’ improvement are usually carved out non-orthogonally, so as to link two particular area of the city. As expected, these new ways led to an unprecedented increase of the closeness.

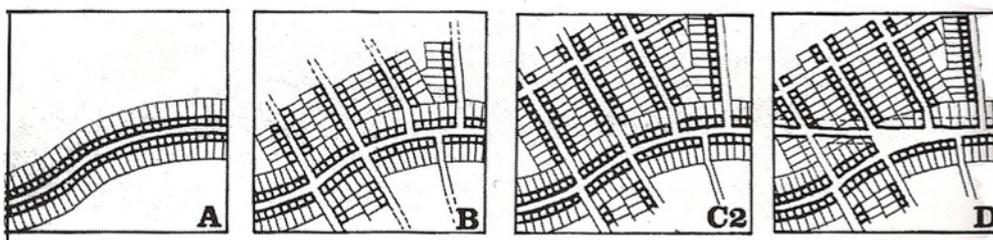


Figure 8 - Sketches showing processes of expansion (A, B, C2) and restructuring (D). (Caniggia, G., Maffei, G. L., & Larochelle, P. (2000).

From the above, it seems that our four indicators were able to highlight different kinds of interventions. While the analysis of the linear density allowed us to distinguish expansion and densification processes, the analysis of the orthogonality and, to a lesser extent, the closeness, revealed more punctual and planned interventions. We can therefore conclude that the spontaneous interventions on street networks lead either to a decrease (when expansion) or to an increase (when densification) of its linear density. We can furthermore conclude that planned interventions do not radically change the linear density of the network – since a global tendency is emerging in our results. However, planned interventions usually have a higher impact on the orthogonality, by introducing various directions in the network, and on the closeness, by improving accessibility (see figure 8).

Of course, these are only hypotheses, based on the analysis of the city of Paris. The next stage would be to test these assumptions on other cities. Furthermore, the analysis of smaller times frames would probably gives further results, since it may allow to better distinguishing moments of spontaneous interventions, moments of planned ones, and to explore the impact of each one of them of the network’s form. This will be the aim of further researches.

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