FROM STREET NETWORK ANALYSIS TO URBAN HISTORY

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The evolution of cities can be studied in different ways. While some researches look for exogeneous reasons (social, economic, cultural, physical...) which could explain the growth or decline of cities, others focuses on endogeneous laws which constraints such phenomenons. Morphology takes place in this second category. It suggests that a theory of urban form's evolution should rely on *models* which simplify reality, in order to focus on a single aspect: the form itself. Furthermore, the modelling that I propose focuses on a single component of urban form: the street network. The purpose of this paper is to show how the analysis of the street network's evolution will bring insights about the city's formative process.
Some authors have insisted on the necessity of perceiving this process as an *action-retroaction mechanism*: on the one hand, local modifications that occur in the street network have an impact on its global properties (in terms of centrality e.g.); on the other hand, the global network yields a conditioning on its elements' substitution, which provokes, at least during a period of time, the stability of its global properties.
To expose those stability and change, I compared the morphological properties of street networks, in a diachronic way. An interesting result was obtained by analysing the street network of the city of Beauvais (France), before and after World War II. I demonstrated significant differences between the newtork's properties, which allowed me to retrace a part of the city's formative process.

Keywords
morphological analysis, street network, evolution of urban form, urban history

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INTRODUCTION

The plan of a city keeps traces of its history, that's the main hypothesis of most morphological analysis. Indeed, the proponents of the approach consider that we can learn things about cities' history by focusing on the evolution of their form. This aspect has been widely criticised, for the bait it may induce by making people assume an auto-perpetuation of urban forms, « *we can't think of urban forms without their social references* » some argue[1]. This said, the city is not either the ground track of social references, since the persistance of urban forms despite various contexts is opposed to that. Furthermore, some criticisms against morphology may come from a misunderstanding of the analysis' purpose : morphology doesn't aim at capturing reality, it only aims at simplifying it, by casting aside all the functions, senses or histories that everyone associate with forms, and focusing on the study of a single aspect, the form itself[2]. *Morphologists* consider that this knowledge is worthwhile and can afterwards lead to a better understanding of the *causes* behind the observed forms.

This approach has been first introduced by August Meitzen (1895)[3], who tried to identify the relationships between patterns of agglomeration and socio-cultural organisations. Since then, the morphology of agglomerations has been studied from different perspectives: while archeologists used it to identify missing structures, architects and urban planners used it as a way to plan projects[4]. For their part, historians' works aimed at identifying typical plans of a certain period rather than describing the processes of transformation that occur. Thus, most of those traditional morphological analyses showed the difficulty of comparing plans of different cities, and looking for generic processes[5]. That's partially why more quantitative morphological analysis appeared since 1970s, such as Space Syntax[6] which purpose was to measure objectively the social, economic and environmental properties of spatial layouts. Those analyses mostly focused on the structure of the street network, and its relationship with movement flows. Since then, various studies explored the morphology of street networks (mainly using graph theory), and demonstrated the relevance of such approaches to understand the relationship between urban streets patterns and urbanisation[7] [8], resilience[9], and better urban design[10]. However, with a few exceptions[11] [12], using quantitative tools for historical purpose remains unusual, but starts spreading because of the recent digitization and georeferentiation of old maps.

The purpose of this paper is to expose the relevance of quantitative morphological analysis in a diachronic perspective, with the aim of revealing processes such as the evolution of cities. This relevance is due to the possibility of comparison permitted by morphological analysis. Indeed, by focusing on the form of objects, morphology allows us to compare many of them, as long as they have some morphological common points. We could then compare a city's form through time, and look for regularities or variances that may be hidden by the spatio-temporal particularities of each context. Besides, with relying on previous quantitative studies mentioned before, I will focus on the morphological properties of the street network, considering it as a major component of the urban form, and a good marker of a city's history.

THE MORPHOLOGY OF STREET NETWORK, BETWEEN STABILITY AND MUTATION

According to Caniggia[13], the evolution of the street network passes through two kinds of processes. On the one hand, each modification is constrained by the global network, which yields a conditioning on its elements' substitution, and restricts the permitted changes. This *inertia* is due to the materiality of such infrastructures, as well as to their ability to adapt to various contexts, functions, senses, etc. It means that despite local modifications (which never stop occurring) some morphological global properties remain stable during periods of time, and that's why we can identify typical properties in antique, medieval, or modern networks.

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On the other hand, it also happens that the sum of those local modifications affect the global network. The network then turns to another state, with completely different properties. This change usually starts gradually, when the existing network is not anymore optimal to people's quantitative and qualitative needs. People then generate a tension on the existant network, until a *boom* phenomenon occurs, which provokes the diffusion of new network's properties, and makes the change global. Besides, it also happens that a planning project provokes a major and very fast change in the global network (we will see an example thereafter).

THE STREET NETWORK, A COMPLEX OBJECT

The two phenomenons mentioned before reveal an important fact: the street network's evolution can't be understood by focusing on a micro scale. Indeed, the stability or the sudden change of the network's morphological properties are emerging phenomenon, which are upper to what is happening locally.

This idea is strongly linked to the paradigm of complex systems, which is the basis of the morphological analysis that I propose here. This theory proposes to consider reality as systems, composed by interrelated elements. Obviously, elements are basic components of a system, but a complex system is not equal to a sum of elements : global properties that don't exist in each part of the system *emerge* on a macro level.

Thereby, the ascertainment mentioned before about the street network's evolution incites us to consider our research object as a complex system with emerging properties. The complex systems theory is opposed to the reductive approach, which consists on decomposing realities into pieces that can be easily studied in laboratory. Complexity avoids those practices, arguing that the knowledge of a part won't tell us anything about the system.

Thus, this theory considers phenomenons as irreducible realities, namely *systems*, and aims at focusing on the relations between the elements, rather than on their number or nature. This process allows to shed light on the organisation of the system, which according to Edgar Morin contains its identity : the fixity of the system depends on the fixity of this organisation, and conversely, any change in the system's organisation change the system.

Considering my aim (i.e. describing the long time evolution of the street network), it appears that if I model[14] the street network as a system, I will be able to reveal its organisation (by studying the relations between its elements), for each period of time. Then, the comparison of this organisation through time may shed light on the two phenomenons mentioned before. Indeed, on the one hand, the fixity of the system's organisation will reveal the stability of the network's morphological properties. Note that this fixity may happen when the modifications affect the nature or the number of elements (streets) but not their relations. On the other hand, significant modifications of the system's organisation will unveil global mutations in the network's properties.

A TOOL TO DESCRIBE THE ORGANISATION OF NETWORKS

Another asset of the complex systems theory is the use of mathematical tools to represent and describe *quantitatively* the organisation of systems. Among those tools, the graph theory, which consists in modelling the elements of the system as nodes, and their relations as edges. This representation makes clear the notion of interrelated elements. Moreover, many indicators have been developed in graph theory, so as to quantify graph properties, the best known being centrality, density, community detection, etc.

As said before, graphs have been widely used to describe the properties of street networks. It generally consists of modelling each street as an edge, and each intersection as a node[15]. We then compute the property of each element, which depends on its topological and metric relations with others. For example, the betweenness

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centrality[16] of a node depends on its topological position regarding to others : the more a node is in an intermediate position between many others, the more its betweenness centrality will be high.

Once the centrality (or any other indicator) computed for each node, the purpose is to describe the global organisation of the system[17]. To do so, I observe how the said property is globally distributed in the network, (i.e. where are situated the most central nodes, etc.). I then try to synthesise this distribution, using diagram, graphs, sketches, etc., which gives an abstract of how the elements are interrelated topologically and metrically. Thus, I finally unveil the global organisation of the system.

As mentioned before, only few researches have used graph theory to compare the organisation of street networks through long periods of time. Yet, we can easily see how relevant would be the comparison of networks' global organisation from a period to another. It will allows us to reveal the two kind of phenomenons mentioned before: the fixity of the organisation despite local modifications, and the mutation to a different organisation.

APPLICATION: CASE STUDY AND MORPHOLOGICAL INDICATORS

Thereafter, I will explain how my methodology has been tested on my main case study, the city of Beauvais, a small town located 78 km north of Paris.

After being the site of a royal tapestry factory in the seventeenth-century, Beauvais remained on the sidelines of the industrial Revolution of the nineteenth-century. Indeed, when most important cities became railway junctions, Beauvais was still in the era of stagecoach till 1876. This delay in the industrialisation of the city[18] allowed it to preserve its urban heritage. Indeed, even if the population of Beauvais doubled between 1850 and 1900, researches revealed that during this period, the urban fabric mainly remained unchanged[19], with regular narrow streets[20], irregular blocks, and wood houses.

Unfortunately, World War II has ultimately destroyed the historical center of Beauvais. Approximately 80% of it caught fire on June 1940. A major and very fast reconstruction project followed, from 1946 and 1960. The main purpose of the project was to adapt the city to new transportation means, thus, major roads toward other cities have been rejected outside of the center, the old paths was at some points preserved, and at some points replaced by more continuous and geometric ones, which often reshaped the ancient blocks.

Thus, it seems that Beauvais passed through various events, which affected or not its urban fabric. Those information was given to us by analysing the history of the city, but what if we cast aside the latter? Can we learn things about Beauvais without knowing in depth its history? Is it possible to read this history by comparing the city's form through time? Or more precisely, by comparing the organisation of its street network?

To answer those questions, I chose to compare the street network of Beauvais' historical center, at three moments. The first moment is 1849, period in which the city is mostly still in its traditional shape, with no train station (1876) nor manufactories. The second moment is 1888, when the city started its industrialisation, but without major urban changes (according to researches). Finally, I will analyse the street network after postwar reconstruction, in 1960, when the street network has potentially been completely reshaped.

Furthermore, I chose two main morphological indicators, so as to describe the organisation of the three street networks. The first indicator, proposed by Salat[21] is a metric one, which means that it describes the metric relations between the elements of the system. Put another way, it amounts to focus on the size of each element (length, width, area, etc.) and describe the global distribution of the latter, which completely depends on each element's size. Here, elements are the streets, and the size considered is their width.

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In practice, the study of the streets width distribution amounts to find the *quantity* of streets (total length) for each width category. To do so, I compute the length and the width of each street, and report it in a table. I then fix width categories, for instance:

- Narrow streets, between 1 and 7 m.
- Medium streets, between 8 and 14 m.
- Large streets, between 15 and 21 m.
- Very large streets, larger than 22 m.

I then compute the quantity of streets that belong to each width category, by summing their length. Next, I describe the obtained distribution: which category is the most represented? Does the quantity of streets increases or decreases when the width augments? Finally, the representation of those results in a synthetic way, through diagrams or sketches, allows me to shed light on the street width organisation of the network: is it mainly composed of narrow streets as in traditional networks, or of larger streets as in modern ones?

After making this analysis on each studied period, I compare the three streets width organisations, the results will be presented thereafter. Note that those results reveal one single aspect of the network's organisation, which is the streets width distribution. As said before, morphology simplify reality, in order to reveal hidden properties that don't appear without focusing on one single aspect and casting aside all the rest.

Otherwise, crossing those results with ones provided by other indicators will be interesting so as to reach a more global description of the network, at each moment. This comparison may also reveal differences between the indicators: some of them may remain stable for long, while others may change faster. Thereby, I will be able to nuance and describe more precisely the morphological changes.

Thus, a second indicator has been chosen, which is accessibility. The latter, developed by Lagesse[22], depends on both topological and metric relations between elements. It reveals how many turns it takes and how far it is, on average, to go from a given street to the rest of the network. Basically, long straight streets have a high accessibility, because they cross the network from one end to the other, and permits to reach a lot of other streets. Thus, the more a street is close to those long straight streets, and permits to reach them with a low number of turns, the more its accessibility is high.

Accessibility has been computed by Lagesse on the street network of the city of Beauvais, for my three studied periods. Those results gave me the organisation of the network's accessibility, which I tried to synthesise by wondering: how the accessibility is distributed? Where are situated the most accessible streets? Where are the less accessible ones? Finally, I compared the three periods and discussed the results in regard to the previous indicator, which is the streets width distribution.

PRELIMINARY RESULTS

The analysis started by a laborious work (that I will not detail here) of digitising, georeferencing, and redrawing nineteenth and twentieth centuries plans of Beauvais. This step allows me to obtain harmonised data for the three street networks, in a GIS format. Note that the streets which surround the city center has not been considered because of their imprecision on the plans. I kept them as borders for the city center.

For the analysis of the streets width distribution, I used the old plans to compute the length and width of each street. The result for 1849 is presented below (figure 1)

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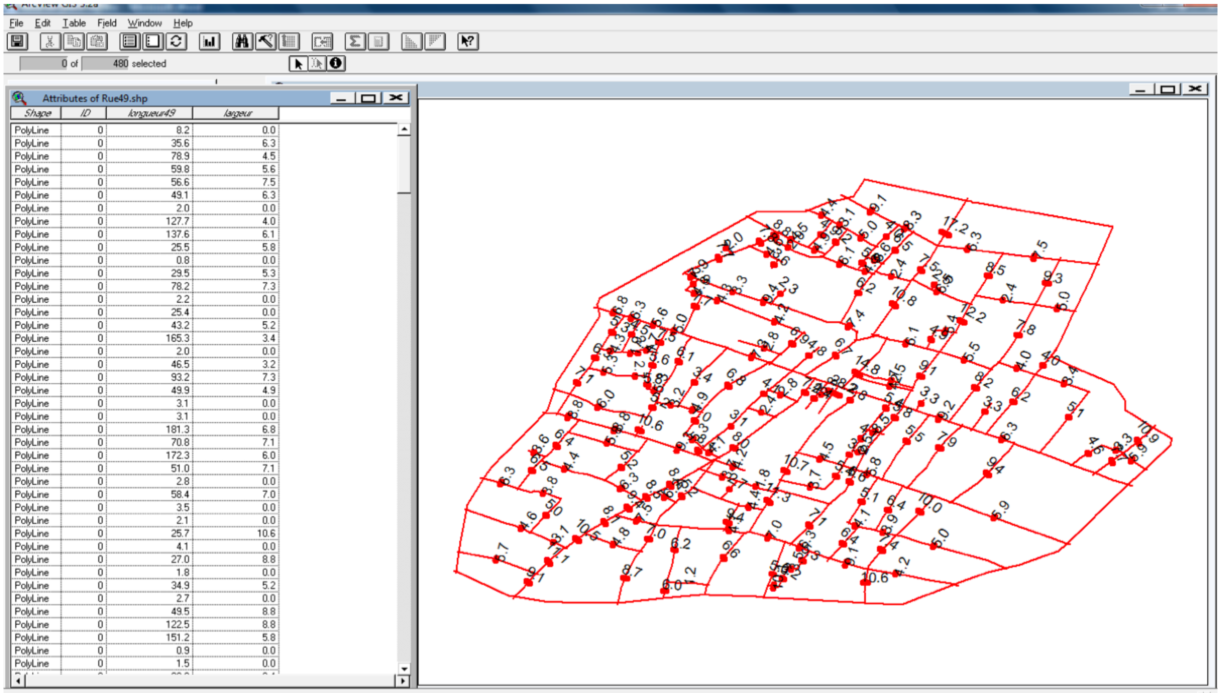

FIGURE 1 The drawing and the table of lengths and widths of streets in 1849.

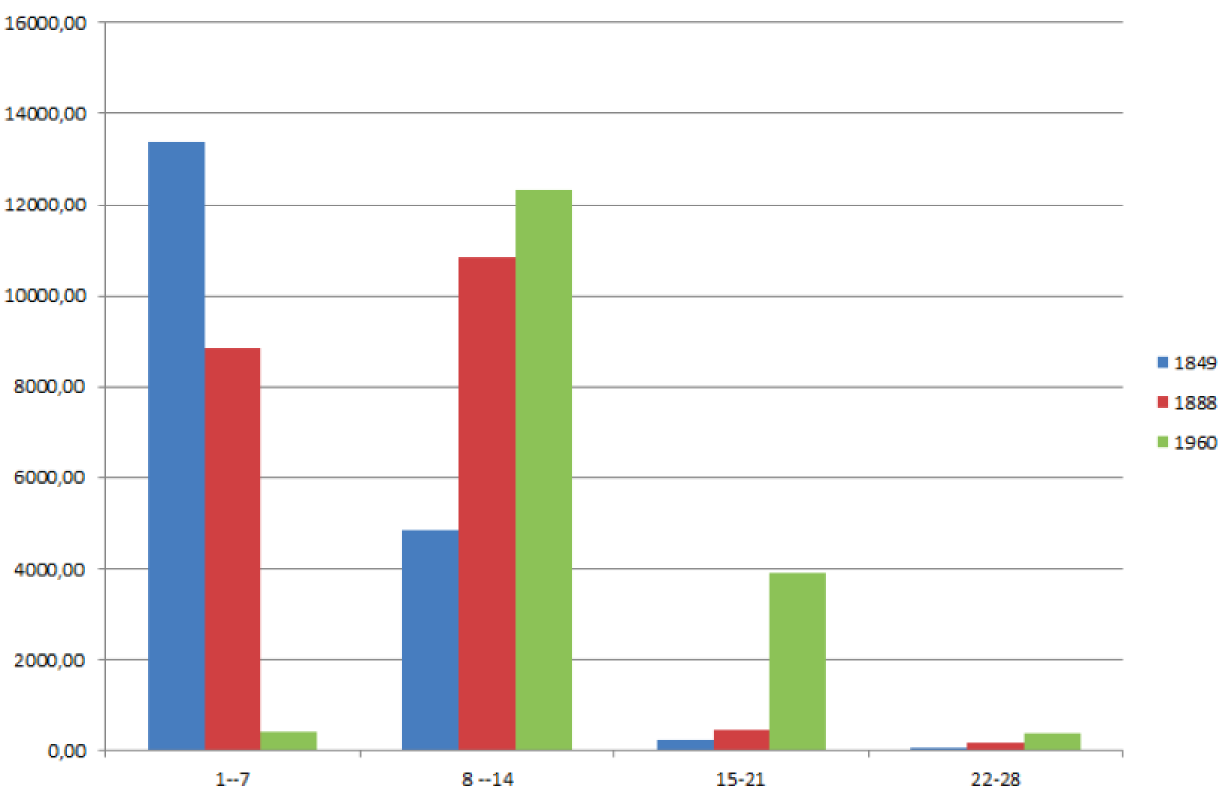

FIGURE 2 The diagrams of the three width distributions : 1849 in blue, 1888 in red, and 1960 in green.

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After that, streets width categories have been fixed as mentioned before, and the emerging distribution for each period has been represented with diagrams (figure 2)

Concerning the 1849s distribution (in blue), the network seems dominated by narrow streets (between 1 and 7 m), and has almost no street wider than 14 m. This distribution was expected, since the city at this period is still in its traditional shape and on the sidelines of the industrial Revolution changes. In 1888 by contrast (red), the total length of medium streets double, while the narrow ones decrease a little. This decrease may be due to a less accuracy of the 1888s plan comparing to 1849s one, but also to the suppression of some very narrow streets during this period. This said, the high increase of medium streets was an unexpected phenomenon, since the researches did not mention major urban changes during the second half of the nineteenth-century.

On 1960 (in green), the distribution is completely different, narrow streets has almost completely disappeared, medium streets keeps on increasing, but the major change is the spread of large streets, which were very few thus far in the city center. This distribution was partially expected, since the postwar reconstruction reshaped the whole network, but this result strongly emphasised on the denial of preexistent narrow streets, and on the will of passing to a larger scale.

For the accessibility, Lagesse only needed the drawing of the network's skeleton. She then used the QGIS plugin she developed[23] to compute many indicators, among them the accessibility of streets. The results for the three periods are represented in figure 3, 4 and 5.

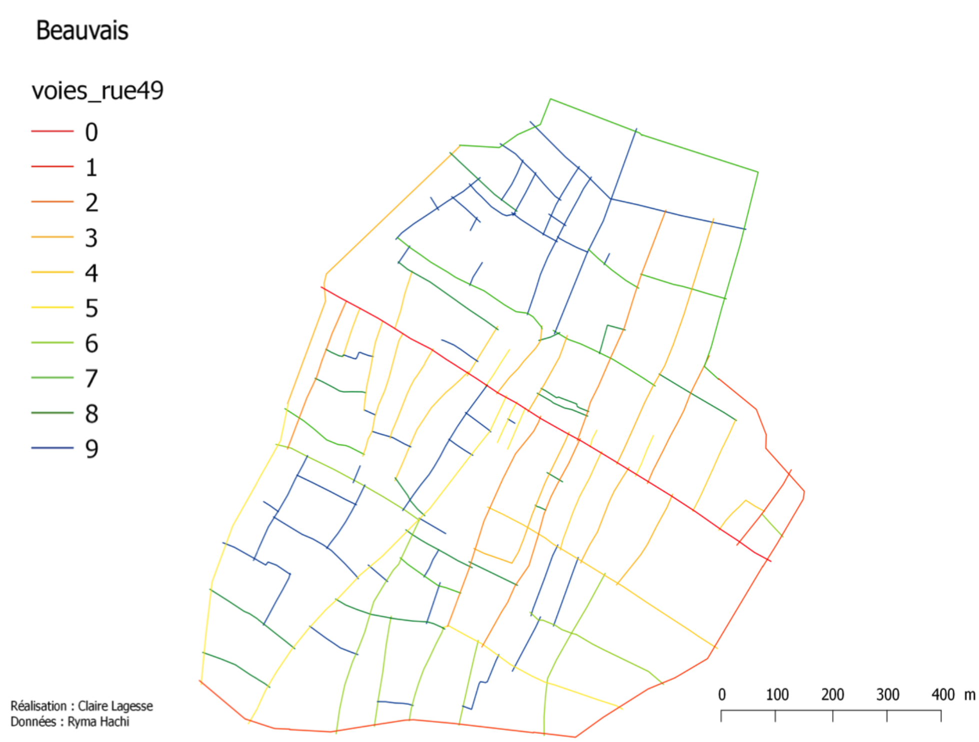

FIGURE 3 The accessibility of streets in 1849. Higher accessibility in red, lower in blue.

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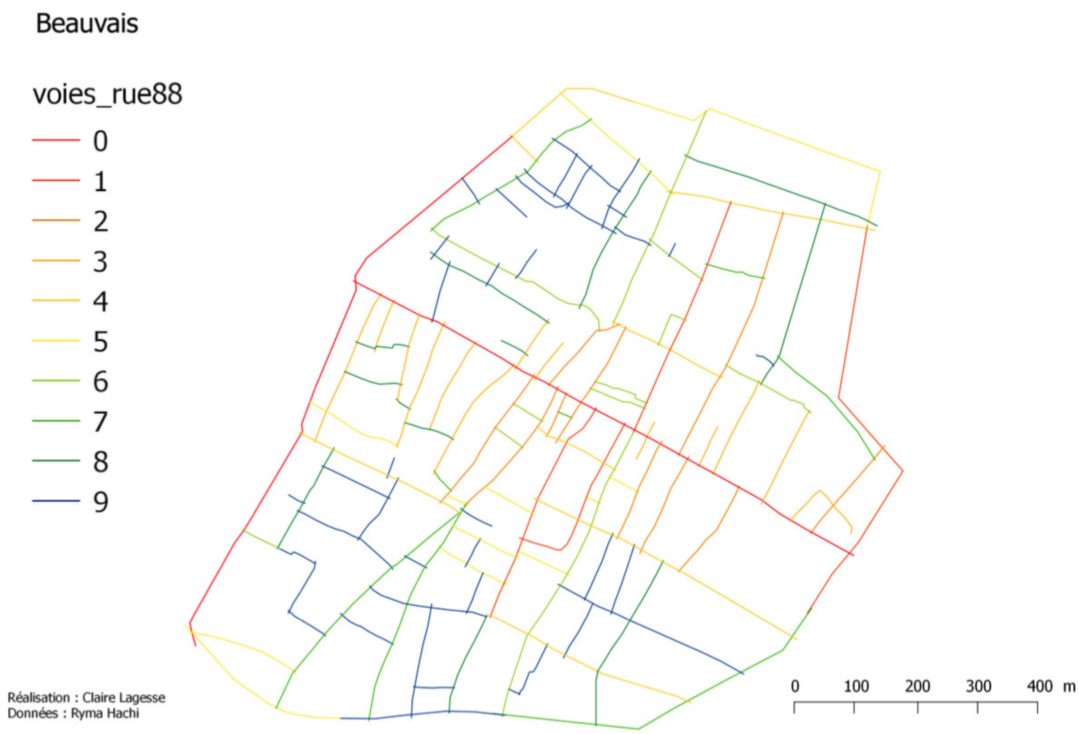

FIGURE 4 The accessibility of streets in 1888. Higher accessibility in red, lower in blue.

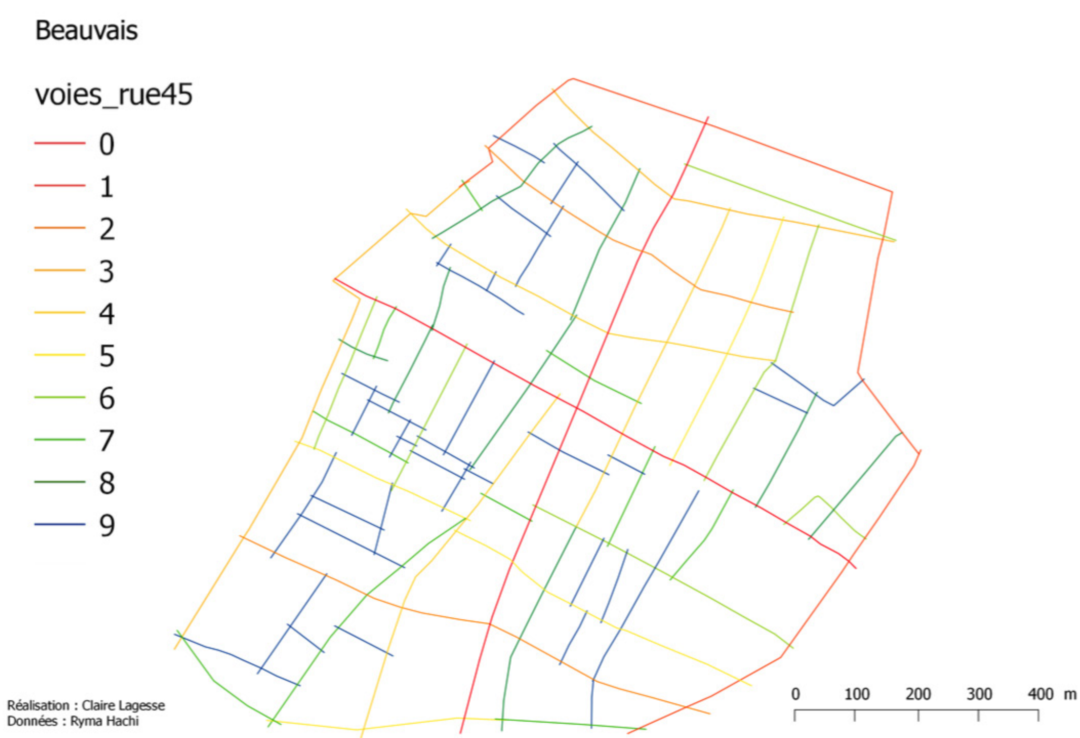

FIGURE 5 The accessibility of streets in 1960. Higher accessibility in red, lower in blue.

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In 1849, the most accessible street (in red) is the long and straight one which cross the city from est to west. As expected, the streets which are directly connected to the latter have also a high accessibility (in orange), even if their length is low. Those red and orange streets correspond to the ancient city center, on which were situated most of the central activities such as the market place and the cathedral. Otherwise, the more a street is far from those streets (in terms of distance and number of turns), the less its accessibility is (represented in blue and green).

In 1888, the accessibility almost remains stable, besides some local changes, due to the alignment of few streets, which provokes the increase of their accessibility. The 1960s results seem very different, since a second very accessible street appear, perpendicularly to the first one. This second street seems to surpass the first one, indeed, the accessibility of streets which are connected to it increased, when the ones connected to the first one lost their accessibility.

This change is probably due to the alignment of the street which cross the city from north to south. This long and straight street became more accessible than the historical one, and provoked a major change in the distribution of accessibility, which leads to a relative exclusion of the ancient city center.

Globally, the organisation of accessibility between 1849 and 1888 is typical of historical cities (see figure 6), with a single major street[24] containing the market square, on which many streets graft, and so forth. In 1960, the organisation is less apparent, two streets have a very high accessibility, the north/south one became the new city center (where are nowadays situated shops and central activities), and the est/west street, which remains accessible because of its length, but does not spread its accessibility anymore. Thus, it seems that the postwar reconstruction has deeply affect the accessibility of the network, by increasing the length and the straightness of many streets, so as to adapt them to cars traffic.

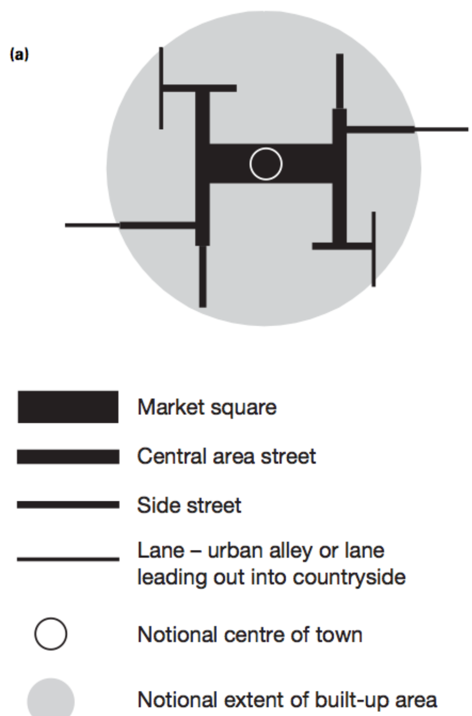

FIGURE 6 A schema of streets' organisation in historic cities.

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DISCUSSION AND CONCLUSION

By considering the street network as a system, and by studying metric and topological relations between its components, I revealed a part of its organisation, for each studied period.

Between 1849 and 1888, I revealed a relative stability of the network's organisation, but also unexpected changes. Indeed, even if the distribution of accessibility remained quite similar, the one of streets width changed. Thus, despite what the researches say about the stability of the urban fabric during the second half of nineteenth-century, I would nuance this affirmation, since it seems that during this period, local modifications started affecting the global organisation of the network. If we introduce the external context, we notice that people's needs started changing during this period[25], and we can expect that the sum of those local modifications were going to induce a *boom* phenomenon, which would spread a global change of the network's organisation.

World War II accelerated this *boom*, and provoked a major change both on the width distribution, and on the accessibility of the network. Indeed, the denial of preexistent narrow streets during the reconstruction, and the emergence of a second very accessible center are two signs of a deep modification of the network's organisation. We can consider this fast change as a mutation of the system, but the latter was already prepared since the second half of the nineteenth-century.

Thus, the analysis of Beauvais' street network did not reveal the expected fixity of the system's organisation between 1849 and 1888. It rather emphasised on two different kinds of changes: a gradually one, emerging from people's local modifications during the nineteenth-century, and then a sudden one, provoked by a global planning project.

Thereby, I demonstrated that using morphological indicators permits to describe quite precisely the organisation of networks through time, and to reveal changes that are not mentioned in literature. This emphasises the relevance of diachronic morphological analysis (which remains slightly used so far) for the study of urban form's evolution.

Otherwise, one of my futur aims is to reveal the potential causes of observed fixities or changes. This purpose implies a wider comparison through time (many periods) and space (different cases studies), so as to identify correlations between a certain kind of external context and the change or the fixity of the system's organisation.

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Notes on contributor(s)
Ryma Hachi is a second year Ph. D. student in urban geography, at the laboratory Géographie-cités (Paris 1 Panthéon-Sorbonne University). She is an architect and she holds a Master degree in Urban History, from Paris Diderot University. Her research is about the use of morphological analysis in the study of cities' formative processes. Her two cases studies are Paris and Beauvais (France).

Endnotes
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5 *Ibid*.
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15 The opposite is also possible (*dual graph*).
16 Linton C. Freeman, « A set of measures of centrality based on betweenness », *Sociometry*, 40 (1977) : 35–41.
17 As in any modelling based on the complex system theory.
18 That was partially due to people's attachment to handicraft.
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20 That mostly followed the antique paths.
21 Serge Salat, *Les villes et les formes, sur l'urbanisme durable,* -1e éd. (Paris: Hermann, 2011), 544 p.
22 Claire Lagesse, *et al*. « A spatial multi-scale object to analyze road networks ».
23 In collaboration with Oslandia company.
24 Which is usually the continuity of regional access roads to the city.
25 With the industrialisation.

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Image sources

Figure 1: Data and realisation : Ryma Hachi.
Figure 2: Data and realisation : Ryma Hachi.
Figure 3: Data : Ryma Hachi, realisation : Claire Lagesse.
Figure 4: Data : Ryma Hachi, realisation : Claire Lagesse.
Figure 5: Data : Ryma Hachi, realisation : Claire Lagesse.
Figure 6: Marshall, S. (2004). Streets and patterns. Routledge.

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