Road Network Analysis Based on Geo-Historical Data

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Abstract

Road network construction results from a subtle balance between geographical coverage and rapid access to the strategic points of space. The understanding of the road network structure is fundamental to evaluate and improve territorial accessibility.

In this ongoing work, a morphological analysis of road patterns over time is developed on three cities (Besançon, Dijon, Pontarlier), over three historical periods (the 18th, 19th and 20th centuries). This study is based on geo-historical data provided by historical maps. Those maps allow us to digitize historical road networks. From those networks, a graph is built, allowing us to compute indicators based on their topological and geometrical properties. Thus, it is possible to compare their characteristics and highlight valuable information through space and time.

In a prospective vision, this work aims to identify mechanisms leading road network evolution. Studying road network morphogenesis to detect indicators stability or variation over time, and to identify similar behaviors, despite geographic and cultural distances, is of major support for better understanding their impact on access and mobility.

Keywords

Geo-historical data - Road network - Spatiotemporal analysis - Urban morphology – Complex networks - Graph theory

Research context

Road network analysis based on geo-historical data

Among the three morphological entities that form the city (road network, parcels and buildings), road layout is the most permanent over time. Actually, road networks undergo minor modifications within city core, and the main changes occur mainly on suburban or interurban areas *(Barthelemy, 2015)*. Analysis and modeling research works have been conducted on road networks *(Bettencourt, 2013; Louf & Barthelemy, 2014)*, to understand their evolution logic *(Strano et al., 2012)*, and to analyze their growth mechanisms *(Casali & Heinimann, 2019)*. Yet, spatial analysis methods and graph theory have proven to be effective in studying network evolution based on historical data (road networks *(Lagesse et al., 2015)*, or transport networks *(Bonin, 2016; Raimbault, 2018))*. Nevertheless, only few authors make the link between road network topology and historical anchoring. For instance, those concepts can be found in the work of *Barthelemy et al., 2013* and *Masucci et al., 2014*, as well as in a recent study based on analyzing snapshots of multiple urban sites, at different growth stages *(Jang et al., 2020)*. Despite all these valuable contributions, mechanisms by which these networks evolve over time remain unclear, and their modeling is in its early steps*(Courtat et al., 2011).* Studying and linking road network structure and city historical evolution is promising, as it would help urban planners to imagine tomorrow cities shapes and territories organizations.

COVADEO project

Road network digitalized geometry is time-consuming to acquire on a large scale of time. Thus, a collaborative digitization of historical road networks appears to be a valuable solution to build a geo-historical database.

Until now, COVADEO project[3] has ensured the collection of 440 historical maps of the Burgundy-Franche-Comté region in France, from the 17th century to the 20th, in which the ancient road network is readable. These maps were collected from different

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3 COVADEO (collection, visualization and analysis of geo-historical road data, 2018-2021, direction: C. Lagesse), funded by the Burgundy Franche-Comté Region, within its funding program (ANER) for new research team support.

sources, such as departmental archives, municipal libraries and Gallica (which belongs to the National Library of France). Subsequently, they have been georeferenced and stored in a structured geo-historical database.

This database will be connected to a web platform, conceived as a serious game, to ensure collaborative digitization of ancient road networks. Data matching will be ensured by overlaying the vector layer of the current road network[4] on the historical map. Thus, crowdsourced geometries of the ancient road network will be created from the ones of the current network. Users will be asked to determine if each current segment is present, absent or if it should be modified on the historical map.

Through a user-friendly interface, it will be possible to visualize the collected historical maps, to access their related information, and to contribute to data collection. Involving a large community in collaborative data production can be of a great interest for scientific research, and for science popularization. A test version of the platform, developed from the code of *Building Inspector* (NYPL Labs), has been launched online[5] in order to make a first experimentation on two historical maps. This prototype helps to understand the stakes of such data production method. In the final version of the game, users will have access to ancient maps on parts of the Burgundy-Franche-Comté region, so data will be created all over the region, from the 17th century to the 20th. Two other functionalities, of segments accuracy evaluation and modification, will be integrated. The final platform will enable to collect data for quantitative and qualitative analyses of the regional road network historical evolution.

Method and first results:

Approach

This work focuses on the topological and geometrical aspects of road networks. Following on the work on space syntax and successors *(Hillier, 2006; Hillier et al., 1976; Porta et al., 2006),* and the idea of continuity on a road network, *Lagesse, 2015* proposed an extended geographical object called the *way*, constituting an hypergraph. Ways are built, by pairing edges at each node of the road network graph (figure 1). Thus, they are constructed by local geographical rules at road crossings, independently from the order in which the network is read. The resulting object is multi-scale, from the single edge to the largest way extending over the whole studied zone. This last property allows us to make stable computations on as large as wanted geographical zones. Topological indicators computed on the ways (as degree centrality or closeness centrality) gain the valuable property to become robust against zoning (no border effect on a consistent zone). To build ways and to compute indicators, a QGIS plugin, Morpheo[6] *(Lagesse, 2015)* is used.

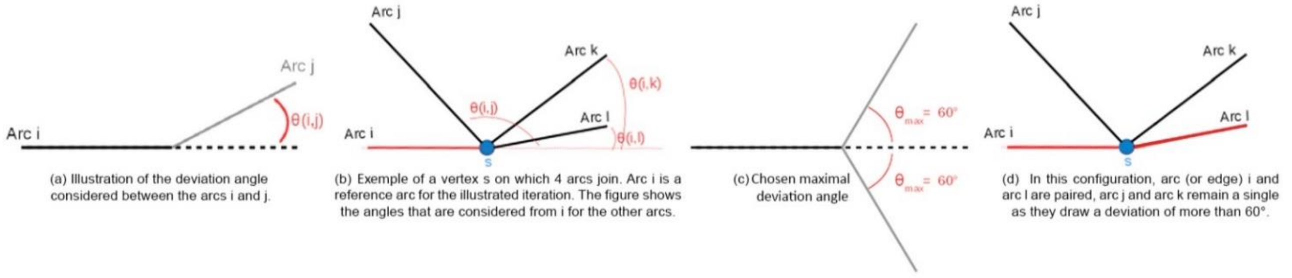

Figure (1): Pairing process to build ways: At a given intersection (node), road segments connected by this intersection, are paired according to their minimum deviation angle (with a maximum threshold of 60°). Segments with large changes in direction (more than 60°) are treated as separate road units.

Source : Lagesse, C. (2015). Lire les Lignes de la Ville [Theses, Universite Paris Diderot-Paris VII]

4 From the BDTOPO, the second component of the large-scale repository produced by the IGN in France.

5 https://covadeo.univ-fcomte.fr/

6 Python package and QGIS plugin for the characterization of spatial graphs, allowing way construction and indicator calculation. (ANR MONUMOVI, MorphoCity research team)

Road network analysis

To be able to carry out first analyses on historical road networks, the digitization was made entirely on three specific cities (Besançon, Dijon and Pontarlier), on three different periods (the 18th, 19th and 20th centuries). Those case studies can illustrate how these indicators (developed in *(Lagesse, 2015)*), computed on ways are revealing city structure. For example, analyzing the access degree indicator of Dijon's historical road network over time, highlight expansion dynamics; from the ancient core to the newest suburbs (figure 2). Roads with is the most important access degree values *(represented in red)* correspond to the main fast traffic roads in the urban structure, and to long old roads. Then the lowest levels *(in green and blue)* represent roads with fine access to local areas. With time, new portions of territories are urbanized, and the most accessible structure will be used as a support of connection, making its accessibility even more important. The analysis of the network structure (over three centuries), allows us to observe how the network evolution and its structural changes affect territorial accessibility (figure 3); and thus, to better understand the impact of urban planners' decisions on territories. Furthermore, through the results of different indicators, it will be possible to analyze the evolution dynamics in cities, and help the different actors of territorial planning to imagine future evolution of road networks.

Figure (2): Historical maps and calculated access degree indicator on the associated road networks, of Dijon in 1790 (a, d), 1883 (b, e), and 1944 (c, f).

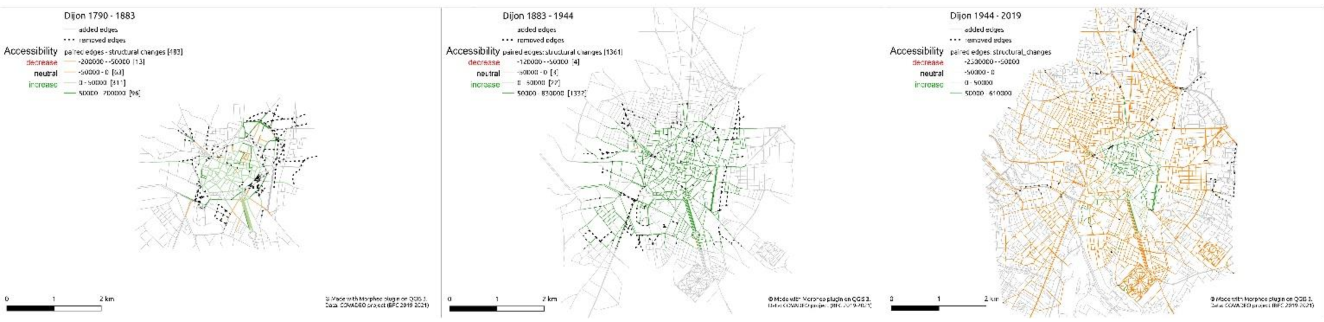

Figure (3): Accessibility variation calculated[7] on the road network of Dijon between 1790, 1883, 1944 and 2019.

7 Calculated with Morpheo (Lagesse,2015)

Discussion and conclusion

In this ongoing work, road network morphology is studied based on their topological and geometrical properties. Such analyses lead to the interpretation of centralities and densities and help us to trace back some aspects of the historical and geographical contexts, regarding city morphogenesis. It is then possible to have information about historical evolution of cities by studying the geometry and topology of their road networks. Yet, while considering diversity and complexity of cities, their morphogenesis can manifest an impressing simplicity and universality. So, in this vision, differential analyses from a t-1 to a t-time will be conducted. Moreover, the web platform will ensure collaborative digitization at a larger scale. The collected vector data of historical roads networks will enable further analysis on different territories over time, to compare their structural evolution.

In the next steps, we will focus on relating road network topology to historical and territorial evolution, including their capacity for emerging new segments, and their resilience to network disruptions. A better understanding of past morphological transformations will help the different actors of territorial planning to imagine future evolution of city road networks.

Declaration:

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