**MORPHOLOGY OF STREET NETWORKS IN URBAN NEIGHBORHOODS IN GHANA – chapter two**

**Review of Relevant Literature**

**2.0 Introduction**

This chapter reviews relevant literature surrounding the study of street networks, the evolution of such studies and works from old point-and-click tools—like QGIS and ArcGIS—to new autonomous ways, using programming languages to create automatable workflows using open data from open-science influenced by the open-source movement. It then continues to explore the different models that are used to model street networks in the study literature and why the chosen one is best for modeling street networks in the study. It then concludes with justification from relevant works on why the chosen methods work best for both practicing planners and those in pedagogy.

* 1. **Street Networks And Models**

Street networks are very important in any urban area in the world, they influence how things are situated in space and how information and data travel through space. As Boeing (Boeing, 2019) put it, Street networks organize and structure human spatial dynamics and flows. They underlie commutes, the patterns of settlement, discretionary trips, and the location decisions of households and businesses. It is important to note that the structure of these networks evolves and is influenced by multiple factors like economics, politics, urban design principles, and population density within particular geographic areas. One of the most important things about street networks is that they can be modeled as mathematical graphs which consist of nodes and edges intersecting to form a web of connections that maintain the geometric and topological features of real-world networks (Barthélemy, 2011b; Boeing, 2017b; Dumedah & Garsonu, 2021a; O’Sullivan, 2014)

In the study by Boeing (Boeing, 2020b), he justifies the use of these methods of analysis and states that they are ubiquitous in the current analysis literature. He starts by introducing street network models used in most of the research literature, including the planar model which does not retain the three-dimensional spatial information that is inherent in real-world street networks. These planar models—two-dimensional representations—make it harder to model and analyze networks consisting of underpasses and overpasses as he noted. He makes the case that even though, the planar model is not sufficient to represent the true nature of real-world networks, nevertheless, in developing parts of the world, where tunnels, overpasses, and underpasses are not prevalent in the street infrastructure the planar models are still useful and retain most of the information of the real world street network.

**2.3 Street Network Analysis**

Complex networks are often organized in the form of graphs where nodes and edges intersect and are embedded in space, according to Barthélemy-Marc (Barthélemy, 2011a). Ranging from transportation, power grids, and social and contact networks, space is very important and topology and geometry alone do not suffice to characterize the true nature of these networks. It is, therefore, necessary that the structure of networks embedded in space—in this case, street networks—be studied because they are crucial to understanding the composition and evolutions of these networks, especially in modern urbanism. Street networks must be studied and analyzed to understand the transitions they go through and how resilient we can make these networks (Sharifi & Yamagata, 2018), they are one of the most long-lived urban infrastructures and we can be locked into the positive or negative decisions that underlie their composition.

The analysis of street networks has been central to network science and transportation planning since its conception: its mathematical foundation; the famous Seven Bridges of Königsberg problem, through which Leonard Euler started the development of the field of graph theory for studying a network of bridges (Boeing, 2017a)—although it was not known as graph theory at the time. Spatial networks are often represented in the research literature as primal graphs of nodes connected by edges, How these graphs are connected is their topology, but there is another dimension to these graphs which is their geometry—because street networks are embedded in space—and thereby they possess shape, width, length among other measures. The mathematical graph model of a street network makes it easy to compute indicators of urban form such as block sizes, intersection density, node degrees, connectivity, circuity, centrality, and many others (Boeing, 2018, 2020b; Brede, 2012; Jiang & Claramunt, 2004).

Street networks are considered by Boeing (Boeing, 2017a) as primal, non-planar, weighted multigraphs with self-loops. They characterize topology and metric measures (Barthélemy, 2011b). Metric measures such as length and area are crucial for transportation planning. Other indicators include the total number of nodes and edges in the network, coupled with their respective distances, centrality measures like betweenness centrality which evaluate the number of shortest paths that pass through each node or edge, which is an indicator of how resilient a network is: if a higher number of shortest paths passes through a particular node or edge, a failure of that node could result in catastrophic disconnects in the graph (Barthélemy, 2004; Boeing, 2017a). The closeness centrality measure is also employed to indicate the distance from a node to all others in the network: more central nodes are on average closer to all other nodes and rank higher in the system of graphs forming the network (Boeing, 2017a). Conversely, since street networks are modeled with graphs, the PageRank algorithm—the algorithm Google uses to rank web pages, which are represented as hyperlinked graphs—is another measure of centrality where nodes are ranked based on the structure of the incoming links and rank of the source node (Boeing, 2019).

**2.5 The Case for Open Tools and Data**

Scientists all around the world look at the world through the tools at their disposal for analysis. Computational tools help us understand the world around us better, it helps us to scrutinize and to seek out the reasons for things around us. But it is the case that most often, these tools and frameworks are built for and by academics and businesses for the sole purpose of their work and not necessarily shared with the general public: the methods used are not replicable and the data closed sourced and often hard to verify. As Boeing (Boeing, 2020c) puts it “to conduct better science, we need to build better tools. Such tool-building allows academics to better operationalize and hypothesis-test theory. Academic incentives must be aligned with the positive externalities of conducting open science and developing open-source spatial research software”. An example of this is the open-source mapping effort that generates the OpenStreetMap spatial database, and the many groups and communities formed around the effort.

Barrington-Leigh and Millard-Ball (2017) found that, as of 2016, OpenStreetMap was 83% complete worldwide, over 40% of countries (including many developing country’s) street networks were effectively 100% complete, and completeness was highest in both dense cities and sparsely populated areas. The use of open methods, tools, and data is setting a precedent for others to develop better geospatial planning efforts, especially in developing countries. These tools and methods help to create workflows that can be adapted to analyze networks on a much larger and broader scale than is achieved in recent studies as Boeing (Boeing, 2020a) demonstrated. Conversely, it gives urban planners the ability and opportunity to use the developments in research by pedagogy to better understand the urban form and develop and evolve it. Accordingly, it is also important that tools and methods be better documented so they are more accessible to the general public, these efforts will lower the barrier to entry for people who are interested in doing geospatial research and network analysis both in academics and in practice.

One such open source tool is OSMnx (Boeing, 2017b) which is used by academics, governments, urban planners, and many other people doing geo-analysis of spatial networks. This tool coupled with others like geopandas, pandas, and networkx are all products of incremental community work started by Boeing, Goeff, and many other researchers worldwide and sets a precedent that needs to be followed if a change is to be made in the field of planning and geospatial analysis and other fields that rely on similar tools, methods, and data. As he famously puts it “it is not Esri's job to satisfy all the theoretical needs of the spatial sciences”. Academics should set aside time to build theory-rich tools to answer difficult questions, rather than just produce empirical research and advance theory. Open-science, open-data and open-source movements address these issues by sharing scientific findings, data, and software for the good of society. (Boeing, 2020c).

It is nevertheless the case that, to use these tools one would require some computer programming skills which raises the bar of entry a little bit for those of a non-computer science background. But since a lot of geodata aggregation and analysis is tightly coupled with mathematical and computational methods—which mostly involve writing macros and scripts for cleaning data and occasionally automating workflows, few have been able to adapt to the new developments, methods, and tools. But most researchers interested in urban form analysis rely on GIS software packages such as ArcGIS or QGIS (Fleischmann et al., 2021). Although intuitive to use, these software packages come with inherent barriers to accessibility. The reproducibility of the underlying research is compromised by the (often undocumented) sequence of decisions manually made, as pointed out by, Boeing (2020b) these toolkits rely on point-and-click interfaces and are inefficient in the era of big data. Due to the limited scope for automation and replicability, a lot of the research is compromised and not of the utmost practical value because the steps followed are manual sequences of decisions that are hard to document and replicate. Consequently, urban morphology—spanning geography, planning to architecture—is an area of study that is constantly focused on the analysis of urban form especially streets and their layout (since their the underlying infrastructure) processes involved in its evolution are important to understanding them (Oliveira 2016; Kropf 2017).

1. **2.6 Examples Of Studies Of These Kind in Local Literature**

Very little is known from the literature about the spatial structure of urban roads networks in Ghana as stated by Dumedah & Garsonu (Dumedah & Garsonu, 2021a), and this is not even talking about street networks (of which road networks are an integral component). In their paper, it is asserted that the spatial structure of road networks shapes traffic flows on a network, and knowledge about this is important in assessing the environmental, economic, demographic, and social dimensions of cities (Xie & Levinson, 2007). Given the rapid urbanization and the growing pressure on urban roads in Ghana, it is important to investigate their spatial structure, efficiency, and connectivity measures to better inform their future management and future changes (Dumedah & Garsonu, 2021a).

He continues to state that, the spatial structure of road networks is rarely considered in transport planning schemes in Ghana. An improved understanding of the structure can lead to improved transport planning and management, and identification of problem areas to address. The study uses a spatial network science approach to characterize road networks in Ghana by using several indicators. The study provides geometric and topological descriptions of urban road networks in the 10 regional capitals of Ghana, with a focus on identifying their characteristic spatial configuration for improving traffic flow. A high-performing and resilient road network can directly facilitate the performance of other urban infrastructures (Freiria, 2015; Li, 2018; Liu, 2017; Sharifi, 2019), and the same is true of the larger street.

He concludes the study with the following findings, the majority of urban road networks in Ghana follow a radial pattern with either a gridded or branching configuration at the global scale. Only Accra and Kumasi are fine-grained and of comparable density to other global cities, based on intersection and street densities. Ghana's capital, Accra, has a typical grid structure with very small street blocks based on the length of individual road segments. The relatively flat topography of Accra facilitates the gridded pattern of the road layout. Kumasi depicts a radial pattern from the urban core and is associated with a branching structure at the local scale; this is partly associated with its central location with access to the major cities in the north, south, east, and west. Road layouts in Kumasi look to have been made to avoid physical barriers because of the area's moderately rugged topography. The findings provide the basis to inform transportation planning and management on critical issues. This conclusion is the reason for choosing Accra and Kumasi as study areas to better understand the finer grain network structure at a lower scale than Dumedah & Garsonu (Dumedah & Garsonu, 2021a) did in their study of urban road networks. And in this study, the overall network is considered, not only road networks as done by Dumeday & Garsonu (Dumedah & Garsonu, 2021b)

Though a thorough analysis framework was developed with the methods and tools advocated for by this study, the data and framework for the study were not made public. To replicate the work done in the study, one has to either contact the authors—and hope they are still holding on to the material and resources—or painstakingly recreate the framework and workflow used from scratch, making it harder to truly build on the work done in the study.

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