**Morphology of street networks in urban neighborhoods in Ghana**

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**CHAPTER THREE**

**PRESENTATION OF STUDY RESULTS AND DISCUSSIONS**

**4.1 Introduction**

This chapter presents appropriately, the various topological and geometric statistical indicators that characterize street networks in urban neighbourhoods. It points out the various differences and similarities between networks from different study areas, the implications on urban form and critical infrastructure and suggest solutions to some short comings identified from network structure and street patterns. It continues to advocate for conducting open-research as undertaken in this study, presenting its data analytics framework, data, tools and methodologies public and free.

**4.2 Morphology of urban street networks in study areas**

Urban morphology is the study of the things and processes that make up environment, from geography, architecture to the social sciences understanding how humans interact in the spaces they live in translate to understand the spaces they live and the choices underlying the creation and transformation of such spaces. Simply put, it is the study of urban form and structure. A brief visual morphological description of the network structure of streets from selected study areas are presented in Figure 1, this outlines make it easy to visualize the characteristic structure and patterns of street networks in the selected study areas. This was gotten by defining 0.7 km2 bounding boxes around urban neighbourhoods picked from Accra and Kumasi based on related literature from Barthélemy & Flammini, (2008) and Boeing (2017).

Just like Dumedah & Garsonu (2021) points out, the grid is more prevalent at the local scale than any other network pattern in Ghana. The grid is usually indicative of a more connected network, they are characterized by short street segments and myriad interconnections coupled with more circuitous routes which improve the resilience of the network in emergency situations (Sharifi & Yamagata, 2018). The characteristic structure of the networks pattern are gridded network patterns all through the study areas, the Adum network has the characteristic radial pattern of a typical Kumasi street and this is because it is in the central part of the metropolis—most of the major streets seem to be emanating from Adum outwards. Networks selected from Accra can be said to be more gridded and of a finer grain than networks from Kumasi and there are more intersections which improve the resilience of the network. In all it can be said that the networks from both region are moderately fine grained networks, indicative of areas with relatively better planning regimes especially in Accra since it is the national capital of Ghana. Major streets from Airport Residential Area, Accra have a characteristic parallel street segments with relatively fewer connections and dead-ends on the local scale. It depicts a kind of moderate grid that is not as thorough as that of Darkuman and Nungua Central. These two are of a finer grid that of the Airport Residential Area and characteristically more connections between street segments. The characteristic network pattern of the Kumasi study areas slightly differ from one another, the Adum network is of the characteristic radial pattern as it is in the center of the metropolis. Atonsu is a characteristic tree-like structure with a gridded pattern on the local scale, also characterized by dead-ends. Tafo on the other hand is more grid-like and similar to networks from the regional capital Accra.

* Average block size of each study area and how they affect patterns (small = finegrained)



Figure 1. Six 0.7km2 sections of street network from Accra (top half) and Kumasi (bottom half)

**4.3 Network Connectivity**

Seeing as the study areas happens to be the most populated cities and neighbourhoods in the country, we sample intersection and density metrics from both cities and the respective study areas to see how connected each network is. Intersection density is the total number of intersections per unit area of the network (in our case per km2 of network area). More connected networks have a higher intersection density and contributes to the resilience and redundancy of the network (Barthélemy & Flammini, 2008; Sharifi, 2019). It is also to be noted that, a highly connected network facilitates the smooth flow of information between nodes/edges in it. From the statistical measures in Table 1, the intersection density in Airport Residential Area is 99.219 intersections per km2, 115.546 intersections per km2 in Darkuman, 114.528 intersections per km2 in Nungua Central, 120.312 intersections per km2 in Adum, 83.103 intersections per km2 in Tafo, and 82.124 intersections per km2 in Atonsu, with Adum’s intersection density greater than all the others, although the difference in density counts are not that different considering all the networks. It is typical to have the more finely grained and gridded networks with a higher intersection density than other patterns specifically the tree-like structure and the radial pattern, which is not the case here. And that is because the Adum network is made up of the best of both network patterns, a radial pattern emanating from the core of the network with a branching and grid-like pattern on the local scale, this results in a shorter street segments and frequent intersections at the local scale providing the network with a better capacity to adapt in emergency situations. Comparatively, all networks of a moderately high connectivity (Boeing, 2017b).

Consequently, all the encompassing networks have a high concentration of 1-way intersections and an even higher concentration of 3-way intersections. 2-way and 4-way intersection are not prevalent in the networks, though there is fair amount of 4-way intersection in the networks. This is a good thing as connectivity is improved with more intersections, 1-way streets typically result in less connected networks that are prone to break downs in emergency situations and less choice routes for commuters (Boeing & Riggs, 2022; Sharifi, 2019). From the related literature, it is stated that more connected networks come with health benefits as they typically promote walkability by their characteristically smaller block sizes resulting in short pedestrian trips and encouraging active commuting with improved access to amenities and services (Sharifi, 2019).

Table 1. Statiscal results for the six street network sections from Accra and Kumasi

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Indicators** | **Accra** | | | **Kumasi** | | |
| **Airport Residential Area** | **Darkuman** | **Nungua Central** | **Adum** | **Tafo** | **Atonsu** |
| n - number of nodes | 245 | 272 | 250 | 278 | 185 | 180 |
| m - number of edges | 543 | 654 | 610 | 618 | 462 | 415 |
| Total edge length (km) | 39.576 | 56.163 | 53.954 | 44.780 | 50.352 | 38.639 |
| Avg edge length (m) | 72.884 | 85.877 | 88.449 | 72.459 | 108.988 | 93.105 |
| Avg street per node | 2.359 | 2.570 | 2.600 | 2.572 | 2.692 | 2.611 |
| Intersection count | 162 | 201 | 198 | 211 | 148 | 141 |
| Total street length (km) | 19.869 | 28.082 | 26.977 | 23.636 | 25.176 | 20.341 |
| Street segment count | 274 | 327 | 305 | 338 | 231 | 222 |
| Avg street length (m) | 72.514 | 85.877 | 88.449 | 69.928 | 108.988 | 91.627 |
| Avg circuity | 1.067 | 1.037 | 1.051 | 1.085 | 1.044 | 1.121 |
| Self-loop proportion | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Clean intersection count | 118.000 | 159.000 | 154.000 | 118.000 | 127.000 | 98.000 |
| Node density (per km) | 150.054 | 156.361 | 144.606 | 158.515 | 103.879 | 104.840 |
| Intersection density (per km2) | 99.219 | 115.546 | 114.528 | 120.312 | 83.103 | 82.124 |
| Edge density (km/km2) | 24.230 | 32.286 | 31.208 | 25.533 | 28.273 | 22.505 |
| Street density (km/km2) | 12.169 | 16.143 | 15.604 | 13.477 | 14.137 | 11.848 |
| Clean intersection density (km) | 72.271 | 91.402 | 89.077 | 67.284 | 71.311 | 57.079 |
| Number of 1 way streets | 83 | 71 | 52 | 67 | 37 | 39 |
| Number of 2 way streets | 0 | 0 | 0 | 1 | 0 | 0 |
| Number of 3 way streets | 156 | 176 | 194 | 194 | 131 | 133 |
| Number of 4 way streets | 5 | 25 | 4 | 16 | 17 | 8 |
| Mean of avg neighbor degree | 2.661 | 2.809 | 2.748 | 2.591 | 2.883 | 2.595 |
| Mean of avg weighted neighbor degree | 0.094 | 0.045 | 0.044 | 0.064 | 0.032 | 0.041 |
| Avg degree centrality | 0.018 | 0.018 | 0.020 | 0.016 | 0.027 | 0.026 |
| Avg clustering coefficient | 0.027 | 0.006 | 0.008 | 0.058 | 0.010 | 0.067 |
| Avg weighted clustering coefficient | 0.004 | 0.001 | 0.001 | 0.007 | 0.001 | 0.006 |
| Max pagerank | 0.010 | 0.009 | 0.009 | 0.009 | 0.011 | 0.013 |
| Min pagerank | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.001 |
| Diameter (km) | 2.664 | 2.716 | 2.418 | 2.776 | 2.894 | 2.851 |
| Radius (km) | 1.570 | 1.423 | 1.373 | 1.488 | 1.511 | 1.428 |
| Avg closeness centrality | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Avg betweenness centrality | 0.051 | 0.049 | 0.051 | 0.057 | 0.064 | 0.065 |

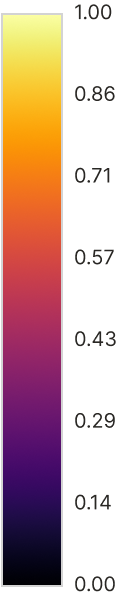
**4.4 Centrality of network components**

To really understand street network structure and form and how they affect human decisions in space, we have to understand that all components of the network are different, and how they differ depends on how they are situated in space, its neighbourhood (other components incident to it) and how it interacts with its neighbourhood. Thus, it is essential to rank nodes/edges—the main constituents of a street network graph—to obtain the centrality (or importance) of nodes/edges in the system. Several measures of centrality exist and have been used in the existing literature (Barthélemy, 2004, 2011; Barthélemy & Flammini, 2008; Boeing, n.d., 2018; Dumedah & Garsonu, 2021; O’Sullivan, 2014; Sharifi, 2019; Yen et al., 2021; Zhao et al., 2019) extensively, because of its importance for understanding the network’s form and functional relationship between nodes/edges and the critical roles they play in the network. From Table 1, the statistical measures of centrality that this study concentrates itself with include betweenness centrality, closeness centrality, PageRank, and degree centrality. This measures give insight into how connected and thoroughly configured the street network of a particular place is. Highly central nodes/edges in the system are priority elements and have to be given special attention and planned properly against failure, the disruption of central elements in the graph result in sometimes catastrophic chain reactions in the network (Sharifi, 2019). For instance, a highly central edge that is located in a disaster prone area (e.g. in a floodplain) can result in a catastrophic break in network and disrupt flow should disaster strike. It is therefore extremely necessary that planners and policymakers work together to protect, strengthen and make this network element redundant and resilient in anticipation of future phenomena that may or may not occur. The statistical indicators quantify what we can see qualitatively by plotting these variables on the street network graph for visual inspection. We take a closer look at each of the measure of centrality in the following subsections.

**4.4.1 Degree and Closeness centrality**

Closeness centrality indicates how close a node/edge is to all other nodes/edges in the graph, hence the “closeness”. Sometimes called the geodesic distance, it ranks network elements based how short the distance is between the element and other elements in the graph. The importance of this particular measure lies in its ability to identify specific nodes that control (or at the very least play a central role) in facilitating the flow of information through the network. **Figure 3**, which shows the spatial distribution of closeness centrality of each edge in each network of the selected study areas, shows that the highly central nodes which are depicted by lighter color (see **Figure 2** for colormap of the graphs) are all situated in core of network and emanate outwards towards the least central nodes. Networks selected from Accra seem to have a lighter colored outer graph (which is indicative of high closeness centrality) than their counterparts selected from Kumasi. But on the average, the closeness centrality index of each selected area (from Table 1) is 0.001 which shows that the closeness centrality of the network regardless of whether situated in Accra or Kumasi are relatively same for all areas. Which also translates to the fact that the more accessible edges in the network are located at the core of each neighbourhood and accessibility decreases as you move outside the neighbourhood. This is not surprising, as there is usually more development efforts hence greater densities in the core of neighbourhoods that the outskirts. Also, it is this development of the urban core that attracts more people to these more development areas, a classic case of cause and effect becoming interchangeable. It is therefore advisable that planning efforts in these neighborhoods focus some of its attention on improving accessibility to the outer part of the neighbourhood and its environs to facilitate flow to these parts and also to create a more redundant, resilient and loosely coupled network that can withstand disasters. To augment resilience of urban form in terms of accessibility, it is essential to consider closeness centrality when making decisions about the location of services and amenities (Sharifi, 2019).

Degree centrality in the simplest, ranks nodes based on how many connections they have. Many streets in most urban areas are characterized by moderate node degrees for most nodes in the network and few nodes with very high degree centralities (Sharifi, 2019). On the average, nodes in Airport Residential Area, Darkuman, Nungua Central, and Adum have 2 edges emanating from it, which is not surprising seeing as 3-way streets are dominant in these areas. On the other hand, Tafo and Atonsu in the Kumasi metropolis register an average of 3 streets emanating from each node in the network. Consequently, this measure is useful in less connected graphs to find nodes with unusually high degree centralities, because a failure in such nodes results in equally catastrophic damage to the network (Boeing, 2018; Sharifi, 2019).



**Figure 2**. Colormap for visual plot of centrality measures.



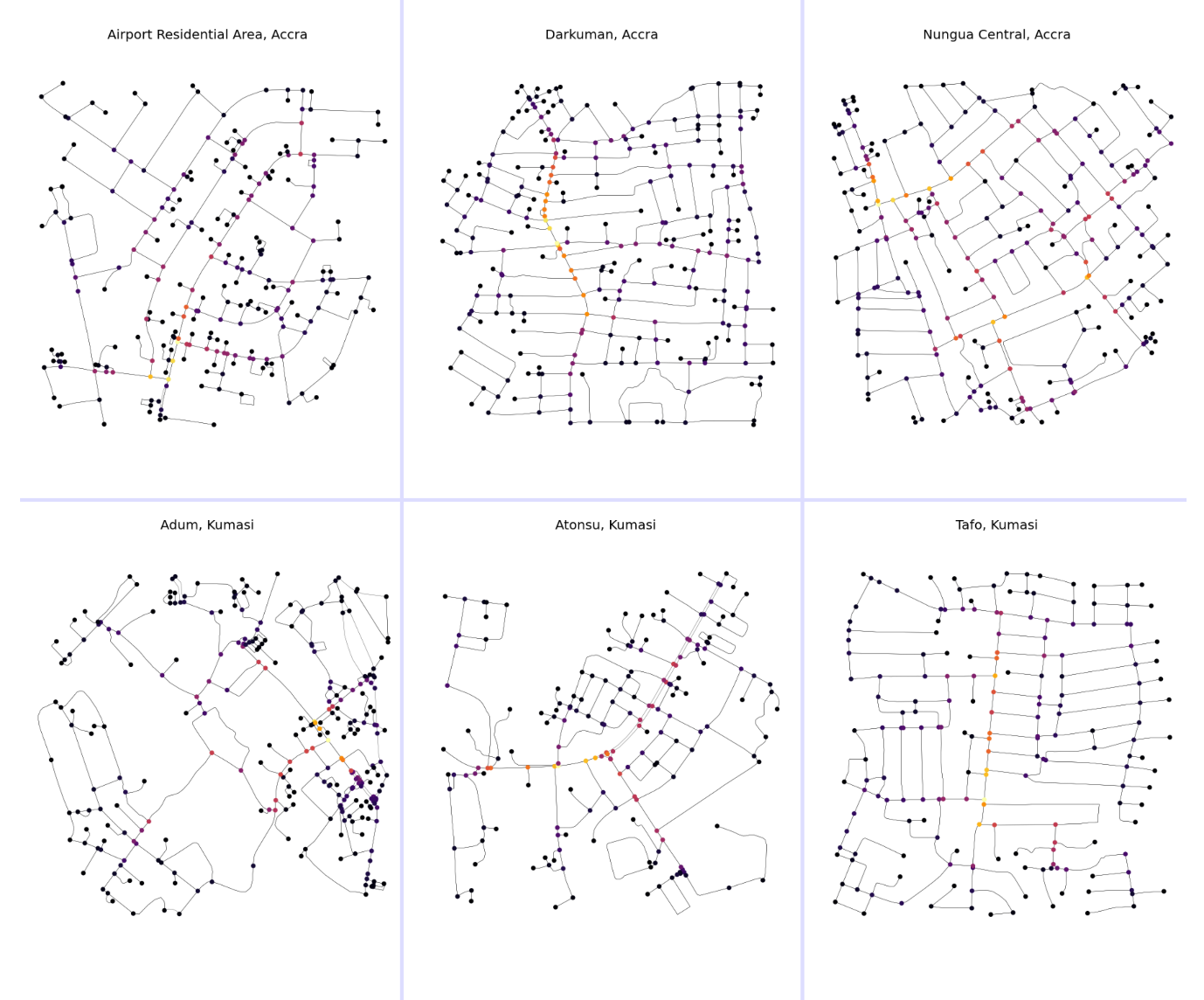
**Figure 3**. Sections of street network graph showing closeness centrality.

**4.4.2 Betweenness centrality and PageRank**

Betweenness centrality is an important measure used to rank nodes/edges on their relative importance in the network, taking into consideration the number of shortest paths that pass through the node/edge. Thus, the nodes that appears most, in all shortest paths of the network is the node with the highest betweenness centrality. From Table 1, the average betweenness centrality indicate that 5% of all shortest paths pass through an average node in Airport Residential Area, Darkuman and Nungua Central in Accra. On the other hand, in Kumasi, 6 % of all shortest paths pass through an average node in Adum and Atonsu, and 7% in Tafo. Once again, these values are not sparsely different from each other. There are more similarities between network structures than there are differences. The spatial distribution of betweenness centrality for each node in the system provides a slightly different lenses with which to view the betweenness centrality of each study site. From **Figure 4**, the spatial distribution of nodes with highest shortest paths are located as usual at the core of most of the networks with a few nuanced differences between each.

Nodes of high betweenness centrality in Airport Residential Area are more concentrated slightly south of the urban core with less central nodes at the fringes as usual. This is great for economic purposes; more central nodes concentrated around the same place generate more traffic hence are more economically viable for businesses but an uneven distribution is not good for resilience (Sharifi, 2019). Something slightly similar is prevalent in the Darkuman street network too, the most central nodes (in lighter colors) are concentrated along the same edge (running north to south) which is also good for business but bad for resilience. The destruction of a single node in the middle will result in a catastrophic chain reaction in the network. Nungua Central on the other hand, features a betweenness centrality distribution that is fairly evenly distributed in the network. This is characteristic of a more resilient network, one where highly central nodes appear at eastern, north-western and southern fringes of the network. Nodes in Kumasi follow the same pattern as Darkuman and Airport Residential Area network, in that, highly central nodes are concentrated at a single core of the network, it can be spotted in Adum in the eastern core of the network, central core in Atonsu (also running along the same edge as in Darkuman) and in Tafo also along the same edge running north to south. Boeing, (2017a) points out that, more important nodes are usually concentrated at the center of the more grid-like networks which can be seen **Figure 4** with the exception of the Nungua Central street network graph which features a more even spatial distribution of centrality. Darkuman and Tafo networks are more prone to disruptions it one of its most important node fails seeing as they are located along the same edge.

PageRank (Page & Brin, 1998) a sub variant of eigenvector centrality algorithm developed by the founders of Google to rank hypertext links has found its effective use the spatial network analysis literature (Barthélemy, 2011; Boeing, 2017a). It ranks nodes/edges based on the structure and configuration of incoming nodes/edges, it is most suited for directed graphs—street networks and other spatial networks. Neighbor degrees have a high influence on the on the centrality of the node, this also makes it harder to normalize (relate the variable to real world values).



**Figure 4**. Sections of street network graph showing betweenness centrality.