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Typology and Geometric Characterization of Urban Roads in Porto-Novo: Morphological Analysis and Implications for Development

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ABSTRACT: This article presents a detailed analysis of the typology and geometric characteristics of the urban road network in Porto-Novo, Benin. Based on a combination of field surveys, satellite images, and cadastral maps, the study identifies the different categories of roads (main, secondary, and tertiary) and examines their geometric parameters such as width, radius of curvature, and alignment continuity. The results highlight deficiencies in sizing and maintenance, contributing to mobility and road safety problems. The analysis leads to recommendations to upgrade and better plan the road network to promote harmonious urban development and reduce accessibility inequalities.

KEYWORDS: Urban typology; Urban engineering; Mobility; Urban planning, Porto-Novo

I. INTRODUCTION

Urban roads play a fundamental role in the spatial organization and development of cities. They determine mobility, accessibility to services, and land use planning. Porto-Novo, the capital of Benin, presents a road configuration inherited from both its precolonial and colonial history, as well as its contemporary urban development. However, few studies have explored in depth the typology and geometric characteristics of its road network.

The objective of this research is to analyse the structure of the road network by identifying its different typologies, geometric parameters and their implications for urban planning. The central problem is: what is the dominant typology of the Porto-Novo road network and how do its geometric characteristics influence mobility and urban planning?

II. METHODOLOGY OF THE STUDY

Porto-Novo is a city of 300,000 inhabitants located in southeastern Benin (INSAE, 2014). Its road network consists of paved roads and numerous dirt tracks. Data collection was carried out using several complementary methods to ensure a comprehensive analysis of the road network.

The main sources include field surveys carried out using GPS, high-resolution satellite images, and cadastral maps provided by municipal services. The use of GIS software such as ArcGIS and QGIS made it possible to process the spatial data, map the road network typology, and perform statistical analyses. Several parameters were examined, including road width, length, continuity, accessibility to urban infrastructure, and road network density. Subsequent field surveys were conducted to complement the map data with qualitative observations on the condition of the infrastructure and the problems encountered by users.

These different sources and methods have made it possible to obtain a global and precise vision of the urban road network of Porto-Novo, thus facilitating an in-depth analysis of its structure and its impact on urban mobility.

III. RESULTS OBTAINED

In this section, we present the results obtained during the analysis of the road network of Porto-Novo, focusing on the typology, geometric characteristics and the impact of these parameters on urban mobility.

A. Conceptual framework and literature review

Urban roads are defined as all traffic routes enabling the movement of people and goods in urban areas (Gbaguidi, 2016). They are often classified into several types (Gbaguidi, 2016). Decree 2001-092 of February 20, 2001, classifying roads of economic, tourist, or strategic interest in Benin, identifies three categories:

- Main roads which are the structural arteries and boulevards;
- Secondary roads, composed of collector roads and local streets and
- Tertiary streets serving mainly residential areas.

Geometric parameters include, according to Brilon et al. (2005), road width, radii of curvature, slope, and right-of-way. Gbaguidi (2013) adds that the organization of urban roads results from a complex interaction of multiple factors, including several historical, geographical, political, socio-economic, and technological dimensions. In this context, the initial configurations of road networks often reflect the history and planning choices of previous eras. Thus, in many cities, including those with a colonial or pre-colonial past, the organization of roads retains traces of urban patterns imposed by aesthetic or symbolic visions, sometimes to the detriment of purely functional criteria. Jacobs (1961) supports this reading by emphasizing that the vitality of a city depends largely on the quality of its urban fabric, which is shaped by historical decisions. Lynch (1960) concludes by describing how the image of a city is intimately linked to the structure of its streets and public spaces, thus illustrating the importance of historical heritage in the current configuration of road networks.

The documentary synthesis thus presented shows to what extent the topography and environmental characteristics of the territory play a determining role in the design and adaptation of road infrastructures. Furthermore, Rodrigue et al. (2009) add that the geography of a territory directly influences the possibilities of implementation and optimization of transport networks, imposing compromises between the imperatives of accessibility and the natural constraints of the environment.

In another register, public policies and urban planning strategies constitute another essential lever in the organization of roads. The absence of coherent master plans or fragmented governance can lead to unequal distribution and progressive deterioration of road infrastructure. Faced with this inadequacy, Moughtin (2003) emphasizes the importance of an integrated approach to urban planning that takes into account mobility, accessibility, and the quality of public space. Similarly, UN-Habitat (2013) highlights the negative effects of poor planning on the quality of urban life, emphasizing how poorly organized road networks can contribute to the exacerbation of territorial and social inequalities. The rapid evolution of the urban population and economic transformations are indeed factors that induce an increased demand for transport infrastructure to the extent that demographic growth and the growth of economic activities require a constant reconfiguration of road networks to meet the needs of diversified mobility (Gbaguidi, 2013).

Technological advances, including the use of geographic information systems (GIS) and urban modelling tools, have transformed the way road networks are analysed and planned (Gbaguidi, 2016). These technologies allow for better visualization of traffic flows, anticipation of changes in demand, and detailed assessment of network performance. Similarly, the emergence of new approaches to sustainable mobility is encouraging a rethinking of road systems to integrate solutions that promote soft and collective modes of transport. Gehl (2010), for example, proposes a human-centered approach that challenges the predominance of the private car and promotes developments that facilitate walking, cycling, and public transport.

In Benin and West Africa, several studies have highlighted the difficulties associated with structuring road networks in African cities. Gbaguidi (2013) showed that rapid urban growth in Benin has not been accompanied by proportional development of road infrastructure. Similarly, studies conducted by Derrible (2012) on urban transport networks in Africa highlight the lack of regulatory planning.

In view of the table thus described, the combined analysis of field surveys, satellite images, and cadastral maps has made it possible to identify a contrasting distribution of the different types of roads in the city.

B. Typology of roads

The road network of Porto-Novo, categorized into three (03) types and includes asphalt roads, earth roads, waterways, and railways. Figure No. 01 shows a distribution of this network.

Figure No. 1: Road network of the city of Porto-Novo

- ***Main roads***

With a total length of 13,471 m, the main roads, often built according to standards inherited from the colonial era, occupy a strategic place in the organization of the city. Although they are relatively few, they provide a link between the main urban activity centers. Table 1 summarizes the entire road network of the primary network.

TABLE 1: SUMMARY OF THE MAIN STREETS OF PORTO-NOVO

Name of the road	Linear (km)	Coating
RNIE 1_bis	2,602	
Rue 40, RNIE 1 bis, Rue 40 RNIE 1 bis	2,554	Asphalt
Lagunaire Boulevard, Djassin Boulevard	8,315	Asphalt
Total Linear	13,471 km	

The analysis of the level of service on this network reveals a varied situation ranging from streets in good condition to streets whose sanitation works and related works are malfunctioning, as illustrated by figure No. 02

Figure No. 02: Damage on the Carrefour Adjarra Docodji - Carrefour Agata section

- ***Secondary roads***

Secondary roads serve as collector roads. They connect main roads to residential areas and outlying neighborhoods and are characterized by dimensions that are often smaller than current standards (reduced width, winding layout).
On this type of road, the level of maintenance varies. While some roads are well maintained, the majority suffer from deterioration due to weather or human activity, as illustrated in Figure 3.

Figure No. 03: Degradation of a secondary street

From this photo, it is clear that the street presents several types of degradation, the most significant of which are related to the removal of road layers. This state of affairs can be explained by human settlements that precede planning, as well as an under-dimensioning of the infrastructure.

- ***Tertiary streets and urban tracks***

Mainly located on the outskirts and in less densely populated areas, tertiary roads serve homes and local amenities. They cover a length of 651.53 km.

Overall, the majority of urban roads (approximately 98.23%) fall into the secondary and tertiary categories. This justifies the need for a redevelopment and maintenance policy to improve accessibility and streamline traffic flow throughout the city.

C. Geometric characteristics of the network

The geometric analysis of the road network focused on several key indicators, including road width, curvature radius, alignment linearity, and network density. The main findings are as follows:

TABLE NO. 02: GEOMETRIC CHARACTERISTICS OF THE NETWORK

Features	Description
Total length of the network	748,623 km
Network density	6.81 km/km²
Average track width	7 to 10 meters for the main roads; 5 and 7 meters for secondary and tertiary roads
Type of coating	cobblestone, asphalt, concrete and earth or gravel
Proportion of main roads	1.80%
Proportion of secondary roads	11.20%
Proportion of tertiary pathways	87.00%
Total number of primary channels	03
Total number of secondary roads	81
Total number of tertiary pathways	3431

Reading this table, it appears that several geometric characteristics of the tracks are not in line with the standards. Thus, the deficiencies by component are presented as follows:

- **Track width**

Measurements indicate that nearly 60% of roads are less than 6 meters wide, which is insufficient to accommodate increasingly dense and varied traffic (light vehicles, public transport, two-wheelers). This finding is particularly worrying for secondary and tertiary roads.

- **Radius of curbature:**

Analysis of the routes shows that the curve radius of the tracks is often less than 50 meters. Such dimensions, combined with winding routes, complicate maneuvers and increase the risk of accidents, particularly for large vehicles.

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- ***Radius of curvature:***

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Figure No. 04: Small radius of curvature

- ***Linearity and continuity***

The road segment study revealed a fragmented network, with sections of roads interrupted or disconnected, particularly in informally developed neighborhoods. This discontinuity limits traffic flow and complicates efficient route planning.

- ***Network density***

The high network density in the historic center contrasts with a more dispersed structure on the outskirts. This geographic disparity contributes to inequalities in accessibility and service quality, negatively affecting mobility in certain neighborhoods.

These geometric characteristics, combined with often poor maintenance conditions, have a direct impact on the quality of traffic and user safety.

D. Impact on mobility and urban planning

The characteristics observed in the road network of Porto-Novo have several consequences on mobility and urban planning: reduced accessibility, congestion and road insecurity and a deficit in development and planning.

The predominance of narrow, winding roads limits access to essential amenities (healthcare services, schools, shopping centers), particularly for residents of outlying areas. This situation exacerbates spatial and social inequalities.

Similarly, the low capacity of main roads and the poor quality of secondary roads lead to recurring congestion, particularly during rush hour. Furthermore, the combination of winding roads and poor maintenance increases the risk of road accidents, compromising the safety of pedestrians and motorists.

The lack of an integrated vision for urban planning, coupled with poorly sized road infrastructure, leads to inefficient use of urban space. Furthermore, the network's discontinuity also limits the implementation of sustainable transport solutions (bicycles, public transport) and hinders overall mobility.

These findings highlight the need for targeted interventions to rehabilitate and optimize the road network, in order to improve the quality of life of residents and promote harmonious urban development.

IV. DISCUSSION AND RECOMMENDATIONS

A. Interpretation of results

The typology and geometric characteristics of Porto-Novo's road network highlight an uneven and sometimes inadequate structure in the face of modern urbanization requirements. The results obtained confirm some observations already noted in the literature on African cities, where the colonial legacy and the lack of rigorous planning generate fragmented road networks (UN-Habitat, 2013).

Comparison with other cities in the sub-region, such as Cotonou or Abidjan, reveals common trends, particularly in terms of weak secondary infrastructure and network discontinuity. However, Porto-Novo also presents specific features, such as a strong presence of tertiary roads in peripheral districts and a marked spatial dispersion, which call for development solutions adapted to the local context.

B. Recommendations for network planning and *management*

Based on the findings, several areas of intervention can be considered:

- A requalification and maintenance of the existing network by a prImproving the renovation of secondary and tertiary roads, in particular by widening lanes where possible in order to improve traffic flow and implementing a regular maintenance plan to prevent the deterioration of infrastructure and guarantee user safety.
- Integrated urban planning across the development of a road master plan that integrates mobility needs, road safety and accessibility to public services as well as the development of intermodality by creating cycle paths, secure sidewalks and integrating suitable public transport solutions.

- Optimization of routes and intersections through redefinition of the geometry of certain roads to improve traffic flow, in particular by adjusting the radii of curvature and simplifying the routes in areas with high congestion and the installation of appropriate signage and traffic control devices at critical intersections.
- Involvement of local stakeholders through interaction local authorities, users and urban planning experts in a participatory approach for the design and implementation of improvement projects as well as the establishment of monitoring and evaluation mechanisms will also make it possible to adjust interventions according to the evolution of needs and constraints on the ground.

These recommendations, if implemented in a coherent and integrated manner, could not only improve mobility in Porto-Novo, but also contribute to more balanced and sustainable urban development.

CONCLUSIONS

The study of the typology and geometric characterization of Porto-Novo's urban road network reveals significant challenges in terms of mobility and planning. The predominance of narrow and winding roads, combined with network fragmentation and insufficient maintenance, limits accessibility and increases the risks of congestion and accidents.

The results obtained highlight the need for far-reaching reforms in road network management and planning. The implementation of an integrated master plan, the redevelopment of existing infrastructure, and the involvement of local stakeholders are essential levers for transforming roads into a real asset for urban development.

Finally, this research opens up avenues for future studies that could explore, for example, the impact of these developments on the urban environment or the socio-economic benefits of a modernized road network. Comparative analyses with other cities in the region would also provide lessons that can be applied to all of Africa's rapidly changing cities.

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