RESEARCH PAPER

OPTIMIZING URBAN PLANNING THROUGH SPATIAL NETWORK ANALYSIS: A CASE STUDY OF DANANG CITY

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ABSTRACT. Urban planning is a complex process that addresses present conditions while shaping future development. However, it often relies on subjective assessments by planners and managers. This study explores the spatial network of Da Nang City through Multiple Centrality Assessment (MCA) and Space Syntax Analysis to provide an objective basis for urban planning. Key indicators, including Connectivity (Space Syntax), are calculated to assess movement, accessibility, flow, and social interaction within the urban network. Additionally, Closeness, Betweenness, Straightness, and Angular Centrality (MCA) are measured, highlighting the significance of streets and intersections in shaping urban dynamics. The findings are evaluated against Da Nang's urban planning framework to assess its effectiveness and propose solutions for optimizing the master plan. The study identifies strengths and areas for improvement in the city's layout, resulting in a proposed urban structure organized around five functional cores to enhance connectivity, efficiency, and sustainable growth. This research offers data-driven insights to assist urban planners in refining Da Nang's spatial framework, contributing to the city's long-term resilience and sustainable development.

KEYWORDS: Space Syntax, Multiple Centrality Assessment, urban configuration, spatial network, sustainable urban development

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INTRODUCTION

The urban spatial network is fundamental to the functioning of a city, influencing the flow of human activity, social interactions, and economic processes. The configuration of the street network plays a vital role in determining how effectively these elements operate. A well-organized street system improves connectivity and accessibility, facilitating smoother movement and shaping land use patterns (Hillier et al. 1993). Recognized as a cornerstone of urban mobility, the structure of urban networks has been studied extensively. Hillier (1996) pioneered Space Syntax, a methodology for examining spatial configurations, which has since been instrumental in revealing how street layouts affect movement dynamics (Seamon, 2015).

A key analytical tool in understanding urban networks is betweenness centrality, which quantifies how frequently a street segment falls along the shortest route between other points. This concept, rooted in graph theory, has become an essential metric for estimating the potential movement of pedestrians and vehicles within urban areas (Turner, 2007). By identifying likely paths of movement, betweenness centrality provides insights into how specific streets might shape land use and economic activity.

Research into the relationship between urban spatial structures and land use has increasingly focused on betweenness centrality. Porta et al. (2006) demonstrated that streets with higher centrality scores are more likely to support dense land use activities, such as commercial and retail functions (Porta et al., 2006b). High-centrality streets naturally attract greater foot traffic, making them ideal locations for businesses that depend on visibility and accessibility.

The interaction between land use and urban form is shaped by numerous factors, including social, economic, and environmental considerations. However, the spatial arrangement of the urban network plays a decisive role in directing land use patterns. Streets with high centrality often accommodate retail and public services, while quieter residential zones are typically located along streets with lower centrality (Marshall and Banister, 2007). Jiang and Claramunt (2004) identified a strong connection between street centrality and the diversity of land use, with high-centrality areas supporting mixed uses that foster urban vibrancy and economic growth, whereas low-centrality zones are often characterized by single-use developments, such as residential or industrial areas (Jiang and Claramunt, 2004).

Incorporating betweenness centrality into urban planning has proven effective in designing more integrated and efficient urban environments. Sevtsuk and Mekonnen (2012) highlighted the value of centrality indices in guiding the placement of infrastructure, transportation routes, and new developments (Sevtsuk and Mekonnen, 2012). Similarly, Shi et al. (2024) underscored the role of spatial analytics in optimizing the siting of commercial projects in fast-growing urban areas, with betweenness centrality serving as a critical factor in planning decisions (Shi et al., 2024).

Urban planning in Vietnam has traditionally been driven by population size, which serves as the primary metric for determining land use and transportation networks. Consequently, the spatial configuration of urban areas often reflects the current state of cities and their projected growth, relying heavily on the judgment and experience of planners. The absence of comprehensive legal frameworks for spatial planning and land use regulation frequently results in adjustments and reconfigurations during project implementation to address unforeseen challenges.

Da Nang, Vietnam's third-largest city, received approval in 2019 from the Prime Minister to undertake a comprehensive urban planning overhaul through 2030, with a longer-term vision extending to 2045 (Prime, 2019). This ambitious initiative encompasses multiple aspects of urban development, focusing on land use, infrastructure, and spatial reorganization. The plan emphasizes restructuring Da Nang's urban framework to promote integrated growth. Key priorities include refining spatial development models, reorganizing urban zones, and aligning economic and social infrastructure. Additionally, the project seeks to integrate road, rail, and waterway networks while promoting non-motorized transport and expanding public transit systems to enhance connectivity and reduce congestion. Another critical aspect involves developing mixed-use zones that combine residential, commercial, and cultural facilities, fostering vibrant and multifunctional urban spaces (Danang People's, 2020)

This study employs Multiple Centrality Assessment (MCA) and the Space Syntax methodology to address gaps in Da Nang's ongoing urban planning efforts. By interpreting the urban network as a spatial configuration, the study examines key indicators, including Connectivity (Space Syntax), along with Closeness, Betweenness, Straightness, and Angular Centrality (MCA) (Porta et al., 2006a). These metrics are analyzed in relation to the city's development plans to assess their alignment and identify areas requiring revision. The study offers valuable insights into Da Nang's spatial network, equipping planners and policymakers with a data-driven foundation for enhancing urban resilience, refining spatial strategies, and promoting long-term sustainable growth.

Literature Review

Research exploring the relationship between street space configuration, betweenness centrality, and land use consistently reveals strong correlations. Rui and Ban (2014) demonstrated that various centrality measures in Stockholm are closely linked to distinct land-use types, illustrating how street characteristics reflect broader urban development patterns (Rui and Ban, 2014). Hillier et al. (1993) introduced the concept of configurational paradigms, proposing that the design of urban grids significantly influences pedestrian movement, with retail areas thriving due to the natural flow of foot traffic (Hillier et al., 1993). Porta et al. (2009) reinforced these findings through a study in Bologna, showing that areas with greater street centrality have denser concentrations of retail and service activities, particularly those associated with global betweenness (Porta et al., 2009). Extending this framework to American cities, Berhie and Haq (2017) highlighted that retail clusters often align with configurational hotspots, shaping residential location choices and commuting patterns (Berhie and Haq, 2017).

Further expanding on these insights, Das (2024) integrated the Gravity Index, Straightness, Betweenness, and Closeness Centrality to analyze the interplay between land use and street network configuration (Das and Ram, 2024). Collectively, these studies underscore the critical role of street configuration and centrality in shaping urban landuse and movement. However, much of this research has been conducted in Western cities, where landuse and urban structures are formalized and clearly delineated. In contrast, the informal and dynamic nature of landuse in Vietnam necessitates further investigation to understand how these relationships manifest in less rigid urban contexts.

Similarly, studies in Asian cities, such as Liu's (2016) research on Wuhan, reveal strong links between street centrality and land-use intensity. Liu's work demonstrates that these relationships vary across land-use types and within subcategories of the same landuse. However, the focus was primarily on landuse intensity rather than the distribution of land uses across the street network (Liu et al., 2016). Li (2019) expanded on the topic by examining the spatial distribution and intensity of landuse, identifying a consistent hierarchy in which different landuse types respond to location centrality, with commercial areas showing the highest sensitivity, followed by residential and industrial zones. This relationship was found to adhere to a power law, reflecting spatial variability in land-use intensity. Despite its broader scope, Li's study primarily examined urban structures at a macro scale and did not account for informal land-use conversions by residents, which often reshape urban networks (Li et al., 2019).

Additional studies by Song (2023), Yin (2022), and Wang (2018) delve into the dynamic relationship between urban transportation (street centrality) and land-use intensity (Song et al., 2023, Yin et al., 2022, Wang et al., 2018). These studies highlight the interactive feedback loop between urban form and mobility. Meanwhile, Kang (2015) investigates the influence of urban spatial network indices on user behavior, focusing on pedestrian movement and human interaction within urban environments (Kang, 2015).

The growing interest in the relationship between street configuration, accessibility, and social interaction reflects an increasing awareness among urban planners, geographers, and architects of the importance of spatial networks in shaping cities. Understanding these connections is essential for designing urban environments that are not only efficient and accessible but also socially vibrant and sustainable.

METHODOLOGY

Data preparation process

Da Nang, located in central Vietnam, serves as the administrative and commercial hub of the region (Fig. 1). As of 2019, the city had a population of 1,134,310 people (Danang People's, 2020) , making it the largest city in Central Vietnam and the fourth largest in the country. This study utilizes street network data extracted from Open Street Map (OSM) using the Python programming language and the Osmnx package developed by Jeff Boeing (Boeing, 2017). This data serves as the foundation for Connectivity analysis in DepthmapX. Furthermore, the Closeness, Betweenness, Straightness, and Angular Centrality indexes were analyzed using the Momepy package created by Martin Fleischman (Fleischmann, 2019). Data regarding urban spatial development orientation, land use, and transportation networks were compiled from the approved master plan of 2013 and the General Planning adjustment for Da Nang in 2030, with a vision extending to 2045 (Danang, 2018).

Axial Map

Urban public space is predominantly linear in nature. The built environment's street grid can be visualized as a network of interlinked axes, with each axis representing the longest sight line within a particular urban space (Fig. 2). These axes form the foundation for calculating the spatial relationships between different urban areas. By simplifying the urban landscape into a spatial model composed of these axes, we can analyze the topological, geometric, and metric connections between various urban spaces. This approach allows for a more structured understanding of how different areas within a city are interconnected.

When creating an axial map, it is essential to draw it on a separate layer and adhere to some fundamental guidelines. The primary rule is to represent all streets, roads, paths, and similar elements as a set of the longest and fewest axial lines. These lines should be drawn to ensure that, at every change in direction, individual axial lines (also referred to as 'axes') overlap accurately. Although this may result in unsightly stubs at junctions and bends in curved streets, it is more important to avoid disconnecting streets that should be connected in the map. Another key principle in space syntax is the need to 'unlink' axial lines that visually cross each other but do not actually connect in reality. Urban spaces often contain overlapping axial lines that, despite appearing connected in a plan view, are not physically connected. Examples of such situations include overpasses, underpasses, tunnels, and stairways. Connecting these overlapping lines on the axial map would result in a

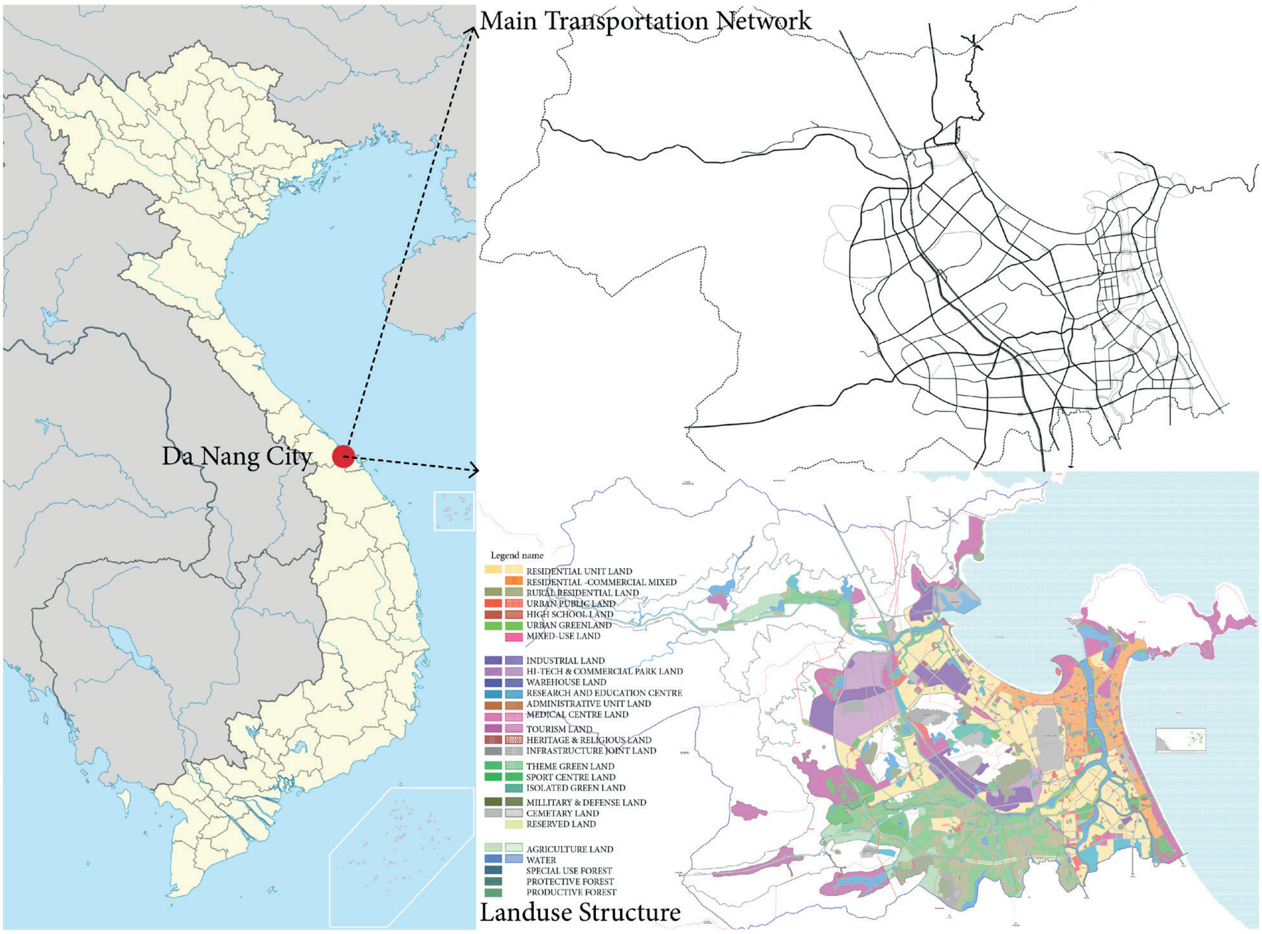

Fig. 1. Danang city location and research boundary

Fig. 2. An axial representation of an urban area in Danang

distorted and inaccurate analysis. Therefore, it's crucial to use space syntax software to unlink these lines to reflect the actual spatial relationships accurately (van Nes et al., 2021).

Space syntax theory and technique

Space syntax theory offers a framework for examining how spatial configuration impacts human behavior. It suggests that the organization of spaces, especially within urban settings, plays a crucial role in shaping movement patterns, social interactions, and other spatial dynamics (Batty, 2004). At the core of this theory is the analysis of street networks and the measurement of spatial characteristics, such as integration and connectivity (Al Sayed et al., 2014). By representing spatial layouts with axial lines and segments, space syntax allows for the measurement of how accessible and interconnected different spaces are (Matějček and Přibyl, 2020). These measurements have been demonstrated to correlate with pedestrian movement, social interactions, crime distribution, and economic activity (He et al., 2021). Space syntax, with its quantitative approach and predictive abilities, provides valuable insights for urban planning, architecture, and other fields focused on understanding and shaping the built environment. However, it is crucial to recognize the theory's limitations, such as its simplification of complex human behavior and the need for careful interpretation of results within particular contexts (Caniggia and Maffei, 2001).

The space syntax algorithm is a set of computational methods designed to analyze and quantify spatial configurations within buildings, urban environments, and other spatial systems. By using these algorithms, we can explore how spaces are connected, accessible, and integrated, as well as how these spatial characteristics influence human behavior and movement patterns. Essentially, the algorithm transforms physical spaces into networks of connections and calculates metrics that describe their spatial relationships (Van Nes, 2014).

An important index in Space Syntax utilized in this research is Connectivity, which measures the direct accessibility of a space (or node). It represents the number of immediate connections a space has with other spaces. Essentially, Connectivity indicates how many other spaces or axial lines directly connect to a particular space, making it a fundamental metric for understanding local accessibility within the spatial system. For a given space or axial line *i*, the Connectivity *k(i)* is calculated as (Eq. 1):

$$k(i) = \sum_{j \in N(i)} 1 \tag{1}$$

where *k(i)* - Connectivity of space *i*, *N(i)* - the set of spaces that are directly connected to space *i*

DepthmapX is an open-source software developed by Alasdair Turner at University College London, based on the Space Syntax research framework. It is extensively used in architecture, urban design, and spatial planning to analyze spatial networks. The software allows users to perform various analyses, including Visibility Graph Analysis (VGA), axial line analysis, and segment analysis, to gain insights into spatial connectivity and movement patterns (Turner, 2001). DepthmapX's graph-based analyses enable the measurement of spatial connectivity, integration, and choice, which are essential in urban planning and architectural design. These metrics assist planners and designers in assessing and optimizing the layout of cities, transportation systems, and buildings, thereby improving accessibility and functionality (Hillier & Hanson, 1988). The software also aids in wayfinding by analyzing how people navigate complex environments, such as airports and hospitals, offering valuable insights for enhancing spatial design. Additionally, DepthmapX produces visual outputs like heatmaps and spatial graphs, which help interpret and communicate spatial data effectively during the design process (Turner, 2007). In summary, DepthmapX is a vital tool for analyzing and optimizing the interaction between spatial configurations and human movement.

Multiple Centrality Assessment (MCA)

Multiple Centrality Assessment (MCA) is a spatial network analysis method rooted in graph theory that evaluates the structural importance of nodes and links within urban networks. By analyzing how streets and intersections contribute to overall connectivity and movement, MCA offers critical insights into urban accessibility, transportation efficiency, and land use patterns (Crucitti et al., 2006). This approach aids urban planners in understanding how spatial configurations shape pedestrian and vehicular flow, informing decisions on infrastructure and development. MCA incorporates key centrality measures that highlight various dimensions of network connectivity.

(1) Closeness centrality reflects how accessible a node is by measuring its average distance to all other nodes, often indicating well-integrated areas that facilitate movement and interaction (Freeman, 2002) (Eq. 2):

$$C_C(v) = \frac{1}{\sum_{u \in V} d(v,u)} \tag{2}$$

where $C_C(v)$ represents the closeness centrality of node v,$d(v,u)$ is the shortest path distance between node v and node u, and V denotes the set of all nodes in the network. A higher $C_C(v)$ value indicates greater accessibility and proximity to other nodes.

(2) Betweenness centrality identifies nodes that frequently appear on the shortest paths between others, underscoring their role as vital connectors or potential bottlenecks in the network (Newman, 2005). These nodes often correspond to commercial hubs or critical intersections (Eq. 3):

$$C_B(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}} \tag{3}$$

where $C_B(v)$ denotes the betweenness centrality of node v,σ_{st} is the total number of shortest paths from node s to node t, and $\sigma_{st}(v)$ is the number of these paths that pass through node v. Nodes with high $C_B(v)$ are critical for facilitating movement within the network and act as bottlenecks or hubs for traffic flow.

(3) Straightness centrality measures the directness of routes between nodes, with higher values indicating more efficient paths that minimize detours (Crucitti et al., 2006). Complementing this, angular centrality assesses the degree of deviation in paths, emphasizing routes with fewer turns, which are typically more navigable and frequently used (Turner, 2007) (Eq. 4):

$$C_S(v) = \frac{1}{n-1} \sum_{u \in V, u \neq v} \frac{d_E(v,u)}{d(v,u)} \tag{4}$$

where $C_S(v)$ is the straightness centrality of node v,$d_E(v,u)$ represents the Euclidean distance between nodes u,$d(v,u)$ and is the shortest path distance, and n is the total number of nodes in the network. A $C_S(v)$ value closer to 1 indicates that the paths are highly efficient and direct.

(4) Angular centrality evaluates the angular deviation along paths, prioritizing routes with minimal turning costs to ensure smoother and more efficient navigation. This metric highlights navigational smoothness, making it particularly relevant in urban studies where wayfinding and the directness of routes play a critical role in influencing movement patterns (Eq. 5).

$$C_A(v) = \frac{1}{\sum_{u \in V} \theta(v,u)} \quad (5)$$

where $C_A(v)$ is the angular closeness centrality of node v, and $\theta(v,u)$ is the total angular deviation along the shortest path between nodes v and u. Nodes with high angular centrality values facilitate more efficient navigation by minimizing angular changes.

By integrating these metrics, MCA enables urban planners to identify high-connectivity areas, improve transportation networks, and optimize land use planning. This comprehensive analysis enhances the design of urban spaces, fostering resilience, accessibility, and sustainable development (Sevtsuk and Mekonnen, 2012).

RESULTS

Closeness Centrality Analysis

Closeness Centrality is a fundamental metric in network analysis used to evaluate the relative "proximity" of a node to all other nodes within a network. It measures the average shortest distance from a given node to all other nodes, providing insight into its potential to quickly access or interact with other parts of the network. In simpler terms, it identifies areas with strong accessibility and efficient connections. Closeness 400 and Global Closeness are two robust analytical tools frequently employed in infrastructure planning, each serving distinct purposes at varying scales of urban planning.

Fig. 3a shows how local closeness centrality (R = 400 m) is spread out, focusing on connection levels within a 400-meter area. Red and orange areas indicate places with good local access, usually found in city centers, transit stations, or crowded areas with effective internal networks. Conversely, blue and green areas reflect lower connectivity levels, often associated with suburban or peripheral regions where infrastructure is less developed. This analysis reveals significant spatial disparities in urban accessibility, underscoring the need for targeted infrastructure investments. Such insights are critical for guiding strategic interventions aimed at enhancing mobility, reducing fragmentation, and promoting equitable access to services across the city.

A comparison of the analysis results with existing and future land-use plans highlights four key areas for consideration (Fig. 4): Area 1: Although designated for mixed-use purposes, including residential, commercial, and tourism activities, this area exhibits relatively low local accessibility within the spatial structure; Area 2: Planned as a new residential area and envisioned as the southern urban center of the city, this region also demonstrates low connectivity in the analysis; Areas 3 and 4: While positioned near the newly planned satellite urban centers, these areas similarly show limited local accessibility, indicating the need for enhanced connectivity.

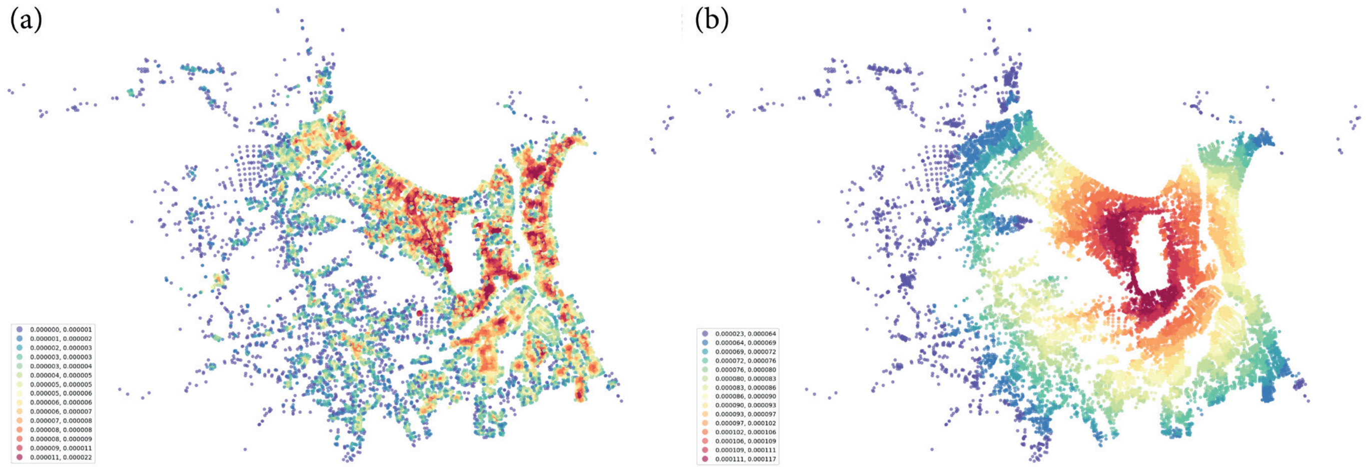

Fig. 3. Closeness Centrality Analysis of Da Nang: (a) R400; (b) Rn

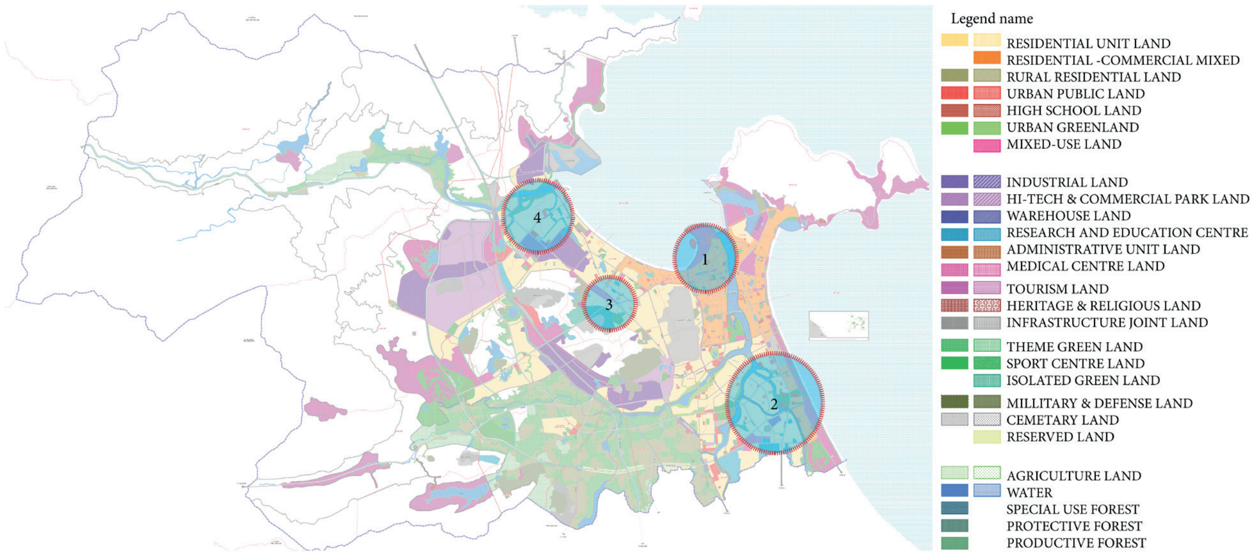

Fig. 4. The planned areas do not meet expectations due to the low local connectivity of the regions

The analysis of global closeness centrality (Fig. 3b) reveals a concentration of high-connectivity zones (red areas) within the city center, indicating a monocentric urban structure. This pattern is predominantly characterized by the dominance of areas surrounding the airport, encompassing districts such as Hai Chau, Thanh Khe, and parts of Lien Chieu and Cam Le. These districts exhibit superior connectivity and accessibility, making them the focal points of urban activity.

In contrast, peripheral districts such as Son Tra and Ngu Hanh Son display low global centrality values, suggesting potential challenges in accessing essential services and economic opportunities. Such evidence highlights the pressing need for infrastructure development in these areas to improve connectivity, reduce spatial inequalities, and foster balanced urban development. Strategic investments in transportation networks could significantly enhance mobility, strengthen the urban fabric, and promote equitable growth across all regions of the city.

Betweenness Centrality Analysis

The edge-based betweenness centrality of an urban road network highlights the importance of various roads in facilitating movement and connectivity across the city. Betweenness centrality measures how often a particular edge (road segment) lies on the shortest path between pairs of nodes, indicating the criticality of that edge in terms of traffic flow and connectivity.

Red and dark orange lines indicate roads with high betweenness centrality, representing key traffic conduits like highways and major transit corridors. Yellow to light purple lines show moderate to low centrality, typically local streets or minor connectors. Purple and blue lines reflect very low centrality, representing cul-de-sacs, dead ends, or peripheral paths. The concentration of high-betweenness edges in the city center and along major corridors highlights the structural importance of these routes (Fig. 5). These areas are essential for maintaining traffic efficiency and reducing congestion. Peripheral roads with low betweenness suggest limited integration with the core network, indicating potential areas for future infrastructure development to enhance connectivity. Roads with the highest betweenness values may face greater risk of congestion or disruption if blocked, underscoring the need for network redundancy and alternative routes to distribute traffic more evenly.

When compared with the planned transportation network, most major roads in Da Nang's master plan align with roads that exhibit high betweenness centrality. However, there are still certain roads with high betweenness centrality (highlighted in black in Fig. 6) that have been overlooked in the planned primary transportation network. Additionally, the circled areas in Fig. 6 warrant reconsideration during the planning of the internal road network. These areas remain disconnected from the primary planned network, highlighting the need for better integration to enhance connectivity across the entire urban system.

Straightness centrality of spatial network

Reflects efficient paths with minimal detours, the straightness centrality of an urban road network, indicating how directly connected each road segment is to others in the network. Straightness centrality measures the efficiency of travel along a network, comparing the shortest path (geodesic distance) to the actual path along the network. High straightness values signify minimal detours, reflecting well-aligned, direct routes (Fig. 7a).

The color gradient from red to blue represents roads with varying levels of straightness centrality, where red indicates high straightness and blue represents low straightness. Areas with high straightness centrality play a crucial role in facilitating efficient movement and reducing travel expenses. In contrast, peripheral regions with low straightness suggest fragmented or less direct infrastructure, potentially increasing travel times and limiting accessibility.

Overall, the urban structure of central Da Nang is relatively coherent and well-oriented, providing convenience for both residents and tourists. However, certain areas highlighted in Fig. 7b require attention to

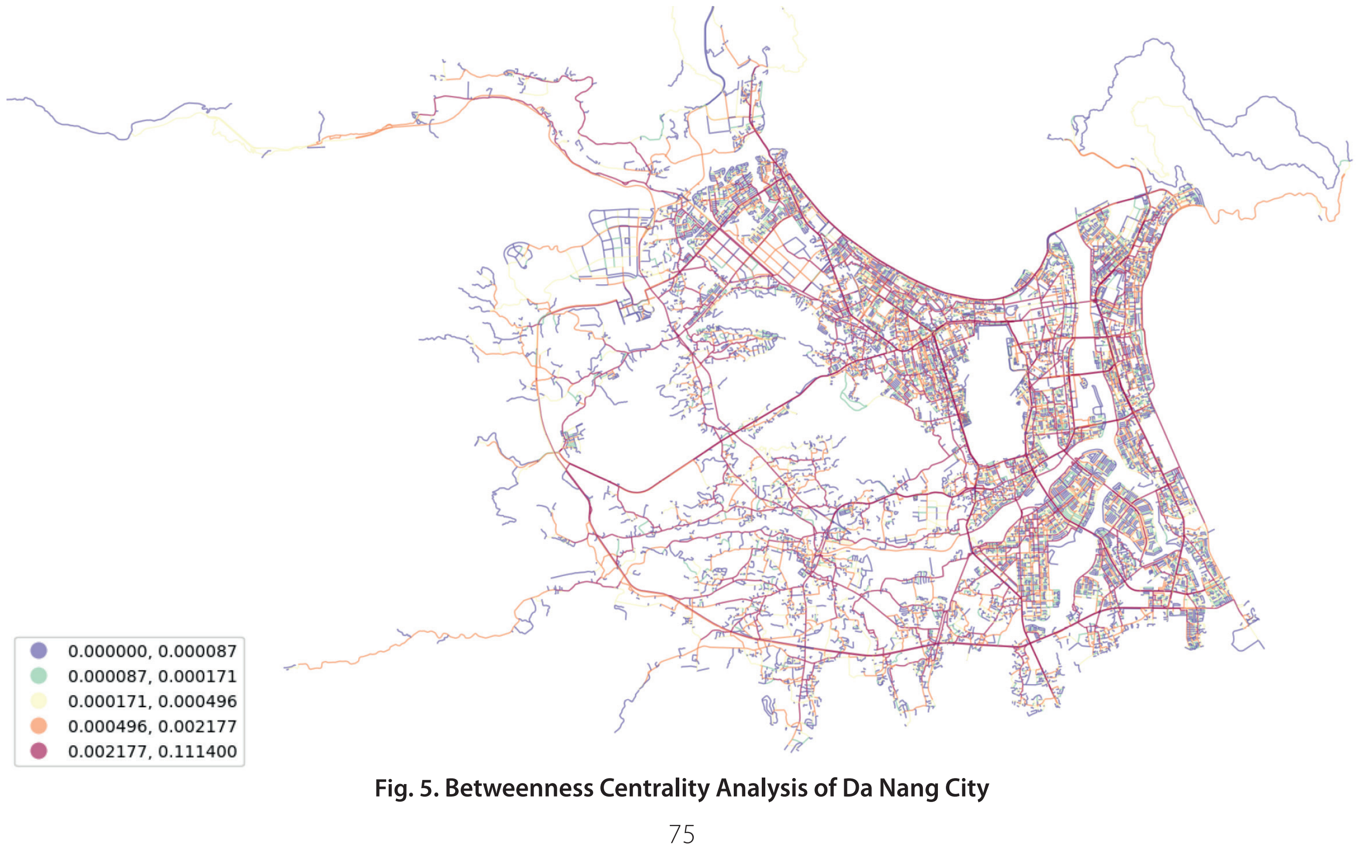

Fig. 5. Betweenness Centrality Analysis of Da Nang City

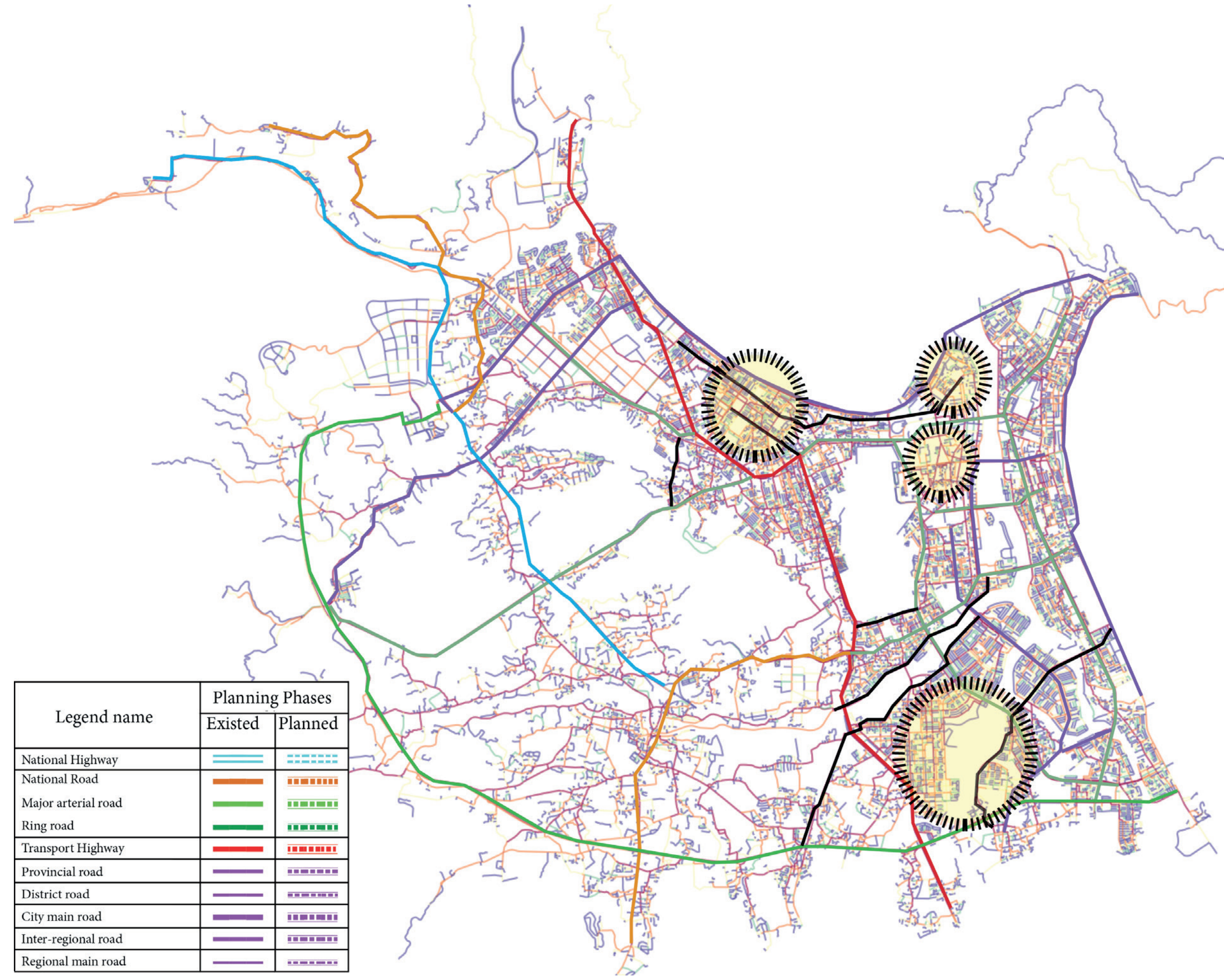

Fig. 6. Overlay analysis of the planned transportation network and Betweenness Centrality

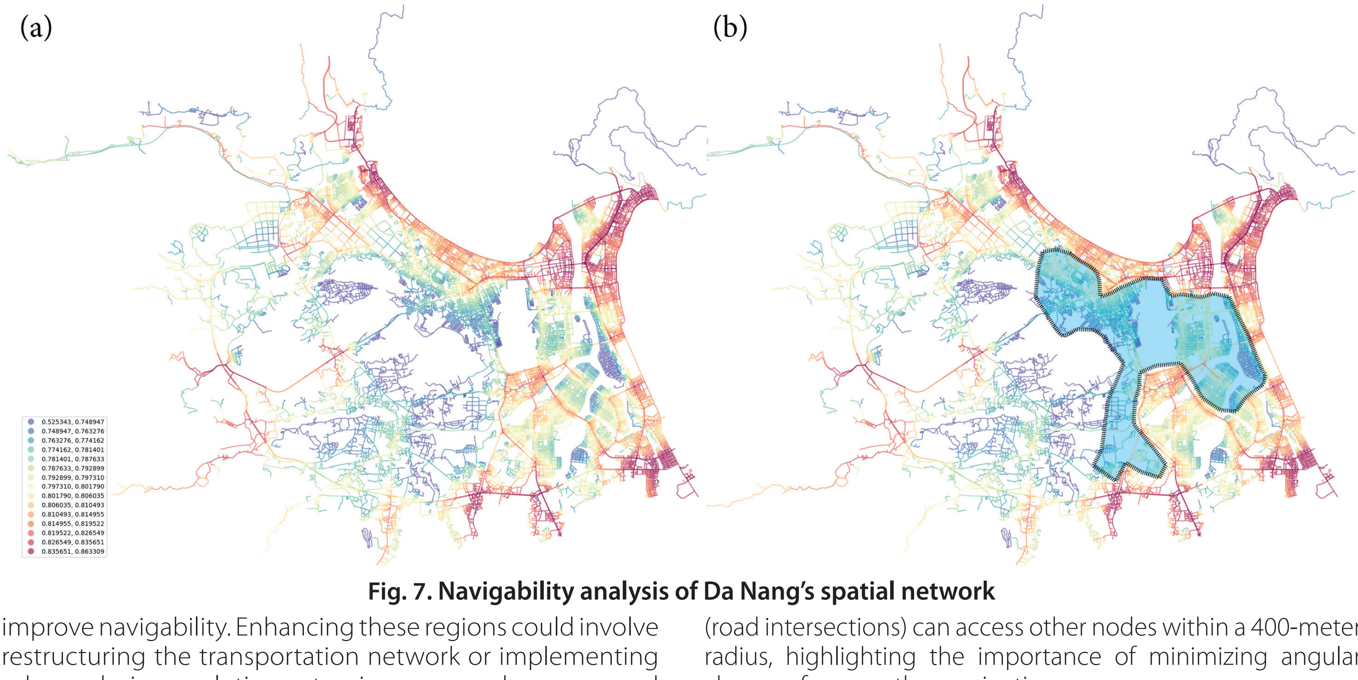

Fig. 7. Navigability analysis of Da Nang's spatial network

improve navigability. Enhancing these regions could involve restructuring the transportation network or implementing urban design solutions to improve coherence and orientation, ultimately fostering greater accessibility and ease of movement.

Exploring angular closeness centrality

Fig. 8a visualizes the angular closeness centrality (R = 400 m) of an urban road network, derived from a dual graph representation. This analysis captures the efficiency of movement across the network, emphasizing angular deviations or turns along paths instead of just physical distance. It reflects how easily nodes (road intersections) can access other nodes within a 400-meter radius, highlighting the importance of minimizing angular changes for smoother navigation.

The color gradient, ranging from red to blue, represents high to low angular closeness centrality. The dense clustering of red and orange in central and coastal areas indicates well-connected urban cores with efficient, direct routes that enhance mobility within these zones. In contrast, peripheral areas with blue and green segments signify lower accessibility and navigational efficiency, pointing to zones that could benefit from improved road alignment or infrastructure investments to reduce angular deviations.

At a global level, the dense red and orange network in the city center and along major corridors suggests robust connectivity across the entire urban area (Fig. 8b). These roads facilitate city-wide movement and play a crucial role in linking various districts and urban hubs, ensuring seamless travel across the city. Peripheral zones with blue and purple roads highlight areas with weaker connections to the overall network, presenting opportunities for targeted infrastructure development to improve accessibility. Roads with high angular closeness are critical for reducing travel time, alleviating congestion, and enhancing network resilience by providing direct routes that minimize detours.

At the local level (R = 400 m), the analysis reveals that the current urban core network has strong potential for supporting pedestrian and cycling activities, particularly in the new urban areas in the southern region. However, older urban districts like Lien Chieu, Hai Chau, and Thanh Khe remain less favorable for these activities due to the high frequency of angular turns in the network (Fig. 8a).

At the global level, the city-wide network demonstrates significant potential for cycling and motorbike activities (Fig. 8b). This connectivity provides a strong foundation for designing cycling routes that interlink the entire city, contributing to Da Nang's ambition of developing as a sustainable tourism-oriented city.

Spatial Network Connectivity

The spatial structure analysis, conducted using the axial map analysis method, is illustrated in Fig. 9. The color gradient, ranging from red to blue, represents connectivity values from high to low. Segments with high Total Connectivity indices often signify intersections where several main roads converge, making these areas ideal hubs for commercial or public activities. Conversely, segments with low Total Connectivity indices typically indicate quieter residential streets with limited accessibility and lower traffic flow, making them suitable for tranquil living environments.

The analysis reveals that the southwestern part of the city exhibits the highest total connectivity index for its transportation networks. In contrast, the central urban area, while having lower overall connectivity, demonstrates a more even distribution (Fig. 9).

Overlaying the connectivity analysis with the land use plan reveals that most areas designated for mixed residential and commercial use, as well as residential areas, align with regions of high connectivity indices, particularly within the urban core and in new urban zones to the south and northwest. Notably, an emerging area with high connectivity indices is planned as a green space and a technical infrastructure hub (marked with a red circle in Fig. 10).

However, despite planning for mixed residential, commercial, and tourism development, the analysis also identifies areas that fail to meet the desired connectivity levels. These zones, outlined with blue dashed lines in Fig. 10, were intended to provide high connectivity and accessibility to attract human activity but are hindered by the current street network structure. In contrast, the area outlined with red dashed lines demonstrates strong potential for attracting human activity, even though it is currently designated as an industrial zone (as shown in Fig. 10).

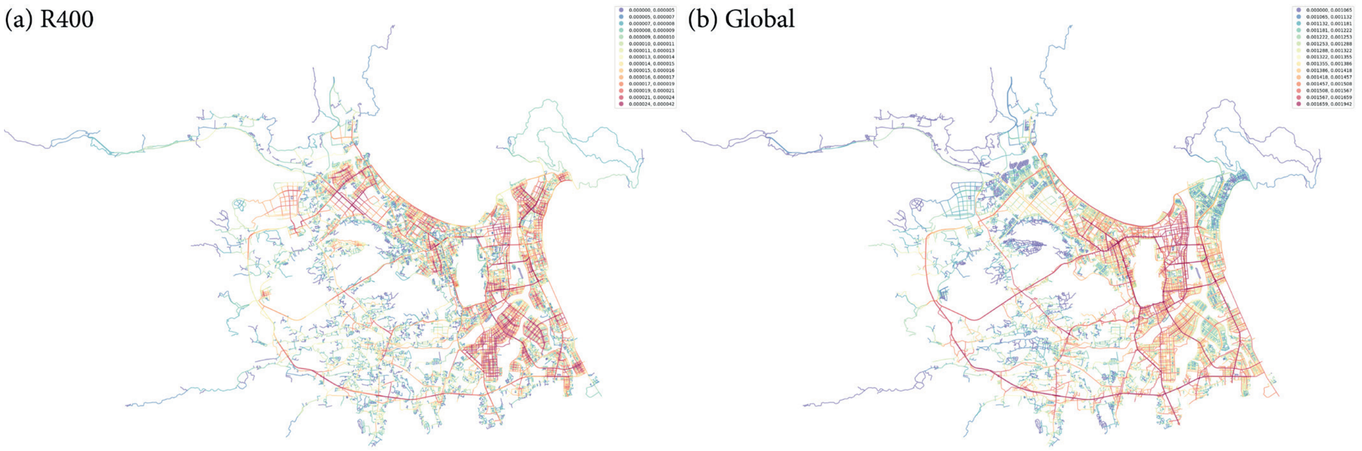

Fig. 8. Angular closeness centrality supporting pedestrian and cycling activities

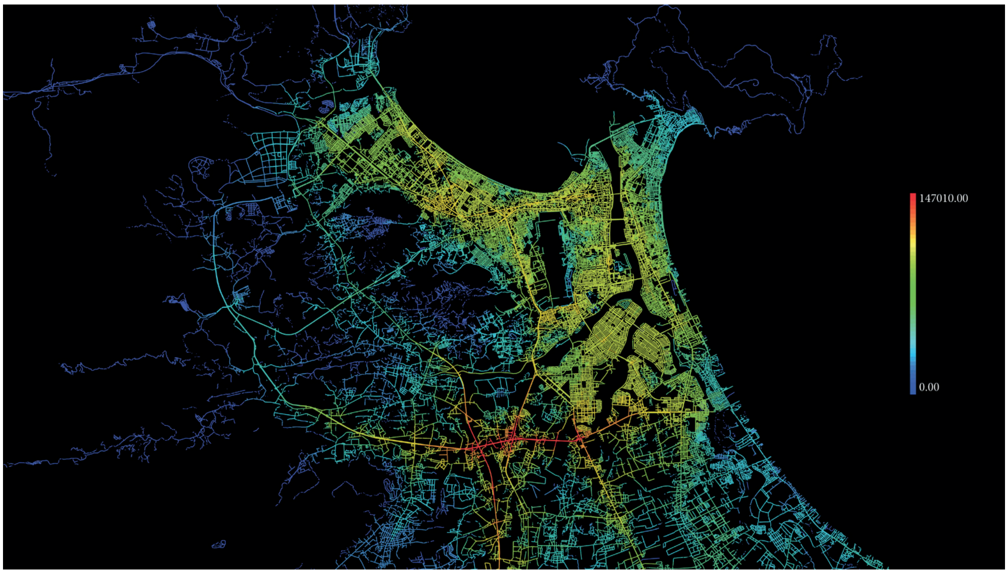

Fig. 9. Total Connectivity (R100)

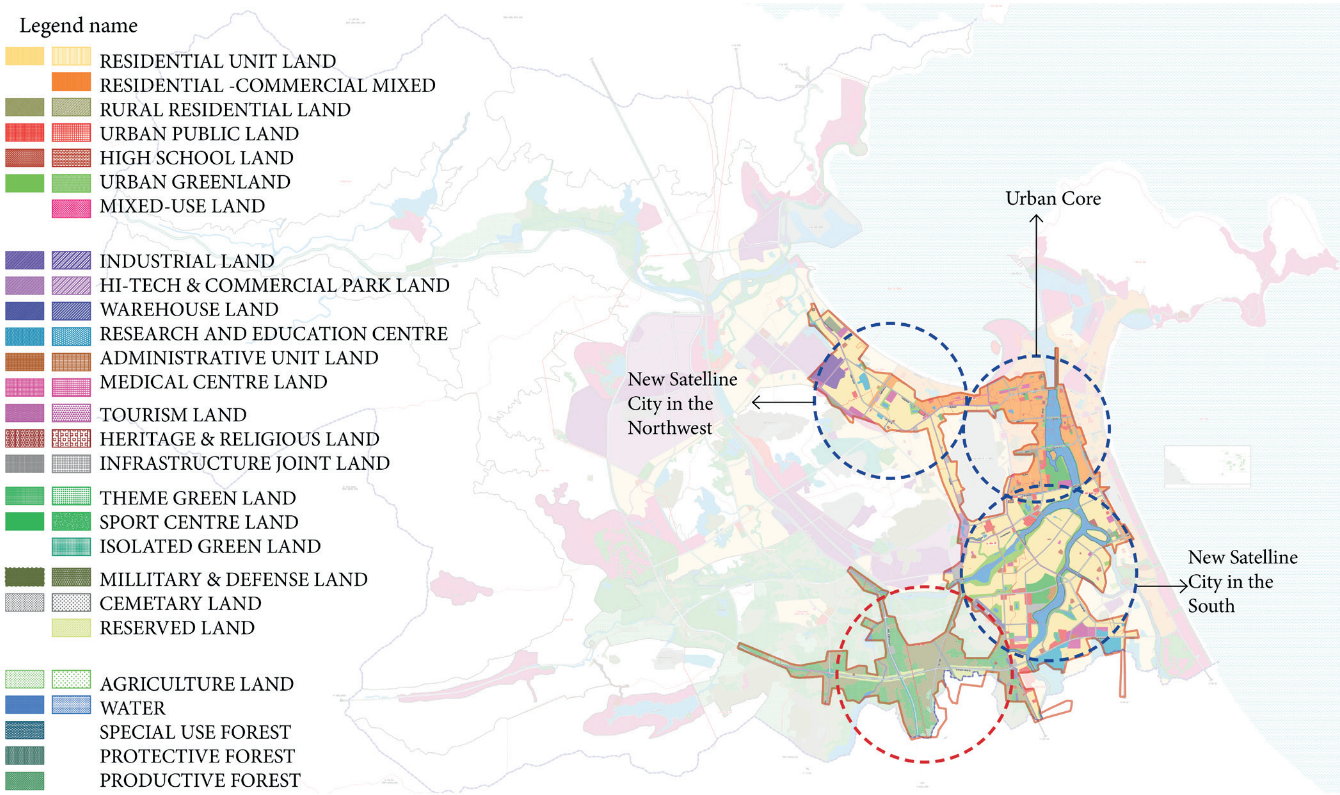

Fig. 10. Comparison of land use and high-connectivity areas in urban configuration using the overlay method

DISCUSSIONS

The Effectiveness of the Adjustment to the General Planning of Da Nang for 2030, with a Vision to 2045

The Adjusted Master Plan of Da Nang City to 2030, with a Vision to 2045 emphasizes the development of a multi-polar urban structure integrated with an efficient transportation network, an approach deemed appropriate (Danang People's, 2020). This aligns with the findings of this research, which focus on enhancing direct and efficient connections across the entire urban network.

The concept of multi-polar urban development envisions creating multiple urban centers or "poles" to decentralize economic activities, alleviate congestion in the urban core, and promote spatially balanced growth. Furthermore, the adjusted master plan proposes a hierarchy of urban zones and small urban models (Danang People's, 2020). This strategy is designed to create self-sufficient hubs equipped with essential services, amenities, and economic opportunities while maintaining strong connectivity to other centers. Such an interconnected structure ensures a more equitable distribution of resources and reduces dependency on the city core, contributing to greater urban resilience.

From a network analysis perspective, this approach closely aligns with the principles of global angular closeness centrality and global closeness centrality, emphasizing the importance of direct and efficient connections across the urban system (Hillier, 2007, Porta et al., 2006a). By prioritizing well-integrated routes between urban poles, the plan seeks to minimize travel times, optimize accessibility, and ensure seamless mobility for residents (Marshall, 2004). This synergy between urban planning strategies and spatial network theory supports not only functional efficiency but also the city's capacity to adapt to future growth and demographic shifts. Integrating these principles into planning frameworks underscores the transformative potential of data-driven, systemic approaches to sustainable urban development (Gehl, 2013).

Based on the existing urban structure, the research findings indicate that much of the city's primary transportation network is reasonably well-designed. However, there is a need to refine detailed urban network planning to enhance connectivity within the city's main transportation system at a broader level.

As observed in the overall urban design framework, most urban axes and focal points are concentrated in areas close to the water, such as along both sides of the Han River and the Danang Bay shoreline (Danang People's, 2020, Danang, 2018). The study also highlights the need for urban planning and design solutions to improve coherence and navigability in older urban areas. Since these older areas were developed organically, the efficiency of their paths, which heavily influences navigation and direct movement, remains limited, making it challenging to achieve coherence.

The study further identifies a strong potential for developing cycling and pedestrian-friendly routes within Danang's spatial network. However, the current master plan does not adequately address the construction of dedicated infrastructure for cyclists and pedestrians (Danang People's, 2020). As a tourism-oriented city, equipping such non-motorized transport infrastructure is essential. This research provides a vital scientific basis for integrating these types of infrastructure into the urban structure.

The planned urban network largely corresponds with roads exhibiting high choice indices, reflecting an overall efficient transportation planning strategy. However, the network remains incomplete, as certain road segments fail to support seamless movement, leading to gaps in connectivity at the local level. Despite these shortcomings, the network provides a strong foundation for essential urban functions such as public transport hubs, commercial centers, and key public services, as these areas are likely to experience significant use and integrate effectively with the local system.

To improve and complete the city's primary transportation network, modifications to the local traffic network are essential, especially in surrounding areas, to strengthen connectivity at the neighborhood level (Turner, 2007). The research also highlights that revising land use patterns can help attract activity flows within this framework. For instance, although Nguyen Huu Tho Street near Danang Airport shows a low choice index in the overall street network, data from the Danang Department of Transportation (Danang People's Committee, 2020) reveals significant traffic flow along this road due to the diverse land use types surrounding it. This observation aligns with other studies that underscore the strong link between land use planning and street-level activity (Do & Do, 2024), as well as the influence of road infrastructure on urban settlements and the socioeconomic characteristics of residents(Won et al., 2015).

Implications for Danang's General Planning

For general urban planning, it is crucial to reorganize the functions of various urban core areas to enhance their service capacity, guided by analyses of the urban network structure. As illustrated in Fig. 11, the city's spatial structure is divided into six distinct zones.

The central urban area stems from the historic core, while two new satellite urban zones have been established to the south and west of this core. These satellite areas are designed to support and reduce the burden on the historic urban core, aligning with the objectives of Da Nang's updated master plan (Danang People's Committee, 2020). This study proposes the establishment of three new supportive urban areas in Danang, strategically located in the northwest, west, and southwest. These areas are envisioned as hub cities that facilitate connections between the city and external regions (see Fig. 11). Serving as critical nodes for urban activities, these hubs play a pivotal role in distributing various activities between internal and external areas. The overall spatial structure is designed to create a hierarchical relationship within the urban network. Arrows illustrate the interactions between urban sub-regions, clarifying the distinct roles of each area within the broader network. Furthermore, this reorganization supports the preservation and enhancement of urban ecological values, ensuring a balance between development and environmental sustainability (Do et al., 2018).

To complement the promotion of mixed land use, it is essential to review and adjust land use structures to align with the functions of the proposed urban framework. Strategic allocation of land types is crucial: residential, commercial, public service areas, green spaces, and other uses should be concentrated in the core urban area and the new satellite urban zones. In suburban regions, facilities such as industrial zones, production areas, road and waterway infrastructure, and large commercial trading hubs should be prioritized. Additionally, static transportation infrastructure should be integrated with open spaces and green areas to enhance connectivity and foster seamless interaction between local regions.

CONCLUSION

The structure of an urban spatial network plays a crucial role in shaping a city's development patterns. As a result, many cities worldwide adopt the transit-oriented development (TOD) model in their urban planning strategies. However, Asian cities, including those in Vietnam, have not effectively leveraged public transportation to guide urban development.. Instead, urban growth typically follows a straightforward pattern of expansion along transportation routes, where construction takes place wherever roads exist.

Fortunately, theories such as space syntax and graph theory provide tools to quantify the geometric properties of spatial structures, enabling the identification of issues related to movement within the urban network. These theories also emphasize the connection between urban configuration and key factors like social interactions, human mobility, and accessibility, offering valuable insights for improving urban development practices.

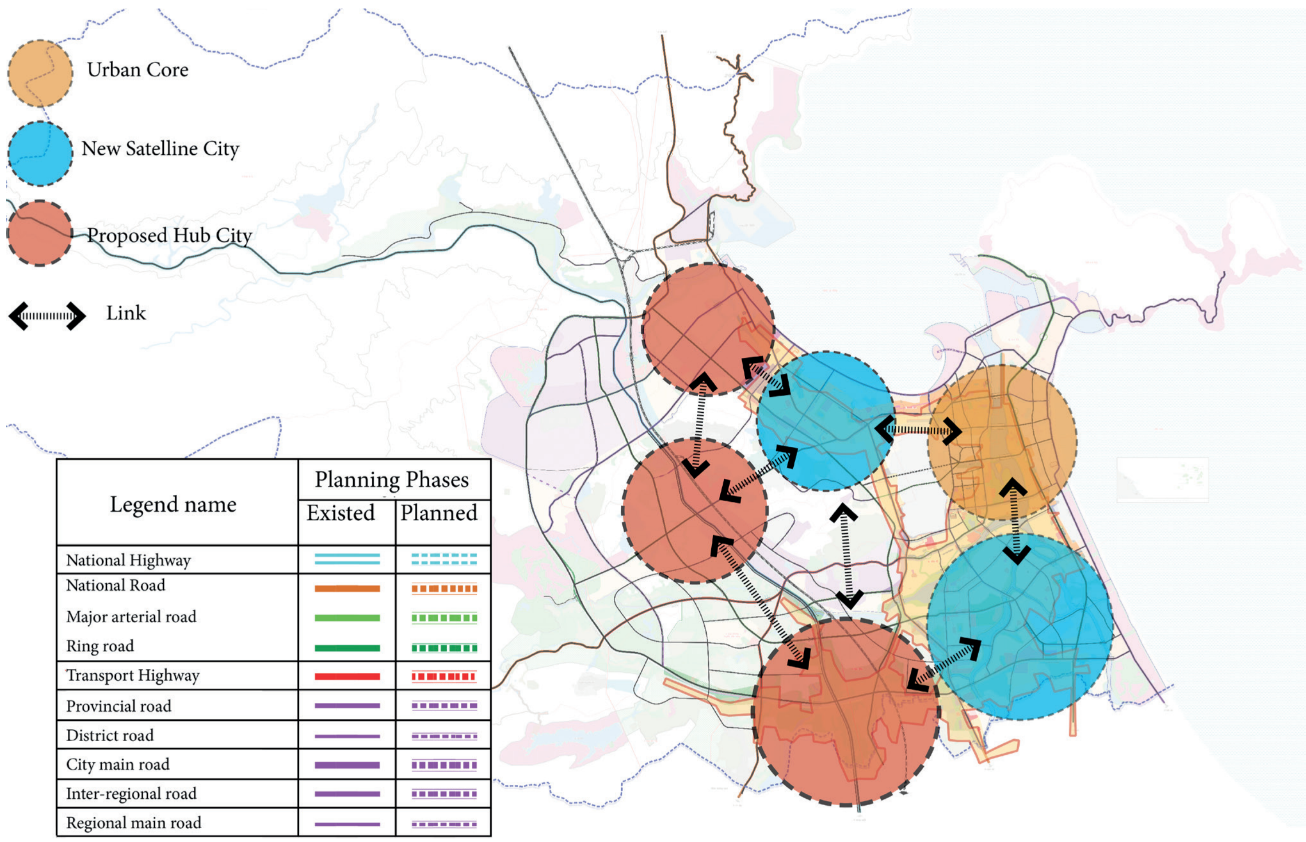

Fig. 11. Proposed urban structure of Danang

Da Nang's general urban plan has undergone several adjustments, yet no scientific basis has been used to evaluate its effectiveness in relation to the city's actual development. This study applies space syntax theory and graph theory to assess the adjustment project of the General Planning of Da Nang for 2030, with a vision to 2045. The analysis examines various aspects, including urban spatial development, land use, and transportation networks. The findings provide urban and transportation planners with a reliable scientific foundation for refining future urban plans and improving Da Nang's overall planning.

This study identifies the strengths and weaknesses of the General Planning of Da Nang for 2030, with a vision to 2045. Balancing these variables is essential to achieving the desired outcomes.

The adjusted master plan adopts a multi-polar urban structure integrated with an efficient transportation network. This approach aligns with the study's findings, emphasizing direct and efficient connectivity to decentralize economic activities, reduce congestion in the urban core, and promote balanced growth. By incorporating the principles of global angular closeness and global closeness centrality, the plan enhances mobility, accessibility, and resilience to future changes.

While the primary transportation network is efficient, gaps in local connectivity persist. Targeted adjustments to the local traffic network and mixed land use patterns can optimize underperforming areas. Furthermore, integrating cycling and pedestrian infrastructure is vital to support Da Nang's tourism-oriented and sustainable development goals.

The study also advocates for the development of three new urban hubs in the northwest, west, and southwest to distribute activities and ease pressure on the historic urban core. Aligning land use structures with these hubs will ensure the effective integration of residential, commercial, industrial, and green spaces, fostering connectivity and ecological preservation.

By combining spatial network analysis with urban planning principles, this research provides actionable insights to refine Da Nang's master plan, supporting sustainable, resilient, and inclusive urban development.

However, this study primarily examines the city at a macro level. Incorporating both quantitative and qualitative research—particularly by comparing the spatial structure of traffic with land use planning at the master plan level—offers valuable opportunities for future planning ideas and strategic orientations. Future research should explore the relationship between three critical factors—urban configuration, urban movements, and land use patterns—at different scales. Such studies will help explain and understand the specific adjustments needed to improve urban mobility effectively. ■

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