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Improving Urban Planning Using Land Use Analysis and Traffic Network Optimization: A Case Study of Da Nang City

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Abstract The spatial structure of urban transportation is closely related to urban movements, as has been demonstrated by numerous previous studies. At the same time, other studies have shown a connection between urban movements and land-use patterns. However, no research has yet examined the three-way relationship between these factors, nor applied them to the assessment and recommendation for urban planning. This study explores the critical relationship between urban configuration, land use, and urban movement in shaping dynamic and socially cohesive urban environments. Leveraging Space Syntax theory and advanced overlay analysis techniques, this research conducts a detailed examination of the street network in Da Nang City, Vietnam, to critically assess the city's comprehensive urban planning project. The findings demonstrate a strong correlation between urban configuration, land use patterns, and urban mobility, highlighting their combined impact on the vitality of urban spaces and the promotion of social interaction. Furthermore, the study identifies both strengths and potential areas for improvement in Da Nang city's revised master plan, providing valuable insights for urban planners. By examining the city's current urban form, the research proposes a new urban structure centered around five functional cores, aimed at optimizing the urban configuration to build on existing strengths and support sustainable urban development.

Keywords Space Syntax, Urban Configuration, Street Network, Sustainable Urban Development

1. Introduction

1.1. Research Background

The urban spatial network is the lifeblood of a city, playing a crucial role in shaping the flows of human activities, social interactions, and economic dynamics. The structure of the street network is a key determinant of how effectively these spaces can function. A well-structured street network enhances connectivity, accessibility, and overall flow of activities within the city, thereby influencing land use patterns [1]. Indeed, the configuration of street networks has long been recognized as a fundamental component of urban mobility. Hillier (1996) introduced the concept of Space Syntax, a method for analyzing spatial configurations, which has since been widely used to understand how street networks influence movement patterns [2]. A key metric for analyzing street network configuration is the betweenness centrality index, which measures how often a street segment appears on the shortest path between other segments. This concept, rooted in graph theory, has been widely used to assess the potential movement of pedestrians and vehicles across various urban spaces [3]. This metric offers insights into the likelihood of movement along a particular street segment and, as a result, its impact on land use.

A series of studies have focused on exploring the relationship between the spatial structure of street networks through the betweenness centrality index and land use. Research by Porta et al. [4] emphasized the importance of street centrality in shaping urban life, demonstrating that streets with higher betweenness centrality often support more intensive land uses, such as retail and commercial activities. Streets with high betweenness centrality typically draw more traffic, making them ideal locations for businesses that rely on high visibility and easy access.

The relationship between land use and urban form is intricate and influenced by a variety of factors, including economic, social, and environmental considerations. Nevertheless, the layout of the street network is a key factor in determining the placement of different land uses. Land uses that depend on high visibility, such as retail, are commonly situated along streets with high centrality [5]. On the other hand, residential areas are often situated on streets with lower centrality, where traffic is lighter, and the environment is more peaceful. Research by Jiang and Claramunt [6] has shown a strong correlation between street centrality and land use diversity. Areas with high betweenness centrality typically display a diverse mix of land uses, which enhances the vibrancy and economic vitality of urban spaces. In contrast, areas with low centrality are more prone to having uniform land uses, such as residential neighborhoods or industrial zones.

The incorporation of betweenness centrality into urban planning practices has yielded promising outcomes in designing more accessible and efficient urban environments. Recent studies, such as those by Sevtsuk and Mekonnen [7], have investigated the application of centrality indices to guide decisions on the placement of new developments, public transport routes, and other essential infrastructure. Shi et al. [8] emphasized the use of advanced spatial analytics to optimize the placement of new commercial developments in rapidly urbanizing regions, with betweenness centrality playing a key role as a critical determinant in the decision-making process.

In urban planning in Vietnam, cities are planned based on population size as the foundation for calculating various indicators, with the planning of transportation networks and land use simply determined on this basis. As a result, how to arrange and structure these elements appropriately depends on the current state of the old city and future urban development orientations. Importantly, this process primarily relies on the capabilities and experience of urban planners. The legal framework for structuring spatial layouts and land use is not detailed enough to effectively control this process. This has led to frequent adjustments and reorientations in planning to address issues that arise during the implementation of planning projects. Indeed, Da Nang, the third-largest city in Vietnam, was granted permission by the Prime Minister in 2019 to undertake a citywide planning adjustment through 2030, with a vision extending to 2045 [9]. Although there are many different aspects to the adjustments, a key focus of this comprehensive plan is the future reconfiguration of Da Nang's transportation network. The improvements include the enhancement and integration of road, rail, and waterway networks, as well as the introduction of a comprehensive non-motorized transport network and an integrated public transport system. This will facilitate more convenient mobility. The planning orientation also aims to develop mixed-use areas that blend residential, commercial, cultural, hospitality, and social infrastructure to create vibrant, integrated spaces [10].

Based on the Space Syntax method and theory, this study aims to supplement and adjust the shortcomings in the current urban planning project for Da Nang. By viewing the urban transportation network as an urban spatial configuration, the study analyzes and explores the nature of spatial structures to evaluate and compare them with the current planning orientation. Additionally, based on the analysis results, the study examines various aspects of land use in relation to spatial structure indices. The findings of this research provide urban and transportation planners with a reliable scientific foundation to achieve coherence and harmony between spatial structure and land use.

1.2. Theoretical Basis and Previous Studies

Research on the connection between street space configuration, betweenness centrality, and land use demonstrates strong correlations. Rui and Ban [11] identified that different centrality measures in Stockholm are closely associated with specific land-use types, showing that street characteristics reflect patterns of urban development. Hillier et al. [1] proposed a configurational paradigm, indicating that the design of urban grids influences pedestrian movement, with retail areas benefiting from this natural flow. Porta et al. [12] further validated this in Bologna, where areas with higher street centrality were found to have greater densities of retail and service activities, especially those related to global betweenness. Extending these insights to American cities, Berhie and Haq [13] showed that retail clusters coincide with configurational hotspots, impacting residential location decisions and commuting behaviors. Another study by Das [14] applied the integration of the Gravity Index, Straightness, Betweenness Centrality, and Closeness Centrality to examine the relationship between land use and street network configuration. Overall, these studies emphasize the significance of street configuration and centrality in shaping urban land use and movement patterns. However, these studies primarily focus on Western cities, where urban structure and land use types are clearly defined and formalized. Given the informal nature of land use in Vietnam, further research is needed to explore this relationship in a different context.

Similarly, in Asian cities like Wuhan, Liu's [15] research indicates strong relationships between street centrality and land-use intensity. Although this study found that the relationships vary not only across different land-use types but also within different categories of a single land-use type, it focused on exploring the relationship between land-use intensity and street centrality rather than examining the connection between the street network and land-use distribution. Another study by Li [16] examines the distribution of location and land-use intensity. The study reveals a consistent pattern in which the sensitivity of different land use types to location centrality follows a typical hierarchy: commercial > residential > industrial. The connection between land use intensity and location centrality demonstrates spatial variability, and this relationship adheres to a power law. Although this study is more detailed and expands its focus to include both land use types and land use intensity, the urban spatial structure was examined at a large scale, and the land use data did not take into account informal land use conversions by residents within the urban network. Similarly, studies that focus on land use intensity and urban configuration, such as Song [17], Yin [18], and Wang [19], examine the interactive relationship between urban transportation (street centrality) and land use intensity. A few studies focus on exploring the relationship between land use, accessibility, and centrality indices in relation to user behavior, such as walking [20].

The connection between street space configuration and land use is increasingly attracting attention from urban planners, geographers, and architects. Gaining insights into this relationship is crucial for creating urban areas that are both functional and sustainable. By examining how the betweenness centrality index relates to different land use types in the Vietnamese context, particularly concerning informal mixed land use, this research seeks to add valuable knowledge to inform urban development practices.

2. Materials and Methods

2.1. Data Preparation Process

Da Nang, located in central Vietnam, is the administrative and commercial hub of Central Vietnam (Figure 1). As of 2019, the city of Da Nang had a total population of 1,134,310 people [10], It has become the largest city in Central Vietnam and the fourth largest in the country. This study uses street network data extracted from OSM (OpenStreetMap) as the basis for building data for analysis in DepthmapX. Land use data was compiled from the approved master plan of 2013 and the adjusted master plan of 2020. According to the 2013 master plan, by 2020, urban construction land was expected to reach approximately 20,010 hectares, with residential land covering around 8,659 hectares. As of now, the urban area has nearly reached the forecast, with more than 18,396 hectares of urban construction land and 8,191 hectares of residential land developed [10]. Therefore, using this land use data is appropriate in conjunction with the spatial structure data extracted from OSM.

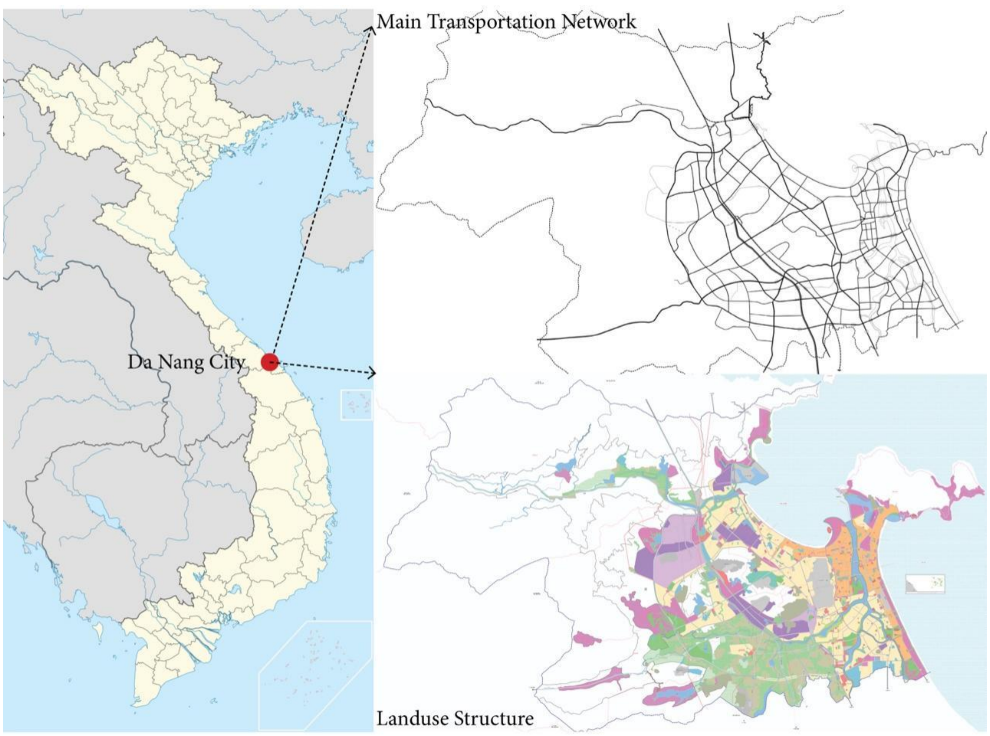

Figure 1. Danang city location and research boundary

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 (Figure 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. The typical quantitative data of the urban street network of Danang is presented in Table 1.

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

Table 1. The urban street network data has been encoded in preparation for the next analysis step

Ref Number	Connectivity	Line Length	Drawing Layer
0	2	6.96419e-05	0
1	2	3.66478e-05	0
2	3	0.000327407	0
3	7	0.000330088	0
4	7	0.00032926	0
5	3	0.000234187	0
……	……	……	……
360488	2	3.0838e-05	4
360489	2	2.94822e-05	4
360490	2	2.55973e-05	4
360491	2	1.43962e-05	4

When creating an axial map, it's essential to draw it on a separate layer and adhere to some fundamental guidelines. The primary rule is that all streets, roads, paths, and similar elements should be represented 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's 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 distorted and inaccurate analysis. Therefore, it's crucial to use space syntax software to unlink these lines to reflect the actual spatial relationships accurately [21].

2.1.1. 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 [22]. The core of this theory is the analysis of street networks and the measurement of spatial characteristics, such as integration and connectivity [23]. By representing spatial layouts with axial lines and segments, space syntax allows for the measurement of how accessible and interconnected different spaces are [24]. These measurements have been demonstrated to correlate with pedestrian movement, social interactions, crime distribution, and economic activity [25]. 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 [26].

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 [27].

Space syntax adopts a graph-theoretic approach to representing spatial configurations. In this framework, spaces are modeled as nodes, while the connections between these spaces—such as paths, streets, or doorways—are modeled as edges in the graph. There are various methods for representing space in this graph-based format, including Axial Lines, Convex Spaces, and Visibility Graphs (Figure 3), each offering a different perspective on the spatial structure and its implications for movement and interaction.

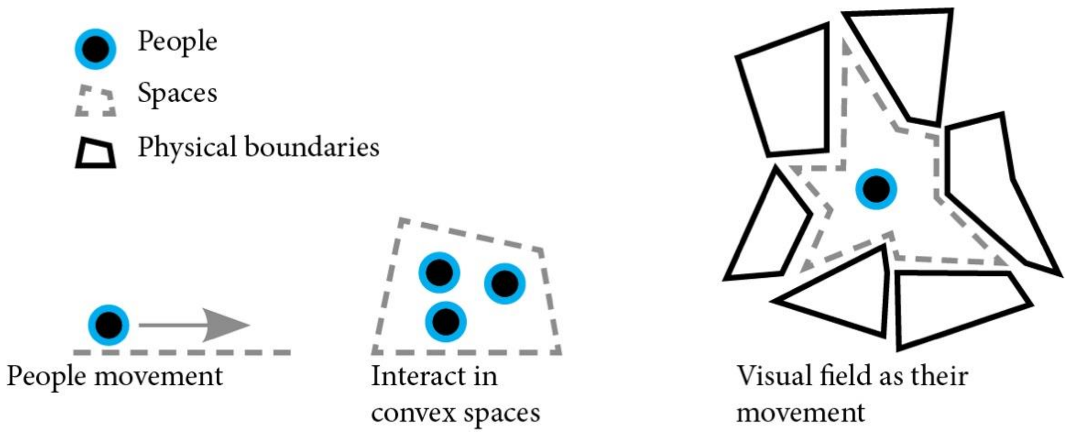

Figure 3. Three kinds of spatial representations (Source:[1])

In Space Syntax, Choice indices, also referred to as Betweenness Centrality, measure the likelihood that a particular space (or line) will be traversed as part of the shortest path between any two other spaces (or lines). This concept is central to understanding how movement flows through an urban layout or building, helping to identify key pathways and spaces that act as crucial connectors. Key formulas for calculating choice indices:

(1) Choice Index (Betweenness Centrality) Formula. Choice index for a given space (or axial line) C(i) is calculated as:

$$C(i) = \sum_{s \neq i \neq t} \frac{\sigma_{st}(i)}{\sigma_{st}}$$

Where:

$C(i)$ = Choice index for space i

$\sigma_{st}(i)$ = Number of shortest paths between space s and space t that pass through space i

σ_{st} = Total number of shortest paths between space s and space t

(2) Weighted Choice was applied when distances or other weights are involved, the formula becomes.

$$C(i) = \sum_{s \neq i \neq t} \frac{\sigma_{st}(i)}{\sigma_{st}} . \omega_{st}$$

Where: ω_{st}= Weight for the path between space s and t

Another important index in Space Syntax 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:

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

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 [28]. 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 [29]. 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 [3]. In summary, DepthmapX is a vital tool for analyzing and optimizing the interaction between spatial configurations and human movement.

Through the analysis of the urban street network of Danang using the total connectivity and choice indices (Table 2), the results show that, for a medium-sized urban area, the values effectively identify connectivity and choice at the R100 level.

Table 2. The analysis results of the Choice and Connectivity indices of the urban street network are summarized

Ref	Choice [Connectivity Wgt] R100	Total Connectivity R100
0	1048824	29201
1	1937659	31762
2	1762463	98269
3	2895762	98269
4	8.72E+08	99145
5	84625816	69717
……	……	……
360486	6640	334
360487	5412	334
360488	4180	334
360489	2948	334

3. Results

3.1. Connectivity Analysis

The results of the analysis of the spatial structure of the transportation network, based on the axial map analysis method, are shown in the Table 2 and Figure 4, with color ranges from red to blue corresponding to connectivity values from high to low. A segment with a high Total Connectivity index could represent an intersection where several main roads converge. This area may serve as a hub of movement and activity, making it an ideal location for commercial or public activities. Conversely, in an area where a segment has low Total Connectivity, it could be a quiet residential street, indicating limited accessibility and lower traffic flow, which may be suitable for a tranquil living environment. The analysis results show that the southwestern area of the city has the highest total connectivity index for its transportation networks. Meanwhile, the central urban area has lower overall connectivity, but with a more widespread distribution (Figure 4).

When comparing the connectivity analysis with the land use plan using overlay techniques, the analysis reveals that most areas designated for mixed residential and commercial use, as well as residential areas, are located in regions with high connectivity indices, particularly in the urban core and in the new urban areas to the south and northwest. Notably, there is an emerging area with high connectivity indices that is planned to be a green space and a technical infrastructure hub (red circle in Figure 5). The analysis also highlights areas that do not achieve the desired level of connectivity, despite being planned for mixed residential, commercial, and tourism development. These areas, circled with blue dashed lines in the Figure 3, were intended to have high connectivity, easy accessibility, and attract significant human activity. However, with the current street network structure, these areas are not meeting the land use planning objectives. In contrast, the area outlined with red dashed lines shows great potential for attracting human activity, despite being designated as an industrial zone (as shown in Figure 5).

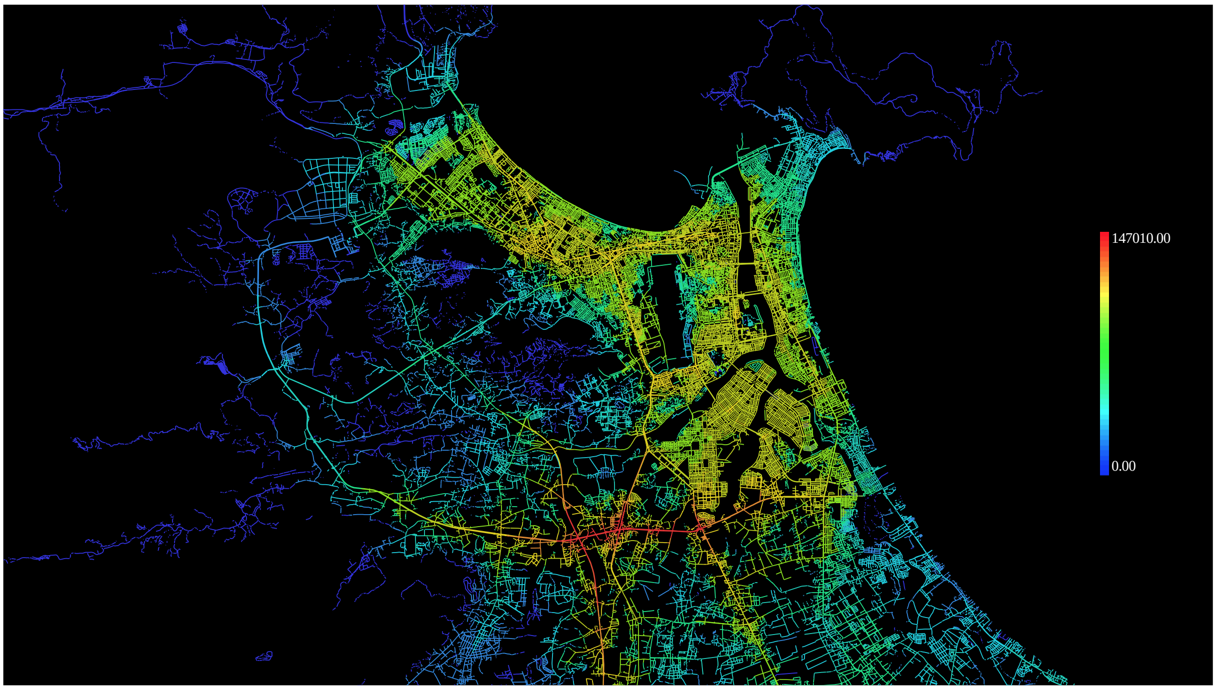

Figure 4. Total Connectivity (R100)

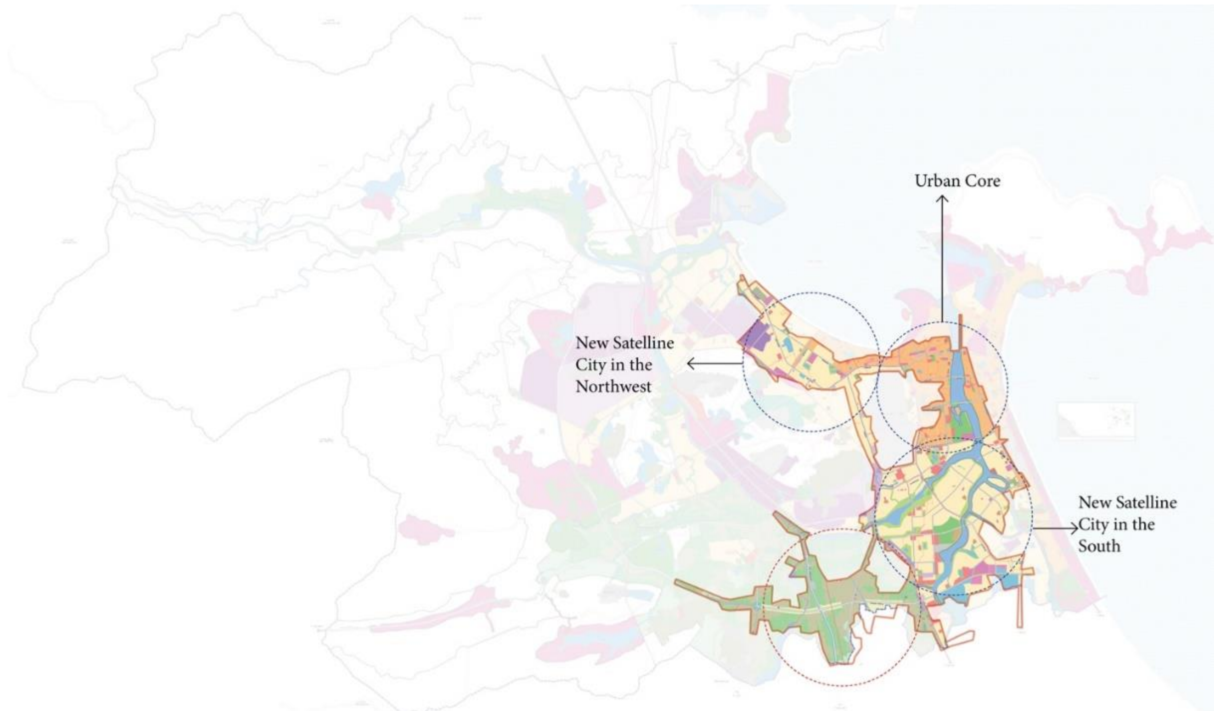

Figure 5. Comparison of land use and high-connectivity areas in urban configuration using the overlay method

3.2. Choice Analysis

Table 2 and Figure 6 illustrate the results of the Choice [Connectivity Wgt] analysis, which is a weighted version of the Choice index, with the weighting factor based on the Connectivity of the segments. Essentially, it measures the betweenness of a segment but places more emphasis on well-connected segments (i.e., those with high connectivity). Similar to connectivity analysis, a color range from red to blue represents the choice values from high to low. Choice [Connectivity Wgt] is a more detailed version of the traditional Choice index, adding weight to segments based on their level of connectivity. It provides deeper insights into the role of well-connected segments within a network, making it a valuable tool for analyzing and planning urban spaces where local connectivity plays a crucial role in movement dynamics.

As shown in the choice analysis in Figure 6, the road network with higher indices highlights the primary structure of this urban area. The network displayed in the analysis (Figure 6) reveals that these roads are not only central within the movement network but that their centrality is further enhanced by local connectivity to surrounding networks with lower indices.

When compared with the planned transportation network, most of the city's main planned routes align well and fulfill their central role within the overall movement network of the city (Figure 7). Indeed, as illustrated in Figure 7, the blue-highlighted road networks indicate the overlap between the planned main roads and the transportation network structure with high choice indices. The areas circled in red show mismatches between the planned main road structure and the reality. This suggests that there are alternative options for the main transportation structure in this area, beyond the currently planned network.

4. Discussions

4.1. The Relationship between the Overall Urban Transportation Structure, Land Use Patterns, and Human Movement

Although the main structure of the planned urban network largely aligns with roads that have high choice indices, indicating high efficiency in the city's overall transportation planning approach, the network is still incomplete. Several road segments do not fulfill their role in overall movement, losing connectivity at the local level. Indeed, this network forms an ideal structure for key urban functions, such as public transport hubs, commercial centers, or essential public services, as these areas are likely to experience high usage and integrate well into the local network.

Therefore, to complete and enhance the connectivity of the city's main transportation network, adjustments are needed in the local traffic network structure in surrounding areas to emphasize the central role of connectivity at the local level [3]. This study also demonstrates that adjusting land use patterns can be a potential solution to attract activity flows within this structure. Indeed, although Nguyen Huu Tho Street (adjacent to Danang Airport) has a low choice index within the overall street network, field data from the Danang Department of Transportation [10] indicates that traffic flow on this street is quite high due to the diversity of land use types along it. This finding is further supported by other studies, which highlight the strong relationship between land use planning and street-level human activity [30]; as well as the impact of road infrastructure on urban settlements and residents' socioeconomic characteristics [31].

4.2. Implications for Danang Master Planning

For overall urban planning, it is necessary to restructure the functions of different urban core areas to optimize their service capacity based on analyses of the urban network structure. As shown in Figure 6, the spatial structure of the entire city is divided into five distinct areas. The central urban area originates from the historic urban core. Two new satellite urban areas have been developed to the south and west of the old urban core. These two urban areas function as neighboring regions to help alleviate pressure on the historic urban core. This aligns with Da Nang's current adjusted master plan [10].

This study proposes the development of two new supportive urban areas for Danang, located in the northwest and southwest, serving as hub cities that connect with external flows to and from the city (See Figure 8). These hubs play a crucial role in distributing various activities between the internal and external regions while also functioning as key nodes for urban activities. The organization of this overall spatial structure creates a hierarchical relationship within the urban network. Indeed, the interaction between the urban sub-regions is illustrated through arrows, clarifying the roles of the different urban areas within the entire network. This new structure also supports the preservation and enhancement of urban ecological values [32].

In addition to promoting mixed land use, it is necessary to review and adjust land use structures to align with the functions of the new urban structure. Residential and commercial land, residential land, public service land, green spaces, and other types should be strategically located in the core urban area and the new satellite urban areas. In the auxiliary urban regions, industrial zones, production areas, road and waterway infrastructure, large commercial trading hubs, and other similar facilities should be placed. Static transportation infrastructure should be integrated with open spaces and green areas to enhance connectivity between local regions.

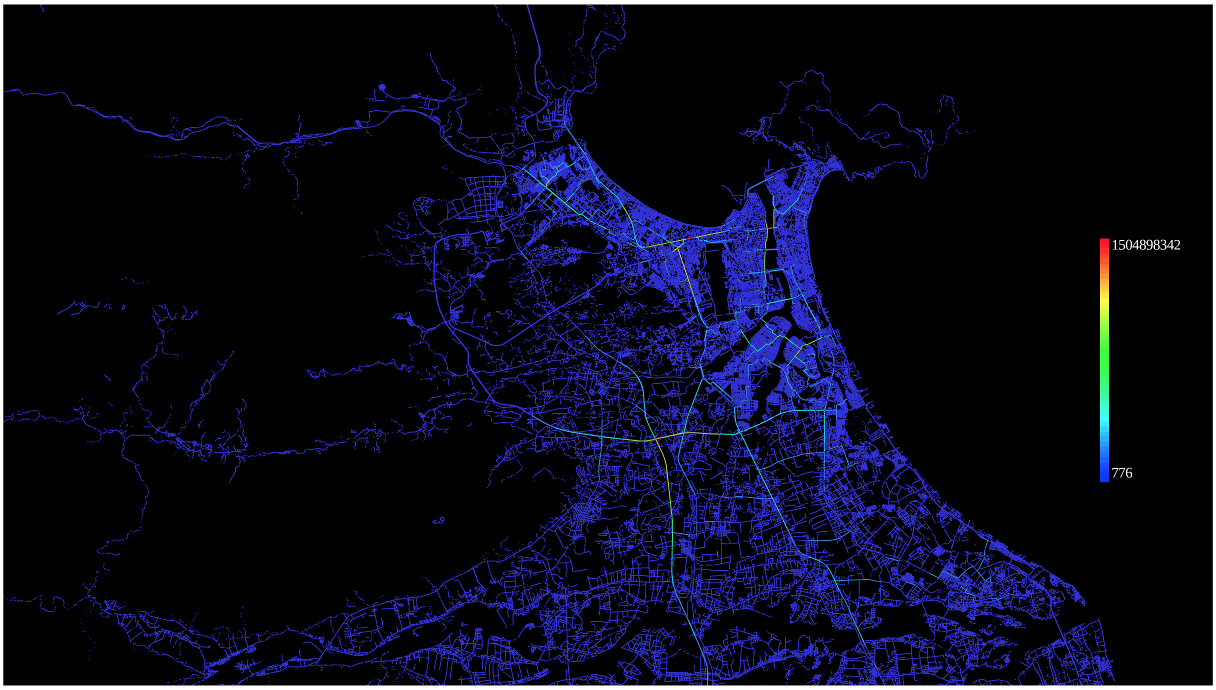

Figure 6. Choice Analysis Map

Figure 7. Comparison of street network system and high-choice areas in urban configuration using the overlay method.

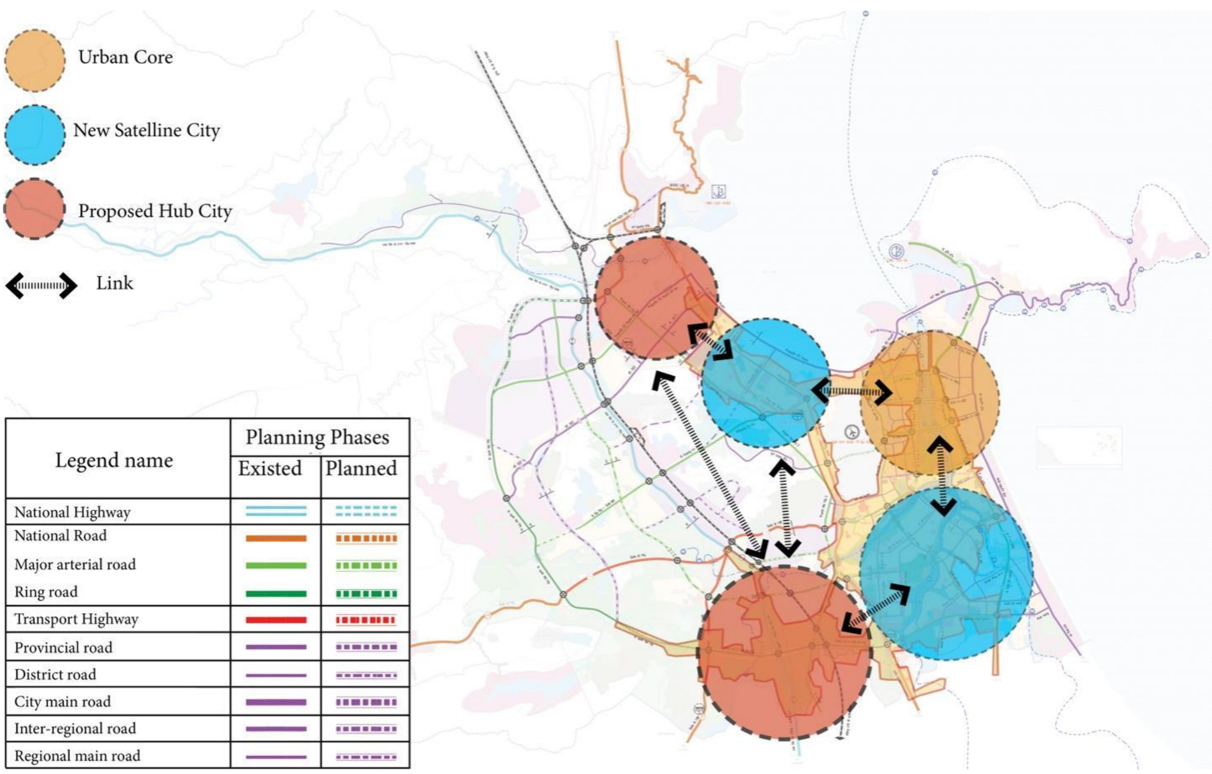

Figure 8. Proposed urban structure of Danang

5. Conclusions

The structure of an urban spatial network significantly impacts the development patterns of a city. Therefore, in urban development planning, the transit-oriented development (TOD) model is widely applied in cities around the world. However, in Asian cities like those in Vietnam, the role of public transportation in guiding urban development has not been effectively implemented. Instead, urban growth tends to follow a simple pattern of building along transportation routes—wherever there is a road, houses are built. Fortunately, the theory of space syntax helps quantify the geometric indicators of a spatial structure, allowing for the identification of issues related to movements within the urban transportation network. This theory also highlights the relationship between urban configuration and social interactions, human movements, and accessibility.

Danang's master urban plan has undergone several adjustments, yet no scientific basis has been used to evaluate the plan's effectiveness in relation to the city's actual development. This study applies space syntax theory to assess Danang's transportation structure and examines the relationship between land use planning and transportation data. The findings from this research provide urban and transportation planners with a reliable scientific foundation for adjusting future urban plans and improving Danang's overall master plan.

This study demonstrates a strong relationship between urban spatial structure, land use, and urban movements. These factors can influence and shape one another. Therefore, it is essential to balance these variables to achieve the desired outcomes. For instance, if the urban structure does not attract significant urban movements, adjustments to land use may be necessary to create more vibrancy within that structure.

The results of this study also indicate that most of Danang's main transportation structure successfully attracts a high level of urban movement, serving as a central hub for activities within the city. This suggests a certain level of success in Danang's transportation planning. However, the network is still incomplete in fully generating the desired urban movement attraction. Therefore, it is necessary to adjust the local transportation structures and develop mixed-use land models to better attract and enhance urban movements.

The study also identifies areas with high potential for generating social interactions and human movements. This serves as a crucial foundation for proposing a new urban structure that optimizes functionality and maximizes the potential of urban street configuration. The new urban structure consists of five different areas (see Figure 8).

The central urban area originates from the historic urban core, along with two new satellite urban areas developed to the south and west of the old urban core. These areas need to integrate mixed-use land, including residential, commercial, public service land, green spaces, and more.

Two new supportive urban areas in the northwest and southwest of Danang will serve as hub cities, facilitating connections with external urban flows. These areas should be designated for industrial zones, production facilities, road and waterway infrastructure, and large commercial trading hubs.

The organization of this overall spatial structure creates a hierarchical relationship within the urban network and aligns with the urban ecological network. Indeed, the interactions between the urban sub-regions are illustrated with arrows, clarifying the roles of different urban areas within the entire network.

This study only examines the city at a macro level. However, combining quantitative and qualitative research, particularly by comparing traffic spatial structure with land use planning at the master plan level, is worth considering for future planning ideas and strategic planning orientations. Future research should explore the relationship between the three factors—urban configuration, urban movements, and land use patterns—at different scales. This will help explain and understand the specific impacts needed for adjusting urban movements.

A key challenge is aligning the planned and actual use of urban spaces, especially in transportation networks. Future research could integrate spatial data analysis with behavioral studies to address this. While quantitative tools predict traffic patterns, qualitative insights into user behavior can reveal deviations from design. Combining these approaches would improve forecasting accuracy and inform more adaptive, user-centered urban planning.

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