Diachronic Morphological Study in Pontianak City as Waterfront City

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Abstract. This research presents a diachronic analysis of the morphological development of Pontianak City as a waterfront city. The diachronic time frame is based on several old maps, made in 1846, 1898, 1942, 1980, and 2020, respectively. The objective of this research was to determine the direction and patterns of waterfront city development based on road network patterns. The space syntax method was selected, because this method analyzes urban morphology through a configuration model and produces spatial patterns in relation to the social character of the residents in the city. Integration analysis was performed to convey the tendency and probability of the next direction of the city's development. The results showed that the direction of the development orientation in Pontianak City underwent some changes over time, from river-oriented to land-oriented, due to the construction of canals and bridges. The development patterns of Pontianak City caused some urban problems, namely North Pontianak (Area C) became left behind and segregated from the city center (Area A). Space syntax was used to predict the development of Pontianak City based on the socio-economic conditions of the community. However, large-scale interventions such as the construction of canals and bridges can override these organic trends, imposing unpredictable growth directions.

Keywords. Diachronic analysis, urban morphology, waterfront city, space syntax, Pontianak City.

Introduction

Waterfronts oftentimes serve as the embryo of settlements that develop into a waterfront city (Sri, 2017). The presence of waterbodies (rivers, seas, lakes, etc.) helps social and economic activities, including finding food sources, utilizing water for transportation, trading, and settlement development, to become increasingly complex (Ali et al., 2020). In general, a waterfront city has four sequential development phases: the emergence phase, the development phase, the decline phase, and the rediscovery phase. In the emergence phase, a group of people on boats dock at the waterfront and start to build a settlement, consisting of buildings and roads, which proceeds to develop rapidly (Timur, 2013). In the development phase, the settlement develops into a city, where maritime trade is what stimulates the development (Timur, 2013). In

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the decline phase, water transportation is gradually replaced by land transportation and finally starts to be abandoned (Timur, 2013). Lastly in the rediscovery phase, the abandoned waterfront starts to function again, this time as a recreational, residential, or commercial area (Timur, 2013).

Pontianak City exemplifies a waterfront city shaped by its rivers, with the Kapuas and Landak rivers playing a central role in its emergence and growth (Provincial Government of West Kalimantan, 2020). Compared to other cities in West Kalimantan, Pontianak City is the busiest and most densely populated one, with its population density reaching 5,817 people/km^2 in 2018, while the population of other cities did not exceed 500 people/km^2 (Central Bureau of Statistics, 2019). In the context of its urban form, earlier studies proposed various models: a concentric ribbon shape (Apriani, 2007), river-oriented linear development (Bayu & Susanto, 2010), and fragmented growth (Destria, 2012). Most agree that Pontianak's form is predominantly linear, but these assessments were often subjective and lacked strong empirical evidence. In addition, the city's development phases remain largely unexplored, particularly from the perspective of its identity as a waterfront city.

More recent research has sought to develop more reliable methods to explain Pontianak's spatial growth and predict future development. For example, Nurhidayati et al. (2017) used Cellular Automata (CA) integrated with Geographic Information Systems (GIS) and binary logistic regression to predict urban expansion in Pontianak. Although the model emphasizes accessibility as a factor, it lacks a comprehensive analysis of accessibility. Nurhidayati and Arianti (2021) applied satellite imagery and remote sensing to analyze spatial development through Pontianak's geographical and historical context, revealing that the city's expansion follows road networks. Meanwhile, Gunawan et al. (2022) based their predictions on historical and geographical patterns centered on the Kapuas River, suggesting the need for more rigorous methods to analyze accessibility.

Motivated by the gaps identified in previous studies, this research aimed to determine the direction and pattern of waterfront city development by analyzing its road network using the space syntax method, applying a diachronic analysis of maps from different time frames. Understanding these patterns is essential for interpreting how the city has moved through the phases of waterfront development proposed by Timur (2013). This research focused on network patterns because there is evidence that the city's expansion is closely tied to accessibility. By clarifying the relationship between spatial structure and urban growth dynamics, the findings aim to support sustainable regional spatial planning for the coming decades and to address pressing social, economic, and environmental challenges. The insights from this research are expected to guide future development strategies in Pontianak and offer lessons applicable to other waterfront cities.

Literature Review

Urban Morphology Theory

A city is an area that is dynamic and continually developing (Alie & Suwandono, 2013). Urban development is herein defined as physical growth (urban morphology) caused by non-physical conditions (the socio-economic conditions of the community) (Alie & Suwandono, 2013). This definition explains that urban development consists of two main elements, namely physical elements such as urban morphology and non-physical elements such as socio-economic conditions. Morphology is the science or way of understanding a city's developing morphology

being a result of socio-spatial changes (Panduu et al., 2018). A benefit of studying urban morphology is finding a direction for urban design in order to create a functional physical environment and better visual conditions for the city (Tallo et al., 2015). Notably, urban morphology can be seen in terms of land use, road network patterns, and building types (Marzuki, 2018).

Oliveira (2016) highlights that urban morphology is the study of urban form and the processes shaping it. The theory of urban form has been explored since 1925, beginning with the concentric zone model, followed by others like the sector and multiple nuclei models. As more theories emerged, research in urban morphology shifted towards objective, evidence-based approaches, such as space syntax, cellular automata, agent-based models, and fractals (Oliveira, 2018). Despite these advances, predicting city expansion and improving accuracy remain interesting challenges.

Space Syntax Applications

Space syntax has been used to predict how people navigate spaces, both within buildings and urban settings (Andi et al., 2021). Studies such as Xia et al. (2019), Morales et al. (2020), and Atakara & Allahmoradi (2021) applied space syntax to predict urban expansion, land values, and growth in cities like Cotton Lake Town, Guatemala City, and Famagusta. Over the last 35 years, space syntax has proven effective in urban planning and morphology studies (Matějček & Přibyl, 2020).

In the context of Pontianak, several studies have used the space syntax method. Gultom et al. (2022) assessed the density and accessibility of Pontianak using space syntax. Affrilyno et al. (2024) applied space syntax to evaluate urban vulnerabilities related to accessibility. The work most closely related to the present research is by Gunawan et al. (2024), who used space syntax with diachronic analysis to examine the deterioration of Pontianak's canal network. However, these studies leave a gap, which this research addresses by focusing on overall urban growth and the prediction of future development.

Several studies have explored Pontianak's urban form using space syntax. However, they did not incorporate the socio-economic factor into the discourse. Socio-economic conditions, such as population density, economic activities, and land use, are critical in shaping urban morphology and can significantly enhance the predictive accuracy of space syntax models. It has become common practice for space syntax studies to integrate socio-economic data with spatial analysis, capturing the human-driven forces behind urban growth and providing a more comprehensive framework for predicting development patterns (Hillier & Hanson, 2005; Xia et al., 2019). Several studies, including those by Atakara and Allahmoradi (2021), Charalambous and Mavridou (2012), Li et al. (2017), Matějček and Přibyl (2020), and Morales et al. (2020), have proven that socio-economic changes heavily influence spatial expansion. Notably, the research by Nes and Yamu (2017) highlights the significant relationship between space syntax and socio-economic factors, showing how spatial configurations directly influence economic activities and centrality shifts within urban areas. Nes & Yamu (2017) demonstrated how space syntax can predict where businesses and economic centers will emerge, which leads to the ability to predict the direction of urban expansion.

Research Method

The space syntax method was selected for the present research, because this method analyzes urban morphology through a configuration model and produces spatial patterns in relation to the social character of the residents in the city (O'Brien & Griffiths, 2017). This research analyzed the physical characteristics of the city in terms of urban morphology based on the non-physical conditions of the city, i.e. the socio-economic conditions of the community. Space syntax method is an appropriate method to analyze urban morphology, because this method uses a science-based approach that focuses on people as well as social, economic, and environmental phenomena (Hillier & Hanson, 2005). Space syntax has the ability to find out the trend of travel demand by analyzing road accessibility, which shapes the urban morphology (Pappu, 2018).

The diachronic approach was used in this research to compare changes from several time frames in order to determine the morphological development of Pontianak City (Camiz, 2018). The morphology in this research was seen from the road networks on old maps of Pontianak City. The maps used in this research were maps from 1846, 1898, 1942, 1980, and 2020. The analysis intervals were intended to be consistent, i.e. every 40 years, but based on the existing documents the interval varied slightly, from 38 to 52 years, with an average of 43.5 years. The selected time frames were expected to represent the following important eras in Pontianak: 1846 is the oldest map identified by this research; 1898 represent the Dutch colonialization era; 1942 represents the Japanese colonization era; 1980 represents the New Order era; and 2020 represents the Reform era.

Space syntax has several configuration models of spatial representation, consisting of axial maps, convex maps, and visual graph maps (Al-Sayed et al., 2014). The axial map is the most suitable technique to represent road networks on an urban scale (Li et al., 2017). An axial map is a set of axial lines or the longest visual line, which is illustrated through a point in a spatial configuration with fewest lines (Siregar, 2014). The function of the axial map is to present and globally display information (unlimited) regarding the network of outer space structures, the network of pedestrian movement, routes that can be taken, the position of the road network within the area (Pramudito & Surya, 2017). The process of making an axial map starts by obtaining records, which may include satellite images or maps to be modeled into an axial map in order to be analyzed (Figure 2). The results are presented in colored lines, where these colors represent values. Red represents a high or maximum value; blue represents a low or minimum value (Figure 2).
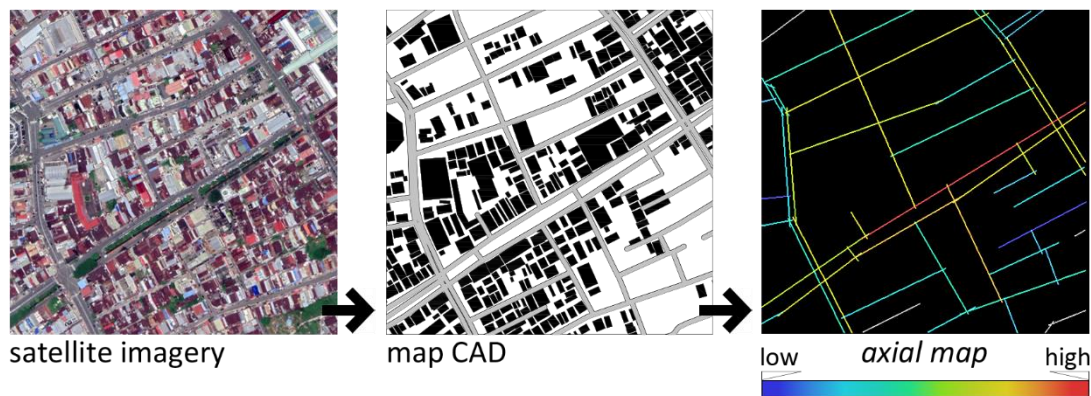
Figure 2. Urban spatial analysis stages.

In assessing space, space syntax uses several types of calculations, i.e., connectivity, step depth, integration, choice, and intelligibility (Al-Sayed et al., 2014). Calculations that are suitable for viewing urban morphology are those guided by the concept of centrality, consisting of integration and choice (Nes & Yamu, 2017). Integration calculation is an assessment of the depth of space globally using the concept of finding the centrality or the center of an area, settlement, or city (Nes & Yamu, 2017). The higher (the redder) the integration value, the more central or the easier to reach a space. Choice calculation is an assessment of space preference or finding a preferred area that can be reached by the shortest route (Li et al., 2017). The higher (the redder) the choice value of a space, the higher the preference for that space. In this study, these calculations were performed using the DepthmapX software (version 0.5), a platform specifically designed for space syntax analysis.

To assess the reliability of the results, integration and choice values were qualitatively validated by comparing them with observed urban patterns in Pontianak City, as documented in municipal planning reports and previous studies. Socio-economic factors were operationalized by mapping the spatial distribution of economic activities, population density, and land use, and then cross-referencing these with the integration and choice outputs to identify spatial correlations. This ensured that the model outputs were tested against real-world conditions and that socio-economic variables were incorporated in a systematic manner.

Results and Discussion

The results and discussion present both an explanation stage and a diachronic analysis. The first stage consists of an explanation of the historical phases of Pontianak City based on non-physical data of the city such as the socio-economic condition of the community (see *Phases of City Development*). The second stage presents the analysis results of the city's spatial structure based on physical data of the city (see *Diachronic Spatial Analysis of the City*). The final stage compiles the development of Pontianak City to explain the direction of the development and differences across development phases (see *Morphological Development of Pontianak City*).

Phases of City Development

This research divides Pontianak City into three zones, namely area A (West, City, Southeast, South Pontianak), area B (East Pontianak), and area C (North Pontianak) (Figure 3). This zoning is based on the fact that the Kapuas River and Landak River separate Pontianak City into three mainland areas. Each of these areas originated from settlements that had different socio-economic conditions. Area A originated from areas under Dutch colonization, which attracted Chinese traders to create a trading area that later developed into the center of the economic activities of the city. Area B is a historical area that is known as the starting point for the establishment of Pontianak City. Area B is home to the family of the sultan and the *hulubalang* (sultanate warriors), while area C developed from the settlement of allies of the sultan (including peasants, Chinese migrants, and local inhabitants allied with the sultanate).

Chronologically, Pontianak City was established in 1771 when Sultan Syarif Abdurahman came with his people to open land on the edge of the Kapuas River and Landak River intersection (Patmawati & Sukmawati, 2018). In the same year, *hulubalang* from Arabia and Bugis built a village named Kampung Arab and Kampung Bugis (Sirrullah, 2019). In 1772, Lo Fong and his people from China came to build Kampung Siantan (Area C) (Sirrullah, 2019). In 1779, the VOC made a contract with Sultan Syarif Abdurahman and occupied the area on the banks along

the Kapuas River, across the residence of Sultan Syarif Abdurahman (Area A) (Firmansyah et al., 2022; Hasanuddin, 2016). In less than ten years, all three current zones of Pontianak City already had settlements. In 1799, the VOC went bankrupt and was replaced by the British East India Company in 1811 (Hasanuddin, 2016). In 1816, the Dutch East Indies government took over Pontianak City and brought several influences, establishing offices, permanent barracks, and fortresses in 1818; building a free port in 1834; and establishing European settlements in 1840 (Figure 3) (Hasanuddin, 2016). In 1816, the Dutch opened the free port due to trade competition with the British colony, who traded goods from Singapore (Figure 3) (Hasanuddin, 2016). In this era, Pontianak City was in the emergence phase of a waterfront settlement developing inland.

The existence of rivers and trade increased the popularity of Pontianak and attracted more newcomers (Bayuardi et al., 2017). In 1846, newcomers from Banjar established Kampung Banjar Serasan and Kampung Saigon (Figure 3) (Sirrullah, 2019). In 1850, Chinese people fled to Pontianak due to the war in Monterado (Hasanuddin, 2016). In 1872, a second batch of Bugis migrants established Kampung Tambelan Sampit, Kampung Kamboja, and Kampung Bangka (Figure 3) (Hasanuddin, 2016). The historical records of the development of Pontianak City from 1857 to 1939 focus on the economic development of the city. The economic development in this era can be seen from several aspects of shipping expansion in 1857, multi-layer trade patterns in 1893, the establishment of factories in 1893, and the development of export commodities from 1857 to 1939 (Setiawan, 2013). In 1939, Pontianak experienced an economic crisis (Hasanuddin, 2016). In this era, Pontianak City was still in a developing phase.
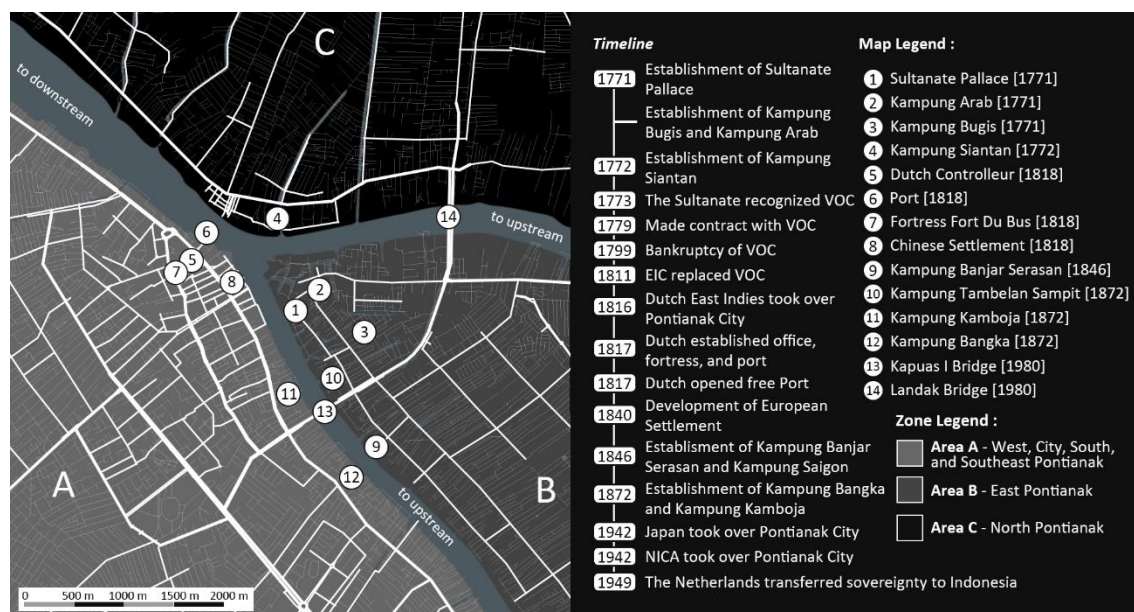
Figure 3. Map of Pontianak City.

The period from 1941 to 1949 was a time of war and conflict for Pontianak. In 1941, Pontianak was attacked by nine Japanese warplanes and two months later, in 1942, Pontianak came under Japanese colonization (Davidson, 2003). From 1945 to 1949, there was a fight against the NICA (Netherlands Indies Civil Administration), until the Kingdom of the Netherlands finally recognized Indonesian sovereignty (Davidson, 2003). After going through the Indonesian revolutionary era, Pontianak developed into an autonomous city and developed rapidly into the

capital of the province and the most densely populated city in West Kalimantan. In 1970, the port in Pontianak allowed for crossing the Kapuas River, connecting area A and area C (Pradana & Mutiasari, 2017). In 1980, Kapuas I Bridge (Hadi et al., 2015) and Landak Bridge (Mustofa, 2016) were built, serving as the main access points connecting the three areas. During this era, the waterfront started to be abandoned, thus entering the phase of decline. Transportation started to shift to land transportation. The three zones were already connected with a permanent route via a bridge, except for area A and area C, which were only connected by ferries.

In 2007, the Kapuas II Bridge was inaugurated. This bridge was built to reduce vehicle loads on the Kapuas I Bridge. The other bridge, the Landak Bridge, was duplicated into two and called the Landak I Bridge (old bridge) and Landak II Bridge (new bridge) in 2019 (PUPR, 2019). Since 2015, the waterfront in Pontianak started to be revitalized, because the area looked like a slum (BAPPEDA, 2015). In 2017, the Government of Pontianak City implemented a waterfront city project to develop the waterfront into a tourist area (JawaPos.com, 2017). In this era, the bridge became increasingly important for vehicles and the waterfront was developed into a tourist area. This means that the city moved into the rediscovery phase.

Diachronic Spatial Analysis of the City

The Kapuas River had become a route with a high trading volume prior to the existence of the Pontianak Sultanate (Andi, 2017). Therefore, the time frame when the waterfront settlements came into existence was selected for this research. From 1771 to 1846, these settlements developed along the waterfront, because the land area was not entirely secure (Andi, 2017). The three areas (A, B, and C) were not connected by roads but by water, so people moved on boats to cross the rivers. These areas together with Kapuas River and its tributaries were the starting point of Pontianak development (Gunawan et al., 2022). Andi et al. (2023) indicate that this early arrangement, as a control placement, would later significantly affect spatial development in the next time frame and is the reason for the different spatial patterns in these three areas.

In 1846, Pontianak comprised distinct zones: the sultanate and its *hulubalang*, European settlements, Chinese merchant markets, Banjar villages, and other trading partner settlements, each with its own integration center. In area A, integration analysis placed the settlement core along the waterfront (red line in Figure 4), which also scored highest in the choice analysis, indicating its role as the main development axis. This axis coincided with the Chinese trading district, which dominated Pontianak's market (Figure 4), guiding subsequent growth toward the waterfront corridor (Figure 5). In area B, the choice analysis highlighted the road along the waterfront as the most traversed route, while integration values were evenly distributed, reflecting a less centralized structure (Figure 4). By 1898, this pattern was reinforced by the extension of a road along the waterfront (Figure 5). In area C, the sparse and simple road network limited the explanatory power of both the integration and choice calculations (Figure 4), but development was still in accordance with the existing street layout.
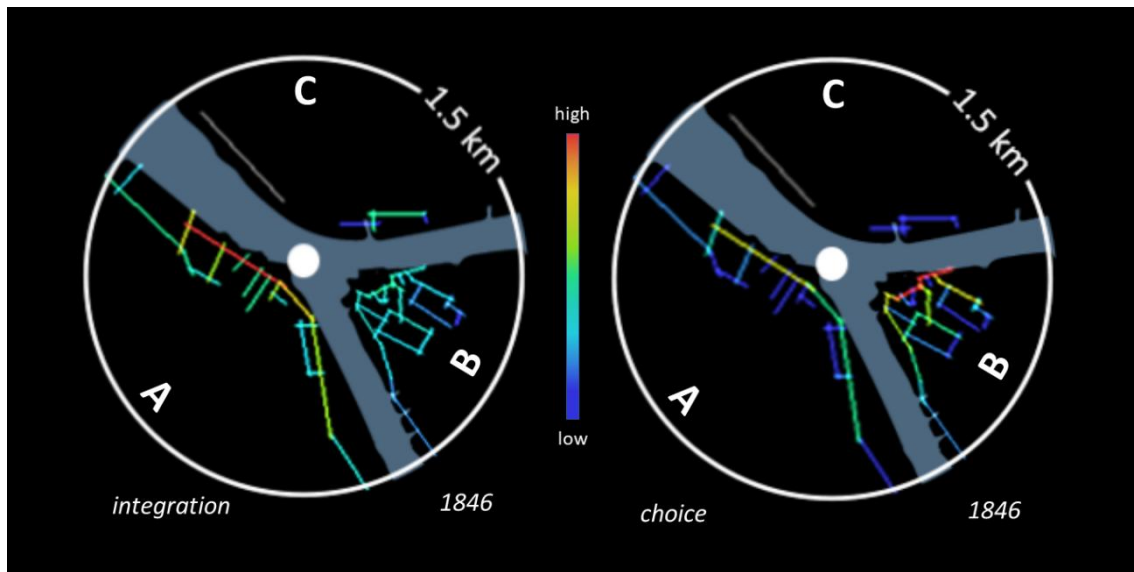
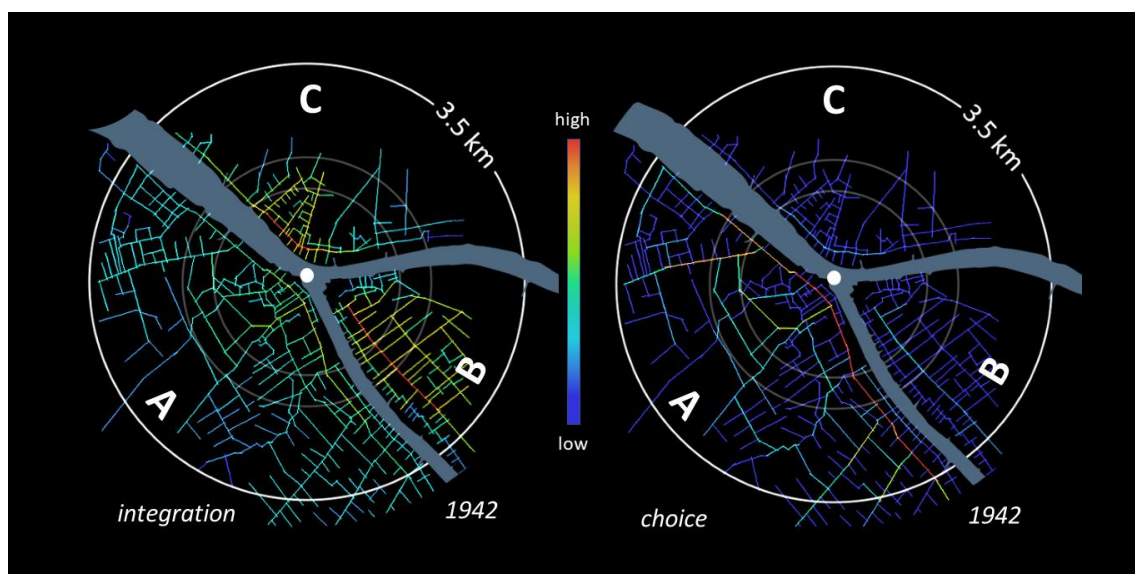**Figure 4.** Integration and choice analysis of Pontianak City in 1846.

In 1898, the settlements in area A expanded inland rather than extending along the river as previously predicted. This shift was influenced by the canal construction project by the Dutch colonial government, which was focused exclusively in this area (Sirrullah, 2019). The integration analysis indicated that the activity center shifted inland but still stayed near the river. The choice analysis showed a preference for inland-oriented roads, suggesting that future growth will follow this direction. In area B, both the preferred road (choice) and the activity center (integration) moved from the middle zone (green road segment Figure 5), likely driving road network development there. In area C, the choice analysis revealed no preferred road, while integration shifted from the waterfront to a second-tier road, indicating the gradual decline of the waterfront route (Figure 5).
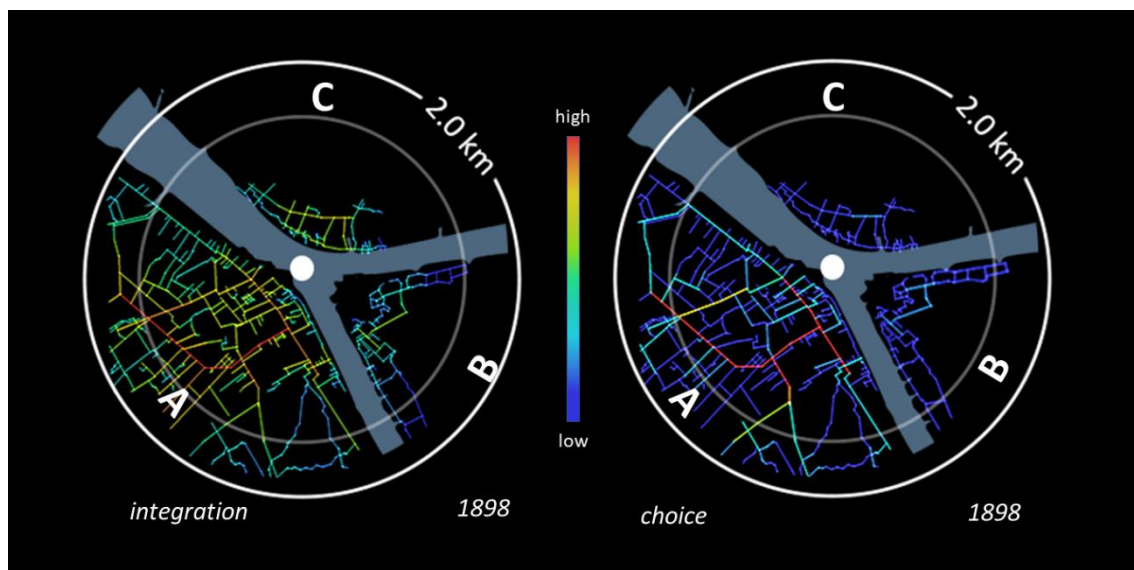
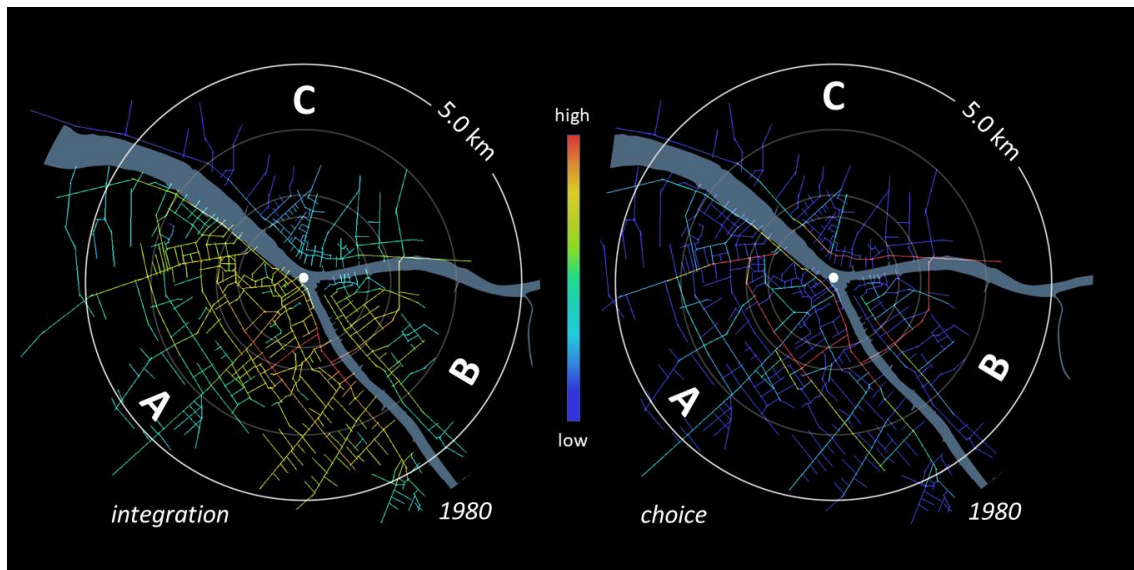**Figure 5.** Integration and choice analysis of Pontianak City in 1898.

For 1942, the integration analysis showed the center of area A shifting back to the waterfront (Figure 6), with the choice analysis predicting development concentrated along the waterfront (Figure 6). This was confirmed, as landward growth remained minimal (Figure 7) and waterfront roads became the main connectors between Pontianak and nearby settlements (Figure 6). In area B, the center shifted to the second-tier road, which later became congested by 1980, while former first-tier waterfront roads declined into alleys and neighborhood streets (Figure 6). In area C, the integration analysis indicated a move from waterfront roads to nearby second-tier roads, yet the choice analysis still predicted growth along the waterfront (Figure 6). This was confirmed in the following time frame, where the development stayed concentrated there (Figure 7). By 1980, the shift from the first-tier road to the second-tier road left many original waterfront routes abandoned, fragmented, or fully disconnected (Figure 7).
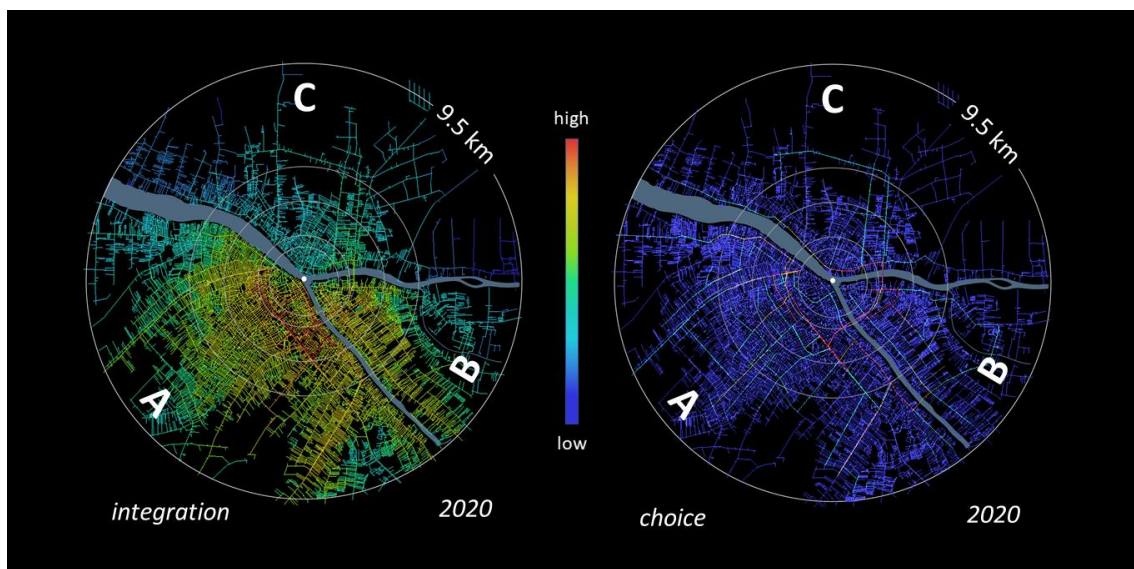

Figure 6. Integration and choice analysis of Pontianak City in 1942.

In 1980, rising land transportation use in Pontianak spurred inland expansion, marked by the construction of the Kapuas I Bridge and the Landak Bridge (Bayuardi et al., 2017). The center of area A shifted toward the Kapuas I Bridge (Figure 7), soon becoming a new trading hub with numerous hotels. In area B, a key route linking areas A and C emerged as the primary development axis, while a riverside road began functioning as an alternative road for the new bridge. Conversely, area C became more segregated from the core (Figure 7), leading to slower growth compared to areas A and B. The choice analysis highlighted these newly connected corridors (Figure 7), which later evolved into Pontianak's principal road network.

**Figure 7.** Integration and choice analysis of Pontianak City in 1980.

In 2020, Pontianak City became increasingly complex with the addition of two major bridges: Kapuas II Bridge (established in 2007) and Landak II Bridge (a duplication, inaugurated in 2019). The integration analysis still identified Ayani Street in area A as the city's core, consistent with 1980. The choice analysis indicated partial landward growth in area A, but a stronger shift toward Sungai Raya Street, driven by the Kapuas II Bridge (Figure 8). Conversely, Landak Bridge II did not direct development toward area C. Instead, it reinforced the connection between area A and area B, further segregating area C (Figure 8). This pattern suggests that area A will face heavy congestion in the future, concentrating city center activity and intensifying movement across the Kapuas and Landak bridges.

Figure 8. Integration and choice analysis of Pontianak City in 2020.

Morphological Development of Pontianak City

Pontianak's growth trajectory closely aligns with Timur's (2013) waterfront development phases. The emergence phase started when the sultan and his group arrived in 1771 (Figure 9) and established an early village. This phase ended in 1872, after the second batch of immigrants settled in Kampung Bugis, marking the ending of the initial settlement formation (Figure 9). The development phase was catalyzed by the free port opened in 1816 (Figure 9), which intensified trade and export–import activities. The decline phase occurred after the construction of the crossing bridge in 1980, as the river gradually lost its central role and residents increasingly shifted to alternative routes. The rediscovery phase started with the implementation of the Waterfront City project in 2017 (Figure 9), which turned the waterfront into a tourist attraction.
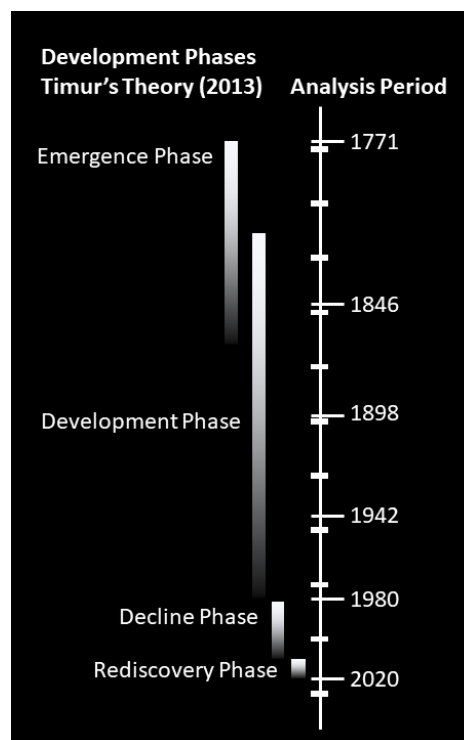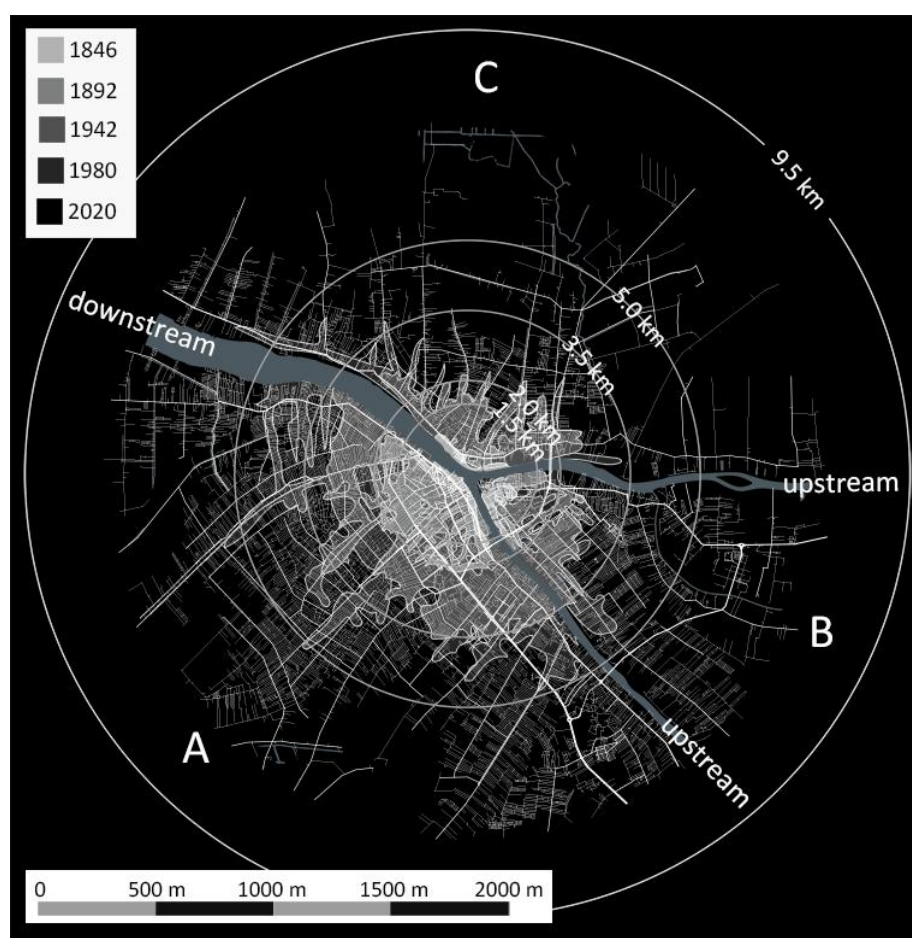

Figure 9. Development phases of Pontianak City.

The city's spatial orientation evolved in line with these phases. In the beginning, the river waterfront served as the focal point of development. Development began to shift landward from 1898 onward due to the construction of the canals. However, the existence of the rivers still influenced the urban development until 1942. From 1980 onward, land-oriented development grew rapidly, resulting in improved road connectivity and reduced water transport use. By 2020, both the rivers and the waterfront underwent a shift in function, becoming tourist areas. The diachronic analysis indicated a clear transition from being river-based, then becoming oriented toward both rivers, and eventually displaying land-oriented urban growth patterns.

Political and administrative divisions also shaped morphology. Since 1779, each of the three zones in Pontianak had been occupied by people. Area A was where the controller of the Dutch colony was housed and area B was the location of the Sultanate Palace, while area C did not

have a clear ruling power. Each of the three areas developed road networks independently until the Kapuas Bridge and the Landak Bridge connected them. While area B was geographically the center of the city, area A's early infrastructure development backing positioned it as the city center and economic core. Area C remained underdeveloped and socially segregated due to its politically weaker and more peripheral geographic position.

The growth rate of Pontianak City reflects these historical dynamics. The radius of the city road network changed as follows: 1.5 km in 1846; 2.0 km in 1898; 3.5 km in 1942; 5.0 km in 1980; and 9.5 km in 2020 (Figure 10). The growth of the city radius was slow from 1942 to 1980 due to national instability and conflict from the 1940s to the 1970s. This contrasts with the time frame from 1980 to 2020, when Pontianak City grew rapidly, marked by the large expansion of its road network (see Figure 10).

Figure 10. Morphology development of Pontianak City.

Conclusions

This research applied diachronic space syntax analysis to examine the direction and pattern of Pontianak's growth as a waterfront city. The findings show that its development orientation shifted over time. Initially, it was river-focused, then gradually became land-orientated after the construction of the canals and bridges. This transformation mirrors Timur's four phases of waterfront city development but has also produced uneven outcomes. Most notably, the

persistent segregation and slower growth of North Pontianak (Area C) compared to the city center (Area A). The city's expansion radius has increased significantly over the decades, with infrastructure (i.e. bridges) decisions playing a decisive role in redirecting growth.

Integration and choice calculations successfully predicted the direction of urban expansion across historical eras, validated by historical maps. This confirms the potential of space syntax to forecast future developments patterns in Pontianak, provided that socio-economic factors remain the dominant drivers. Nevertheless, large-scale intervention such as the construction of canals and bridges or other politically driven infrastructure can override these organic trends, imposing artificial growth directions.

For urban planners, the research highlights two priorities. The first priority is to improve accessibility and connectivity in underserved areas (especially area C). The second priority is to balance land-based expansion with waterway integration to preserve Pontianak's waterfront identity. Anticipating growth patterns can help prevent segregation, guide equitable infrastructure investments, and support sustainable urban development. These lessons are not only relevant to Pontianak but also resonate with challenges faced by other waterfront cities in the Global South, where rapid landward expansion and uneven accessibility often threaten the cultural and economic value of riverfronts.

This research has three main limitations including scale, physical, and non-physical aspects. In terms of scale, the analysis considered only internal spatial patterns, without accounting for regional influences from neighboring cities. In terms of the physical aspect, the main limitation of this research is the fact that the assessment of the urban morphology only focused on the road network without considering the aspects of land use, building typologies, or integration with transport and land value data. In terms of the non-physical aspect, the main limitation of this research was the fact that the space syntax analysis focused on the socio-economic aspects of the community, while the political policy aspect is unpredictable, for it changes depending on the will of those who hold political power. Future research could address these limitations to provide a more comprehensive understanding of waterfront city morphology in the Global South context.

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