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Establishing Urban Green Infrastructure Networks Through Connectivity Analysis: Focused on Incheon*

연결성 분석을 통한 도시 그린 네트워크 수립에 관한 연구: 인천광역시를 중심으로

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Abstract: Despite the various environmental and ecological benefits of green spaces, the diminution and disconnection of green axes are becoming significant challenges due to rapid urbanization. To enhance the connectivity of urban greeneries, a green infrastructure plan presenting comprehensive green-axis measures allowing for regional characteristics is in need. This study examines the connectiveness of existing green spaces and derives new green axes for two types of cities in Incheon, South Korea: Yeonsu-gu (a new town) and Namdong-gu (an old city center). By conducting connectivity analysis through utilizing GIS and Conefor, three types of greenery are categorized and visualized: significant core, complementary core, and stepping stone greenery. The results show that Yeonsu-gu contained 13 significant cores (IIC: 0.74-35.44), 19 complementary cores (PC: 0.06-4.24), and 12 nodes, while Namdong-gu had six significant cores (IIC: 0.14-18.99), 15 complementary cores (PC: 0.06-3.25), and 13 nodes. Based on the results, two additional green axes are proposed for Yeonsu and Namdong-gu with policy recommendations to better link isolated green patches. The results of this study provide insights to local planners and decision-makers about how they can effectively maintain and improve the overall green infrastructure network in the long-term.
Key Words: Conefor, Green Space Planning, Connectivity Analysis, Networks, Incheon

요약: 도시 내 녹지공간의 다양한 환경적·생태적 이점에도 불구하고 급속한 도시화는 녹지축의 감소와 단절을 지속적으로 가져왔다. 녹지의 연결성 향상을 위해서는 지역의 특성이 고려된 녹지축 중심의 장기적 그린인프라 계획이 필요하며, 본 연구는 인천광역시의 대표적인 신도심인 연수구와 구도심인 남동구의 녹지 연결성을 분석하여 지역의 특성에 적합한 새로운 녹지축을 도출하였다. 연결성 분석은 GIS와 Conefor를 활용하여 이

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루어졌으며, 이를 통해 3가지 녹지(거점 녹지, 준거점 녹지, 징검다리 녹지)를 분류 및 시각화 하였다. 연구결과, 연수구는 13개의 거점 녹지(IIC:0.74-35.44), 19개의 준거점 녹지(PC:0.06-4.24), 12개의 노드가 나타났으며, 남동구는 6개의 거점녹지(IIC:0.14-18.99), 15개의 준거점 녹지(PC:0.06-3.25), 13개의 노드가 도출되었다. 연구결과를 바탕으로 연수구와 남동구의 새로운 2개 녹지축을 제시하였으며, 단절된 녹지간의 연결성 개선을 위한 정책적 함의가 이루어졌다. 본 연구는 지역계획가와 의사결정자에게 있어 그린인프라 네트워크를 효과적으로 유지하고 향후 연결성 높은 녹지축 방안을 마련하는데 큰 도움을 줄 것이라 판단된다.
핵심주제어: Conefor, 녹지계획, 연결성분석, 네트워크, 인천광역시

I. Introduction

Today, rapid urbanization has led to increased risk of hazard for cities, accelerated the deterioration of ecosystems, and resulted in more frequent and diverse environmental disasters (Kim and Tran, 2018; Lin et al., 2017). As cities are increasingly becoming denser both in structure and population, planners and local advocates have an equally increasing pressure and need to manage and maintain the network of green spaces; and thus, pursue more sustainable and resilient cities. Parks and green spaces play a vital role in urban areas as they protect natural landscapes, aid in reducing negative impacts from climate change, improve the residents' quality of life and health, and help ease negative social pathology phenomena with their therapeutic effects (Bowler et al., 2010; Byun et al., 2002; Kim et al., 2017; Hilty et al., 2006; Moser et al., 2015; Mun, 2001; Shafer, 1994). To most benefit from the environmental, economic, and social aspects of green spaces, the connectivity of green axes, or green infrastructure network, is one of the most important considerations a city needs to take when planning (Benedict and McMahon, 2006). A "green-axis" can be defined as spaces, where natural areas are a central focus and connected via green areas, streams, gardens, and other green infrastructure, such as street trees, in the urban area to provide habitats for wildlife and allows ecological corridors to open for increased biodiversity (Benedict and McMahon, 2002; Park, 2019). Many studies have emphasized the importance of green axes by examining their environmental and social benefits (e.g., air purification; stormwater reduction; heat mitigation; biological diversity; social vulnerability reduction) to urban areas across a range of disciplines (Ga, 2007; Kim and Park, 2016; Kong et al., 2010; Lennon and Scott, 2014; McCarty et al., 2021; Meerow and Newell, 2017; Choi and Kim, 2019).

Considering the positive effects of a developed green-axis, more thorough green infrastructure planning, with a focus on the connectiveness of green spaces, is highly recommended. While policies related to green infrastructure are being reviewed and introduced in South Korea, they are heavily focused on the quantitative expansion of green spaces centered on single-unit projects. Additionally, prior studies are limited to examining the effects of structural techniques for a single green infrastructure facility (Kang et al., 2012). In order to efficiently benefit from the various aspects of green spaces, a green infrastructure plan that reflects the overall regional characteristics, considering already existing natural and man-made spaces, should be established.

This study determined the existing degree of connectivity by quantitatively analyzing the distribution of existing green spaces throughout the urban area. Two study sites, each being a borough representing one of two distinct types of developed areas (new- and old-towns) in Incheon, South Korea, were selected to be analyzed resulting in policy recommendations addressing the unique characteristics of each site. Three different connectivity indexes derived using the Conefor 2.6 GIS software package (Saura and Torné, 2009) were used to study and classify the green infrastructure within each study site. The new green axes proposed in this study were compared with a previous plan from the 2030 Incheon Parks and Green Spaces Master Plan (PGSMP). In addition, various low impact development (LID) practices that may link with the green axis at the site-level were recommended to establish a green-friendly and daily living environment.

In the following sections, the paper first introduces the concepts of green infrastructure and green space planning in South Korea, the modeling tool used in this study, and prior studies that have examined green space connectivity. Second, the paper discusses the study area selection processes and research methods. Third, the indices derived from the connectivity analysis were further analyzed to reveal and extract important green areas in terms of functionality. Finally, the results are elaborated on with discussion to suggest new green axes and provide policy implications for improving the connectiveness of existing green patches within each study area.

Ⅱ. Literature Review

1. Green Infrastructure & Parks and Green Spaces Master Plan

Green infrastructure is a concept first introduced in North America in the late 1990s in response to climate change mitigation plans aiming to achieve sustainable urban development. The term is more generally defined as a network of interconnected green spaces that preserve the features and functions of the natural ecosystems while interacting and working alongside man-made ones (Konijnendijk et al., 2013; Lee and Kim, 2020). That is, green infrastructure is an element of urban space that, by utilizing the structure and function of natural features, can be used as a means of pursuing sustainable spatial planning for the coexistence of nature and human (Kwon et al., 2019). Because green infrastructure planning helps in the evaluation of types and availability of exiting natural spaces and resources, as well as helps in the prioritization of open spaces for conservation, it is necessary to consider it in any preservation and sustainability planning, especially during periods of rapid urbanization. In addition to simply protecting green spaces, planning is required to prevent isolated green patches, a lack of connectiveness in the overall infrastructure, and consider various social and economic factors (e.g., recreation, tourism, and economic development) which impact residents' quality of life (Kang, 2018).

As a response to their positive impacts on the urban environment, the role of parks and green spaces is becoming increasingly important (i.e., environmental restoration, plant and wildlife habitat preservation, recreational functions, and disaster prevention; Lee et al., 2018). In South Korea, the PGSMP was established by each locality to comprehensively provide directions for the expansion, management and use of green spaces within urban areas. This plan plays as a major guideline in presenting future goals and implementation strategies. Incheon, where old city centers rapidly grew due to the large-scale development projects in late 1900s, also established their 2030 PGSMP to comprehensively manage green spaces and present the future direction of park/green space policies in response to the changing urban environments. Particularly, the plan proposed various types of greenways such as the east-west green axis and the Y-shaped green axis, centering on the S-shaped green axis (range of mountains), which is the core green network of Incheon. Several measures were also suggested to improve the overall connectivity of the green axes which have been previously disconnected from road construction projects.

2. Green Space Connectivity Analyses

A number of studies have examined the connectivity of green spaces in various aspects. By using the APACK 2.17, Ahn et al. (2003) analyzed the landscape status of Seoul and suggested several alternatives to enhance the connectiveness of greeneries using the derived indices. Song et al. (2013) conducted a connectivity analysis to identify whether habitat fragmentation affects chickadee's habitat distribution. Indices, such as patch area, area-weighted shape index, tree vegetation ratio, patch connection order, and parch mediation, were primarily considered in this study. Linkage Mapper, a software that utilizes and calculates the minimum cost distances, was also frequently used to determine the connectivity of core regions (Kwon et al., 2018).

Studies that have examined the landscape connectivity by employing the Conefor were primarily focused on the ecological aspects. Through the connectivity analysis, Kang et al. (2019) derived core green spaces and ecological axes for preservation and management of the national landscape. In addition, Rho (2013) used this software to develop the wetland ecological network of Korea. Song (2017) highlighted the importance of urban parks with the betweenness centrality index, one of the indices derived from Conefor, to quantitatively analyze how the structure and connection of urban parks affect the diversity of birds' inhabiting potential. Some other studies assessed green area connectivity to determine priority areas of unexecuted parks in Korea. While Kang et al. (2018) identified the conservation priorities for long-term unexecuted urban parks for Seoul by considering the existing parks' connectivity, Ahn et al. (2014) attempted to reveal the order of priorities within the existing unexecuted parks in Seongnam through evaluating the city's overall green space linkages. Choi et al. (2019)

identified the priority management areas in two boroughs of Incheon by reflecting the pattern of green infrastructure through MSPA (Morphological Spatial Pattern Analysis). In addition, several studies (Yoon, 2016; Kang et al., 2011) adopted the graphic theory and employed the connectivity analysis to quantitatively analyze the green space networks.

By emphasizing the importance of habitat connectivity, existing domestic studies have demonstrated that the networks of green spaces should be thoroughly considered within urban areas. However, the scope of prior studies tends to be set too broadly and have failed to contemplate the entire green infrastructure facilities while exploring the landscape connectivity. More specifically, most research has merely focused on the importance of greenery linkage rather than providing new green axes from in-depth reflection on the characteristics of a specific region, which has resulted in less practical green space network systems. This study, therefore, analyzed the green space connectivity at the borough (gu) level in Incheon and attempted to provide feasible green space axes that could suit well in current 2030 Incheon's PGSMP.

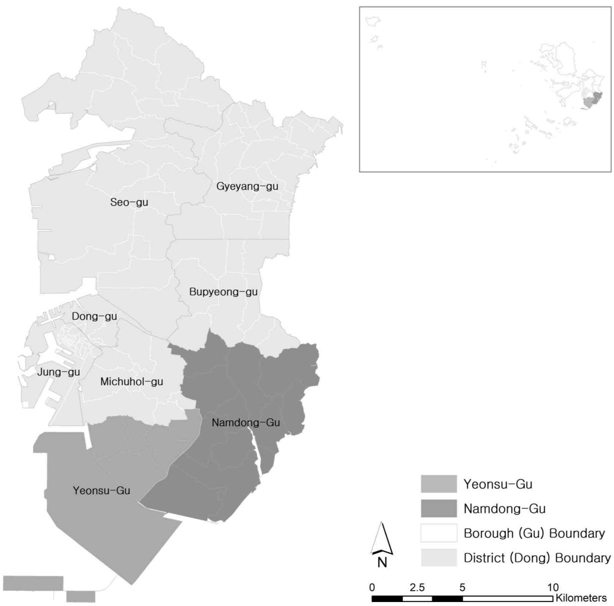
Ⅲ. Research Methods

1. Study Area Selection

Among ten administrative boroughs (*gu & gun*) in Incheon, two boroughs – Yeonsu and Namdong-gu, representing new and old towns respectively, were selected for the spatial sample frame for this study (see Figure 1). Both boroughs are located in the southern part of Incheon, but their urban forms and characteristics differ significantly. While

Yeonsu-gu is consisted with mix of old downtowns and newly developed areas, Namdong-gu is primarily comprised by old urban centers with heavy industrial complexes. Land cover for both boroughs was additionally used for assessing the green infrastructure networks of the areas. Considering the 41 sub-categories of the land cover GIS data provided by the Environmental Geographic Information Services (EGIS), only the categories belonging to the "green infrastructure" type were extracted (〈Table 1〉).

〈Figure 1〉 Study area



〈Table 1〉 Selected green infrastructure land covers from the EGIS

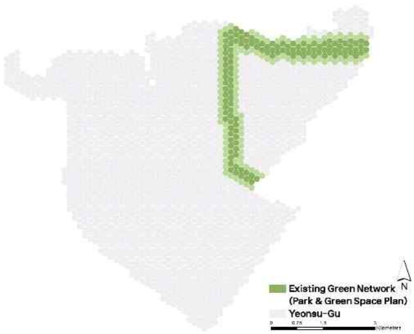
Low-Level	Mid-Level	High-Level
Agricultural Area	Paddy	Readjusted Paddy
		Unadjusted Paddy
	Field	Readjusted Field
		Unadjusted Field
	Facility Cultivation Area	Facility Cultivation Area
	Orchard	Orchard
	Other Cultivation Area	Ranch Farm
		Other Cultivation Area
Forest Area	Broadleaf Forest	Broadleaf Forest
	Coniferous Forest	Coniferous Forest
	Mixed Stand Forest	Mixed Stand Forest
Grassland	Natural Grassland	Natural Grassland
	Artificial Grassland	Golf Course
		Cemetery
		Other Grassland
Bare Ground	Natural Bare Ground	Beach
		Riverside
		Rock
Water	Inland Water	River
		Lake Water and Swamp

1) Yeonsu-Gu

Yeonsu-gu, adjacent to Michuhol and Namdong-gu, can be divided into north and south based on the stream splitting through the center. While low-rise residential and mountainous areas mainly coexisted in the north, the southern part of the borough is developed as a new town after the land was reclaimed from the ocean and it predominantly comprises apartment complexes, parks, and educational facilities. Yeonsu-gu includes Songdo, one of the three representative new towns within the Incheon Free Economic Zones, and the population is continuously growing as the borough is designated as a key new development planning area in Incheon. The 2021 population was approximately 391,000, which accounts for 13% of the total population of Incheon. Considering the total size of 73.29㎢, green areas take the largest portion at 30.66㎢, following by residential (22.53㎢), and industrial area (7.79㎢). While the green space ratio of Yeonsu-gu is approximately 42%, the green space per person is 83.64㎡, which is relatively insufficient compared to the entire Incheon area (101.92㎡). In addition, the park area per person of Yeonsu (3.67㎡) is less than the overall Incheon (16.18㎡). Figure 2 shows the existing green axis in Yeonsu-gu.

The study area has been divided into four sections by considering the regional characteristics of each administrative district (〈Figure 3〉). With the Cheongryang Park as a core park, Section 1 (9.3㎢) primarily includes low-rise residential and commercial buildings, as well as green spaces, such as a golf course and a lake. Section 2 (10.3㎢), where Jangmi Park and Dongchoon Park function as core parks, contain green spaces that are seated within existing apartment complexes. The total area of Section 3 is about 7.9㎢, and it contains the most recently developed areas in Songdo where significant portion of green areas are related with potential residential construction sites. Finally, Section 4 (12.9㎢) is the first phase development area of Songdo, including several facilities having large influxes of floating populations, such as universities, industries, and distribution facilities.

〈Figure 2〉 Existing green axis in Yeonsu-gu



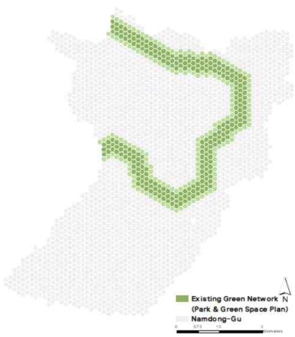
〈Figure 3〉 Four sections in Yeonsu-gu

2) Namdong-Gu

Namdong-gu is bordered by Bupyeong-gu to the north and Michuhol and Yeonsu-gu to the southwest. Several mountains, such as Mt. Geoma, Su and Deumbae, are located in the east and center, while Sorae Port and Jangsu Stream flows to the southeast. Namdong-gu was divided as an administrative district in 1988 and classified as a representative old city center of Incheon, which includes several urban regeneration projects. The population of the borough is approximately 521,000 as of 2021, comprising 18% of the total Incheon population. Of the total area of 68.65㎢, green spaces occupy the largest portion with 28.45㎢, followed by residential (16.16㎢), and industrial areas (10.3㎢). The green space ratio is about 41.5%, which is similar to Yeonsu-gu. However, the green space per person (53.41㎡) is about half that of the entire Incheon region (101.92㎡). Lastly, the park area per person is 12.96㎡. The S-shaped green axis, which is the core greenway of Incheon according to the 2030 PGSMP, passes through Doryongnyong Park, Incheon Grand Park, and Sorae Wetland Ecological Park, whereas street canopies are planned along Baekbeom-ro from the north of Jungang Park to the vicinity of Incheon Grand Park and adjacent streets near the Namdong industrial complex. The existing green axis suggested by the 2030 PGSMP is shown in Figure 4.

Regarding the four sections in Namdong-gu (see Figure 5), Section 1 (7.6㎢) includes 11 administrative districts, while the urban structure is mostly comprised of apartment complexes, low-rise residential areas, and commercial districts. Section 2 (3.9㎢) is an area that plays as a corridor for connecting Mt. Su and Byzanie and is consisted with the mixture of residential areas and mountains. Section 3 (5.7㎢) connects Mt. Obong, Jagna, and Sorae Wetland Ecological Park, and Section 4 has a total area of 3.3㎢, linking Mt. Deumbae and Gojan Neighborhood Park. These three sections include three administrative districts, respectively.

〈Figure 4〉 Existing green axis in Namdong-gu



〈Figure 5〉 Four sections in Namdong-gu

2. Connectivity Analysis

Conefor 2.6, a software package that quantifies the importance of habitat links, patches, and landscape changes to maintain and improve the overall landscape connectivity (Saura and Torne, 2009), was used in this study to calculate the connectivity of greeneries. Bodin and Saura (2010) defined the program as a network modeling tool that can derive patch priorities according to the degree of connectivity. Previous studies have often used Conefor together in analyzing the habitat connectivity with a focus on animal movements (Lee et al., 2012).

Conefor produces various connectivity indices by objectively quantifying the strength of linkage between different nodes (or patches) and measures the connectivity of nodes in two aspects: structural and functional connectivity (Saura and Pascuak-Hortal, 2007). Binary indices simply examine the spatial distribution of landscapes and structurally assess the connectivity. Indices, such as number of links (NL), number of components (NC), harary index (H), betweenness centrality (BC), landscape coincidence probability (LCP), integral index of connectivity (IIC), are generated from this process. However, these structural indices were limited to reflect the movement of species within the landscape. To complement this issue, probabilistic indices were introduced to functionally evaluate the connectivity of patches by considering the movement characteristics of different habitat species. Flux index (F), area-weighted flux (AWF), and probability of connectivity (PC) are the example indices produced in this step (Saura and Rubio, 2010).

Among aforementioned evaluation indices, two structural (IIC and BC) and functional (PC) indices were employed to analyze the connectivity of green spaces in this study. Through IIC, the importance of connectivity can be precisely calculated and it may represent the degree to which two patches are directly linked in terms of patch size and minimum distance between specific patches. PC considers the number of possible cases in which various connections can be made and expects the most minimum cost patches that the connectivity may improve in the actual landscape (Ahn et al., 2014). Finally, BC identifies all patches that serve as stepping stones and is widely used to determine spatial connection structures.

The data was analyzed in four steps to derive three types of greeneries (significant core area, complementary core area (corridor), and stepping stone area) and to represent the green infrastructure network for each region. First, greeneries that may act as significant core areas were found by using the Integral Index of Connectivity (IIC), a representative index for explaining the structural connectivity and most accurately calculating the importance of habitats in ecosystem connectivity (see equation 1; Saura and Pascual-Hortal, 2007).

$$IIC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{a_i \times a_j}{1+nl_{ij}}}{A_L^2} \tag{1}$$

where, ai and aj indicate the size of patch i and j; nlij represents the number of shortest paths between patches i and j; n specifies the total number of patches distributed throughout the entire landscape.

Particularly, IIC evaluates the connectivity by considering the size of connected nodes. When the distance between two patches is less than a specific limit, the degree of direct linkage for both patches is represented as the index value (Pascual-Hortal and Saura, 2006; Saura and Torné, 2009). In this study, therefore, areas with high IIC values were selected as significant core greeneries that play key roles within a specific region. However, since IIC derives the connectivity value heavily by the size of patches, some greeneries that play an important role may not receive high IIC values due to their limited size. To compensate this issue, greeneries that play a crucial role within a specific region were selected as functional core areas, by referring to the 2030 Incheon PGSMP, and they were distinguished from the structural core areas, where IIC values were high.

Second, Probability of Connectivity (PC), a functional connection index, was used to derive the complementary core greeneries that act as a corridor for significant cores. PC refers to the probability of a range in which wildlife animals can arbitrarily reach within the entire patches. The index was calculated by the following equation.

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i \times a_j \times p^{ij}}{A_L^2} \quad (2)$$

where, ai and aj indicate the size of patch i and j; pij refers the connectivity value that maximizes the possibility of diffusion between patches i and j.

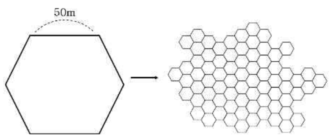
Third, stepping stone greeneries that link the complementary core patches were drawn by using the Betweenness Centrality (BC) index (Equation 3). BC measures the centrality of a particular patch in the connectivity between patches within the entire network and analyzes the number of patches related to a particular patch. That is, the number of patches positioned between different paired patches is calculated.

$$BC = \sum_{i \neq j,\ i \neq v,\ j \neq v} \frac{g_{ivj}}{g_{ij}} \quad (3)$$

where, gij refers the entire number of patches between patches i and j; givj specifies the number of patches that is related with a specific patch v between patches i and j.

Finally, a new green infrastructure network (or green axis) was constructed by connecting all three greeneries (significant core area, complementary core area, and stepping stone area). In order to efficiently visualize the green axis, a hexagon fishnet with a length of 50m on one side was employed for linking high connectivity areas (〈Figure 6〉).

〈Figure 6〉 50m hexagon fishnet for visualizing green infrastructure network



Ⅳ. Results

1. Significant Core Greeneries

1) Yeonsu-Gu

In Yeonsu-gu, A total of 10 greeneries, including Jangmi Park, Dongchoon Park, Cheongnyang Park, Dalbit Park, Sae-Achim Park, were identified as significant core areas based on the IIC values derived from the connectivity analysis. Three of these cores were recognized in the 2030 Incheon PGSMP, having the following IIC values Jangmi Park (35.44), Cheongnyang Park (24.05), and Dongchoon Park (17.03). The remaining seven cores that are not identified in the PGSMP were found in Songdo, indicating that most of the structurally significant cores are located in new town areas. However, only the greeneries located around mountainous areas or existing core areas received high scores due to the nature of the IIC index. Because some greeneries were not detected as significant cores even though they play a crucial role in a region, three functional significant cores (Songdo Central Park, Michuhoul Park, and Haedoji Park) were additionally identified in this study (〈Table 2〉; 〈Figure 7〉).

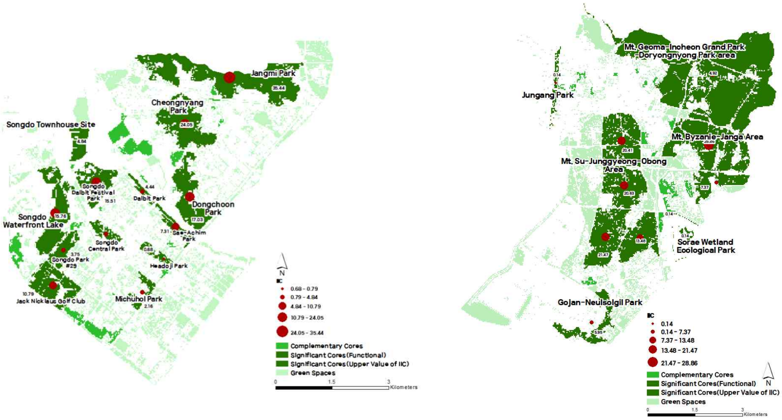
2) Namdong-Gu

Seven greeneries (Mt. Byzanie, Mt. Deumbae, Mt. Junggyeong, Mt. Su, Mt. Obong, Mt. Janga, Gojan Park, and Neulsolgil Park) were revealed as structural significant cores in Namdong-gu, which had high IIC values. Among them, neighboring greeneries were merged together, and final three areas were selected, which are: Mt. Byzanie-Janga area (18.12), Mt. Su-Junggyeong-Deumbae-Obong area (18.99), and Gojan-Neulsolgi park area (5.95). Moreover, Jungang Park (0.14), Mt. Geoma-Incheon Grand Park-Doryongnyong Park area (4.92), and Sorae Wetland Ecological Park (0.14) were identified as functional significant cores by referring the PGSMP.

〈Table 2〉 IIC values for greeneries in Yeonsu and Namdong-gu

Core Type	Yeonsu-gu	IIC	Namdong-gu	IIC
Structural	Jangmi Park	35.44	Mt. Su-Junggyeong-Obong Area	18.99
	Cheongnyang Park	24.05	Mt. Byzanie-Janga Area	18.12
	Dongchoon Park	17.03	Gojan-Neulsolgil Park	5.95
	Songdo Waterfront Lake	15.76	-	-
	Songdo Dalbit Festival Park	15.51	-	-
	Jack Nicklaus Golf Club	10.79	-	-
	Sae-Achim Park	7.31	-	-
	Songdo Townhouse Site	4.84	-	-
	Dalbit Park	4.44	-	-
	Songdo Park #29	3.75	-	-
Functional	Songdo Central Park	2.31	Mt. Geoma-Incheon Grand Park-Doryongnyong Park area	4.92
	Michuhol Park	2.16	Sorae Wetland Ecological Park	0.14
	Haedoji Park	0.74	Jungang Park	0.14

〈Figure 7〉 Distribution of significant core greeneries based on IIC



2. Complementary Core Greeneries

The PC values were used to find the adequate complementary core greeneries, and the cores with high PCs have high connectivity that can serve as mediators in linking the significant cores.

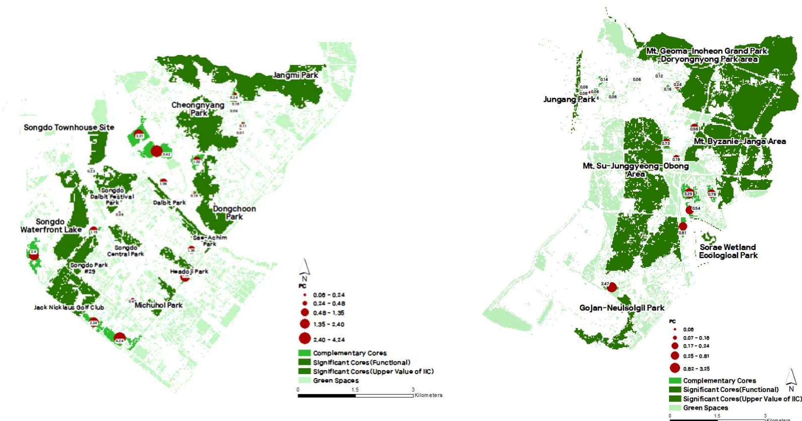
1) Yeonsu-Gu

Within Section 1 of Yeonsu-gu, five complementary cores were identified between Jangmi and Chengnyang Park (significant core) corridor, while two complementary cores existed within the Songdo golf course and potential urban development project site corridor. In Section 2, three complementary cores, including mountainous area in Dongchoon 1-dong and mountains near Dongchoon Park were produced. In the case of Section 3, parks were mostly selected as complementary cores, such as Songdo Landmark City Park #2, Dorandoran Park, Marine West Boat House, and Landmark City Neighborhood Park #13. University campuses, parks, and Damsoo reservoir were identified as complementary cores in Section 4 (〈Table 3〉).

2) Namdong-Gu

In Namdong-gu, a total of seven complementary cores were detected, including Incheon City Hall nearby areas, apartment complex landscapes, and children/neighborhood parks within Section 1. This section particularly encompasses several greeneries that are built in large apartment complexes. Since the green area with the highest PC value in Section 2 was fragmented due to the Yeongdong Expressway and the 2nd Gyeongin Expressway, the rest of three complementary cores were identified in this section, which are: Namdong Cultural and Sports Plaza and agricultural lands near Jangsu stream and Jinheung apartment. Sections 3 and 4 contained four and one complementary cores, respectively, and the cores for both sections had the highest PCs at the park areas (see Figure 8).

〈Figure 8〉 Distribution of complementary core greeneries based on PC



〈Table 3〉 PC values for greeneries in Yeonsu and Namdong-gu

No.	Yeonsu-gu	PC	Namdong-gu	PC
1	Damsoo Reservoir	4.24	Gaetgol Park #3	3.25
2	Songdo Golf Club and Dongchoon-dong Vacant Lot Area	3.42	Hogupo Neighborhood Park	2.47
3	Incheon National University	2.24	Farmland near Sky Baseball Stadium	0.81
4	Openspace in Okryeon-dong	2.21	Mullbaram Waterfront Park	0.79
5	Inha University Aerospace Convergence Campus	1.98	Namdong Cultural Sports Plaza	0.73
6	Sinsong Park	1.35	Farmland near Jinheung Apartment	0.56
7	Landmark City Neighborhood Park #13	2.40	Nuri Park	0.54
8	Songdo Theme Park	1.06	Mansu Neighborhood Park	0.24
9	Songdo Marine West Boat House	1.15	Farmland near Jangsucheon Stream	0.19
10	Mt. Bongjae	1.02	Adan Children's Park	0.16
11	Saerom Park	0.48	Ganseok Raemian Apartment	0.14
12	Baekje Well Children's Park	0.24	Hyangchon Humansia Apartment	0.12
13	Land Mark City Park #2	0.23	Incheon City Hall	0.06
14	Mountains near Dongchoon Park	0.19	Guwol Hill State Apartment	0.06
15	Buffer Green Area of Hyojeong Apartment	0.18	Catholic Shelter House	0.06
16	Yongdam Neighborhood Park	0.11	-	-
17	Dorandoran Park	0.09	-	-
18	Cheongdam Children's Park	0.07	-	-
19	Sidae Children's Park	0.06	-	-

3. Stepping Stone Greeneries (Nodes)

By using the BC index, stepping stone greeneries were identified, which connect the complementary cores determined through the above step. A 50m hexagon fishnet was used to better visualize the connection axis. Based on this fishnet, connection routes were presented by selecting and connecting hexagons with high BC values between complementary cores.

1) Yeonsu-Gu

In terms of Section 1 for Yeonsu-gu, three nodes (Nodes 1, 2, 3) were derived, while the BC value for Node 3 was relatively lower than other nodes due to the limited number of green spaces (〈Table 4〉). Two nodes (Nodes 4, 5) were produced in Section 2. We have specifically referred to the PGSMP in order to suggest a connection route from Jangmi Park to Songdo new town area. Regarding Section 3, four nodes (Nodes 6 to 9) were produced, and Node 7 had the highest average BC value. This section, located in the Songdo new town area, has proposed connection routes focusing on linking the townhouse site in District 8 to park area in District 6. The last section (Section 4) contained three nodes (Nodes 10, 11, 12), with Node 12 receiving the highest average BC value. There was no detailed greenway plan created in the existing PGSMP for this region. Thus, connection routes were suggested to comprehensively link the green spaces from Songdo Dalbit Park to Jack Nicklaus golf club. Figure 9 shows the specific nodes that were determined through the analysis process.

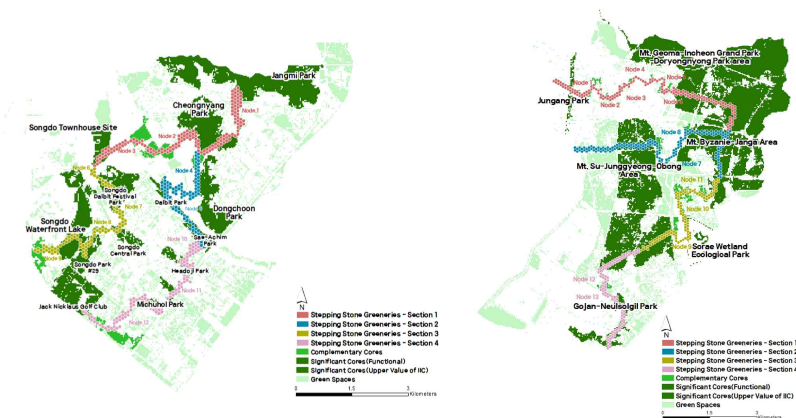
2) Namdong-Gu

With regard to Namdong-gu, we could identify six nodes (Nodes 1 to 6) in Section 1. While Node 4 received a relatively lower than average BC value, it was included as an exception because the street canopies following the Baekbeom-ro continuously established the connection route. Nodes 7 and 8 were derived in Section 2. Specifically, Node 7, which connects agricultural lands near Jangsu Stream and Namdong Cultural Sports Plaza, showed a fairly high BC due to trees within and near both areas. In Section 3, three nodes (Nodes 9, 10, 11) are produced, and Node 10, which connects Gaetgol Park #3 and Nuri Park and surrounded by small parks, had the highest BC. Lastly, two nodes (Nodes 12, 13) were found in Section 4. Node 12, connecting Mt. Su, Junggyeong, Deumbae, and Obong area and Hogupo neighborhood park, obtained the highest BC among all stepping stone greeneries in Namdong-gu due to its nearby apartment complex green spaces.

〈Table 4〉 BC values for greeneries in Yeonsu and Namdong-gu

Node No.	Yeonsu-gu BC	Namdong-gu BC
Node 1	0.017	0.024
Node 2	0.007	0.006
Node 3	0.010	0.008
Node 4	0.001	0.008
Node 5	0.001	0.002
Node 6	0.002	0.003
Node 7	0.067	0.027
Node 8	0.002	0.001
Node 9	0.003	0.007
Node 10	0.002	0.029
Node 11	0.001	0.003
Node 12	0.006	0.060
Node 13	-	0.011

〈Figure 9〉 Stepping stone greeneries and suggested connection routes (Nodes) based on BC

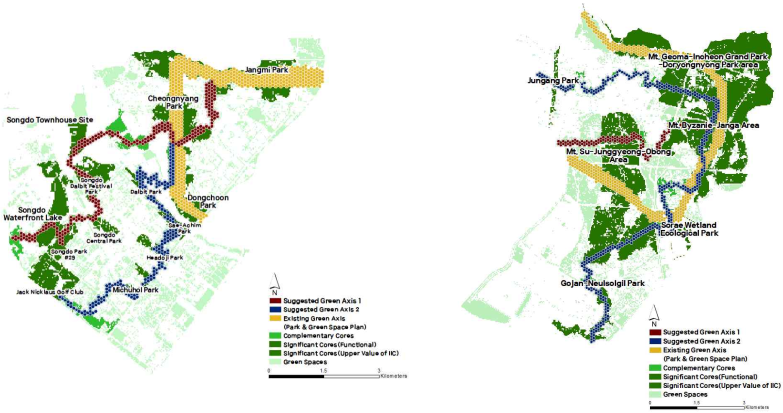


4. Green Infrastructure Network (Green Axis)

As a result of above processes, two additional green axes have been suggested for Yeonsu-gu. The first green infrastructure network (red axis in Figure 10) starts with Jangmi Park and extends to Songdo Landmark City Park #13, connecting Sections 1 and 3. Although this axis has not been disconnected, it appears to be fragmented due to Aahm Lake located in the middle. Since some complementary core greeneries within Okryeon and Dongchoon districts currently have urban development projects, future developments require an in-depth consideration for maintaining the overall connection of the green-axis. The second green infrastructure network (blue axis) connects greeneries from Jangmi Park to Jack Nicklaus Golf Club and covers Sections 2 and 4. Eight significant core greeneries are included in this axis. The green axis presented in the area corresponding to the northern part of Yeonsu-gu follows the similar direction with the existing green axis (yellow axis), which was pre-determined by the 2030 PGSMP.

Similar to the result of Yeonsu-gu, two new green axes have been proposed for Namdong-gu. The first green infrastructure network (red axis) connects areas near Mt. Su-Junggyeong and Mt. Byzanie-Janga. This axis was created to link the key greeneries in the central part of the borough and support the existing green axis (yellow axis), which does not pass in the east-west direction. The second green infrastructure network (blue axis) starts at Jungang Park on the northwest side and connects to Gojan Neighborhood Park in the south. This new axis was set up to compensate the lack of existing green axis, which was not extended to the southern part of borough.

〈Figure 10〉 Suggested green infrastructure network for Yeonsu and Namdong-gu



Ⅴ. Discussion & Conclusions

The purpose of this study is to analyze the connectivity of green infrastructure in two different urban structural areas, Yeonsu-gu (new town) and Namdong-gu (old city center), and suggest new green axes that can be more harmonizable with existing greenways. The results first revealed that several green hubs presented in the PGSMP were not identified as significant core areas. While the possible reason can be related with the calculation method of IIC, which derives the connectivity values by heavily considering the size of specific patch, we may also presume that green hubs in the PGSMP are fragmented with insufficient green spaces nearby. Disconnection of green spaces was mostly caused by roads or streets except in low-rise residential areas and potential urban development project areas. This result corroborates prior studies that demonstrated the fragmentation of habitats was influenced by road constructions (Barrientos, et al., 2021; Reed, et al., 1996). In addition, newly suggested green axes for both boroughs showed different configuration compared to the existing axes. This indicates that previously proposed green axes need to be updated as cities grow and planners, as well as policy makers, should continuously monitor land modifications and continuously create practical green infrastructure planning for both the long and short term.

Another important result stemming from the connectivity analysis is the necessity of green spaces near the significant core greeneries. To improve the overall network of green infrastructure, spatial strategies that can increase the connectivity close to the significant cores should be developed and then the sites where stepping stone greeneries can be placed within a corridor of cores should be secured. Particularly, strategic plans are recommended to increase the connectivity of fragmented green spaces. As discussed previously, there are some common characteristics of disconnected green spaces which can be categorized into three major types. The first type is fragmentation caused by highways/roads construction. To enhance the connectivity of this type, local governments should provide street design guidelines with green median strips and install adequate LID practices following the roads such as, dry swales, filter strips, infiltration trenches, and tree box filters. Greening the existing pedestrian overpasses can also be considered as an alternative approach. The second type of fragmentation is areas planned as apartment complexes and urban development projects. As the Ministry of Environment is now emphasizing the natural infringement scheme to minimize the natural damage caused by future urban developments, these areas should preserve green spaces that play as key stepping stones and maintain the linkage with nearby greeneries during the construction process. The third type is greeneries cut off due to the concentration of low-rise residential areas. This type mainly appears in the old city centers rather than newly developed areas. Because of limited vacant lots and lands, these areas may consider installing LIDs in existing buildings, such as roof gardens, vegetated walls, and parking gardens to maintain the connectivity.

When Incheon's 2030 PGSMP was examined, the plan omitted the southern part of Yeonsu-gu, where the Songdo new town is now located. Although the Incheon Free Economic Zone's Parks and Green Spaces Plan separately dealt various maintenance policies for Songdo's parks and street trees, neither core greeneries nor green axes were considered in the planning. The findings from this study, thus, recommend three parks (Songdo Central Park, Michuhol Park, and Haedogi Park) to perform as significant core greeneries and green axes should be established based on linking those core areas. In addition, various green space improvement and expansion tactics were suggested on the east side of Cheongnyang Park, where the S-shaped green axis passes, while the western part is neglected. Since Nodes 2 and 3 in this area play an important role in improving the connection between core greeneries, connection plans should be prepared by considering the fragmentation type as mentioned above.

The green hubs illustrated for Namdong-gu in the 2030 PGSMP were all concentrated on the northern and eastern parts of the borough, indicating that a connectivity gap exists on south and west corridors. Therefore, Mt. Su, Mt. Junggyeong, and Gojan Neighborhood Park, where IIC values are high, need to be selected as significant cores. Since the majority of existing hubs received relatively low IIC, green spaces adjacent to these areas should be strategically established. While 20 small parks are currently planned to be developed between Jungang Park and Incheon Grand Park corridor, densely packed low-rise residential buildings near that area may hinder the actual connectivity. Thus, LID facilities should be jointly introduced while securing the green space connectivity in this area. In addition, more specific street greening approaches following the Baekbeon-ro, Cheongneung-daero, and Namdong-daero should be appended in current PGSMP by considering the patch fragmentation characteristics.

Overall, the connectivity analysis result adds insights into the establishment of new green axes in two study areas. The existing green axis (S-shaped axis) should be supplemented from the findings of this study and provide more practically connected and accessible green infrastructure network. In particular, the inter-connectivity of green infrastructure should be broadly considered while amending the current 2030 Incheon PGSMP, with more detailed LID-oriented approaches added microscopically in linking existing parks and open/green spaces. The results from this study can be generalized into other regions that have disparity issues with low green infrastructure connectivity. Furthermore, each borough's Environmental Conservation Plan should also follow the direction of the PGSMP and strategic spatial policies are required for linking fragmented patches caused by road constructions, maintaining the overall green infrastructure network system and minimizing the impacts from future developments.

While this research attempts to understand the importance of green infrastructure networks by employing the connectivity modeling tool and approaches the findings from a planning perspective, it should be considered as an initial study in examining the greenways, and several points should be further considered in future research. First, the resolution of satellite images is obvious limitation in this study. Future work should obtain more precise resolutions to identify and examine small-scale green spaces. Second, there are some limited aspects in interpreting the connectivity of green spaces using only IIC, PC, and BC values obtained by Conefor. Since diverse connectivity indexes can be obtained from this modeling package, future study should employ more indexes as well as different modeling programs to understand and better justify the connectivity on diverse aspects. Finally, while this study broadly examined the regional green infrastructure networks, further study should explore local- or site-level connectivity strategies by investigating the different types of greenery fragmentation and suggesting appropriate locations for the installment of LID practices.

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