

Article

# Analysis of Large-Scale Residential Development on Walking Environments in Surrounding Neighborhoods: A Before-and-After Comparison of Apartment Complex Developments in Seoul, Korea

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**Abstract:** Pedestrian mobility is an indicator of urban sustainability insofar as it affects walkability and social cohesion. This research focused on the relationship between large-scale residential development and the walking environments of surrounding neighborhoods in Seoul, Korea. Large-scale residential developments, such as apartment complexes, might disrupt pedestrian walking networks fully or partly, causing the separation of urban spaces and social disconnection. This paper conducted before-and-after analysis of apartment complex development on the walking environments of surrounding neighborhoods using the Urban Network Analysis (UNA) tool and Rhinoceros three-dimensional (3D) software. With UNA measures such as reach, gravity, straightness, and betweenness, this study examined three apartment complexes constructed between 2010 and 2017 in Seoul. Analysis results indicated that large-scale residential development in existing urban environments is likely to hinder walking environments in surrounding neighborhoods. This study suggests policy implications to improve walking environments in surrounding communities when large-scale apartment complexes are developed in existing urban environments.

**Keywords:** apartment complex; gated community; urban network analysis; walkability

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## 1. Introduction

### *Research Background and Objectives*

Streets have always been regarded as critical components of the built environment for urban vitality [1]. Even though the physical appearance of streets has evolved throughout history, streets have always been a medium for the circulation of people and goods. Because of this critical role in sustaining urban life, modern urbanists have compared streets to blood vessels in the metaphorical anatomy of cities [2]. Extending the metaphor, a city loses its vitality if the circulative role of urban streets does not work efficiently.

A variety of factors impact people's walking activities. The most crucial factors are spatial characteristics, such as urban form and street networks. Urban physical form has strong influences on the daily walking activities of residents.

Since the beginning of the second half of the last century, rapid urbanization has made apartment complex redevelopment one of the best solutions for housing shortages all over the world [3]. Urban planners such as Le Corbusier offered the first conceptual ideas of apartment-style redevelopments in the classic example of Radiant City in the 1930s [4,5].

The types and features of apartment complexes have evolved over time, and the characteristics of apartment complexes vary in different countries. In the late 1950s, large-scale apartment complexes started to appear alongside the traditional non-gated neighborhoods in Seoul [6].

According to the Korean Population and Housing Census [7], apartments account for more than half of total housing in South Korea. Large-scale urban development and redevelopment projects are most likely to transform existing urban physical environments. The development of large-scale apartment complexes, highway construction, and other types of large-scale urban development projects inevitably affect proximate walking environments, as well as the sense of community for residents [8]. In particular, trends in the development of gated communities, such as enclosed apartment complexes, may have substantial effects on the walking environments of surrounding areas and the formation of community consciousness in neighborhoods.

The effects of gated community-style apartments on society have been widely discussed [9,10]. The work of Lynch [11] emphasizes the importance of continuity in street networks as channels for possible movement. However, little research has been conducted to examine the walking environments of surrounding communities in terms of micro-scale analysis. Large-scale apartment complexes may yield unexpected physical barriers to walkability in surrounding neighborhoods.

Therefore, this study examines the relationships between large-scale apartment complexes and the walkability of surrounding neighborhoods in existing urban fabrics, and suggests policy implications to improve urban walkability. This study utilizes urban network analysis (UNA) and Rhinoceros 3D software to conduct micro-scale urban network analysis before and after the development of apartment complexes in three case study areas.

## 2. Literature Review

### *Built Environment and Accessibility*

Simply defined, walking is the act of getting from one point to another by foot. Walking enables people to have both social and spatial interactions [12]. These interactions help to build livable communities by increasing a sense of togetherness among people within common spatial parameters [13,14].

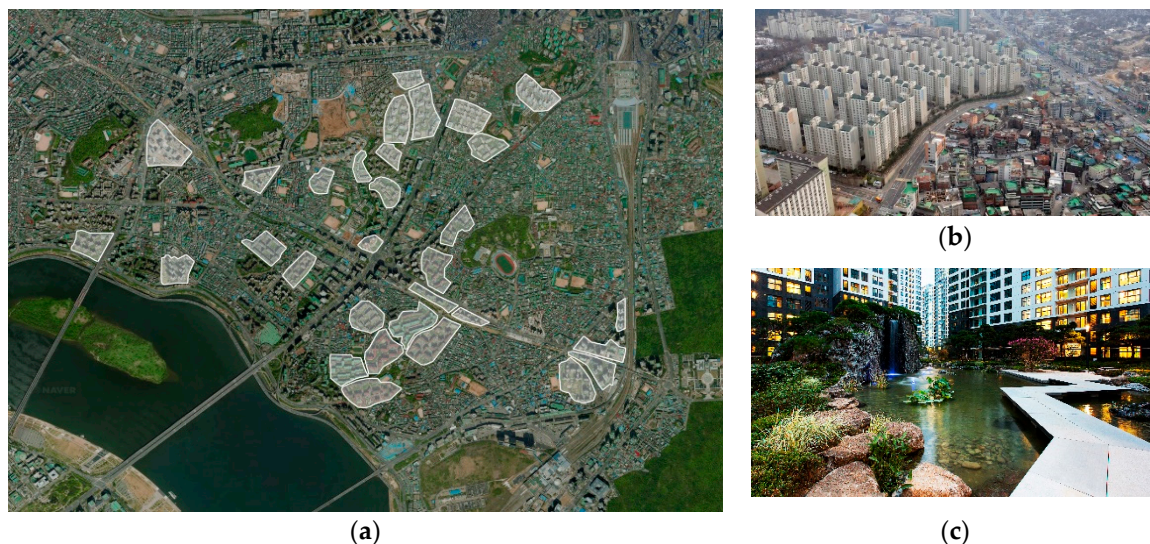
Numerous studies have classified walking into two groups according to its purpose: walking for transportation and walking for recreation [15–17]. The factor of distance has a different impact on these two types of walking. Some studies suggest that increasing distance to a destination positively affects walking for recreation in urban areas, and negatively affects walking in all other situations [15]. Walking is associated with an overall environment that includes physical, social, and cultural aspects for pedestrians [18]. In walking for transportation, a shorter distance to a destination is one of the critical factors in pedestrians' route choice.

The last several decades have seen the proliferation of enclosed apartment complexes in existing urban fabrics. In most cases, apartment complexes are considered to be a type of gated community. Grant [19] defines gated communities as "housing development(s) on private roads closed to general traffic by a gate across the primary (point of) access ... The development sites may be surrounded by fences, walls, or other natural barriers that further limit public access" (pp. 913–930).

According to Grant's definition, most apartment complex sites are in the category of "gated communities", even though apartment complexes are not enclosed by walls or controlled by guards. The term "gated community" is used and understood differently by planners and researchers. A gated community may refer to a settlement that is walled and truly gated—but sometimes the gate may be only an ornamental element and actual walls do not even exist. Blakely and Snyder [3] classified gated communities into three groups based on their characteristics: lifestyle, prestige, and security zone features. The intentions behind the building of gated communities shape the gate form and the enclosure type too. In some contexts, segregation by gated communities happens due to ethnicity,

religion, or ideological issues. For instance, many residents cluster in gated communities in Indonesia, South Africa, and many cities in South America for reasons along these lines [20,21].

Many cases show that residents' desire to live in an apartment complex is usually triggered by socioeconomic issues [9,22]. In some countries, walls and gates provide visual separation for residents inside a gated community, thereby facilitating perceptions of a prestigious lifestyle within communities [23,24]. This is seen in societies where socio-economic segregation is high. So-called "paradise sites" in Istanbul are an example of this type; in order to create a private central area, which can be converted to a park or a pool for exclusive use by the community, blocks are located alongside the borders of the site, while the central area is left empty. This morphological setting confirms a statement in the work of Landman and Schönreich [25], that isolated gated communities create inaccessible islands or buckets inside the urban fabric and in this way disrupt the continuity of the urban fabric. In short, the intention behind the building of a gated community determines its physical form. Moreover, the physical form of a gated community directly affects the surrounding walking environment for pedestrians. Figure 1 demonstrates the development of apartment complexes in the traditional fine-grained urban fabric in Seoul, Korea. These apartment complexes may have some negative impacts on pedestrian walking environments in the surrounding traditional neighborhoods.

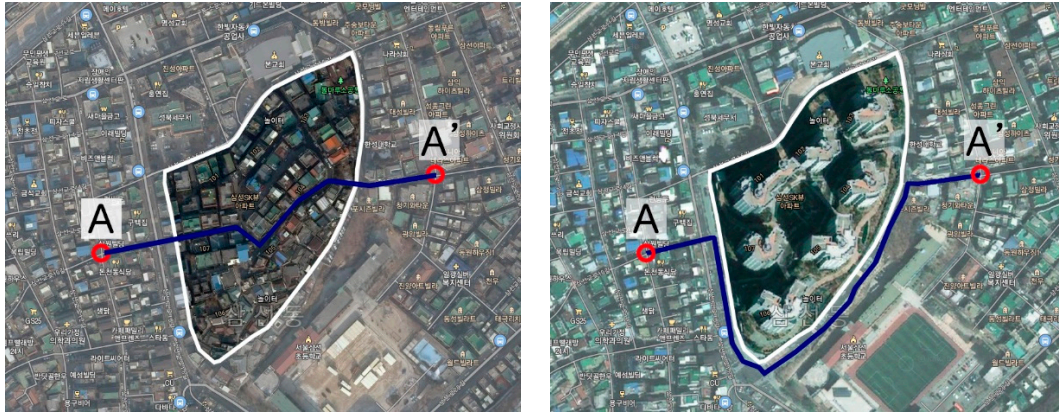


**Figure 1.** (a) Development of an apartment complex in Seoul. (b) Newly developed apartment complex and traditional fine-grained neighborhoods [26]. (c) Inside area of an apartment complex [24].

The work of Ozdemir and Dogrusoy [27] studies enclosed gated communities in Turkey. That research emphasizes the absence of a transitional space hierarchy between urban space and physical areas of gated communities, which prevents the creation of common areas that are open to shared interactions as part of the city. Physical segregation due to gated communities negatively affects the quality of public open spaces in the vicinity of enclosed housing sites. This happens in part because the new built environment obstructs pedestrian accessibility and encourages automobile accessibility [28].

In her seminal book, *The Death and Life of Great American Cities*, Jacobs [1] suggests preconditions for urban vitality. Jacobs argues that small block sizes in an urban context increase alternative routes that are most likely to increase social interaction among urban residents. In addition, small block sizes yield shorter travel routes for pedestrians. The amount of walking that occurs around gated communities depends on many factors, which have been mentioned. Across studies [29,30], street shape and block size stand out as the prevailing factors. Here, Jacobs's view is the most prominent one. She suggests that smaller city blocks improve walkability, asserting, "Most blocks must be short; that is, streets and opportunities to turn corners must be frequent" [1].

As is seen in Figure 2, the coarse-grained morphology of apartment complexes contradicts with the concept of Jane Jacobs. Compared to the previous fine-grained urban form, through the development of apartment complexes, the large shape of blocks is more disadvantageous for movement.



**Figure 2.** The pedestrian walking environment before-and-after apartment complex development.

Jacobs further argues that border vacuums are important components of urban vitality. She defines border vacuums as the division of communities by large single-use territories or corridors. According to Jacobs, large-scale apartment complexes (so-called “gated communities”) create a physical barrier to pedestrian activities in the same way that transportation infrastructure such as roads and railroads do.

One previous study examines how to decrease the negative effects of border vacuums caused by landscape design proposals [31]. Using a case study of a subway station in Dubai, the research indicates that planting and vegetation ought to be considered as good tools to mitigate negative effects. Another study by Apak [32] suggests that graffiti and artwork are other solutions to decrease border vacuum effects around the walls of apartment complexes by making the areas more walkable. That research, however, specifically explores a correlation between the existence of graffiti on the walls of gated communities and segregation. The study shows that so-called graffiti appears where walkability is worse, and that so-called “gang graffiti” is a sign of poor security in proximate areas. While these studies suggest the use of mature trees for shading and blocking dust or noise and the use of artwork to promote walkable streets, the research does not consider mobility issues for pedestrians due to border vacuums.

Thus, much of the work to date on gated communities has focused on social segregation and some cosmetic strategies to improve walking environments for pedestrians. However, there is little research to quantify the impact of gated communities on walking accessibility for pedestrians in surrounding environments. In particular, before-and-after analysis of gated communities stands to show the specific impact of gated community development on existing urban areas.

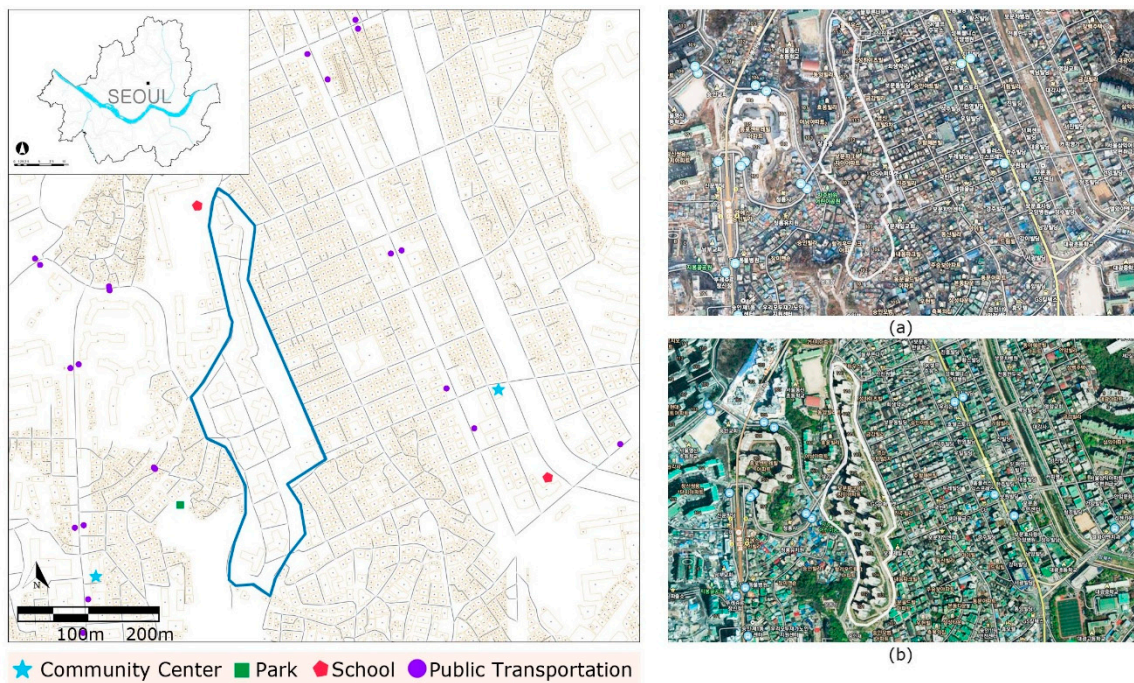
### 3. Methodology

#### 3.1. Case Study Areas

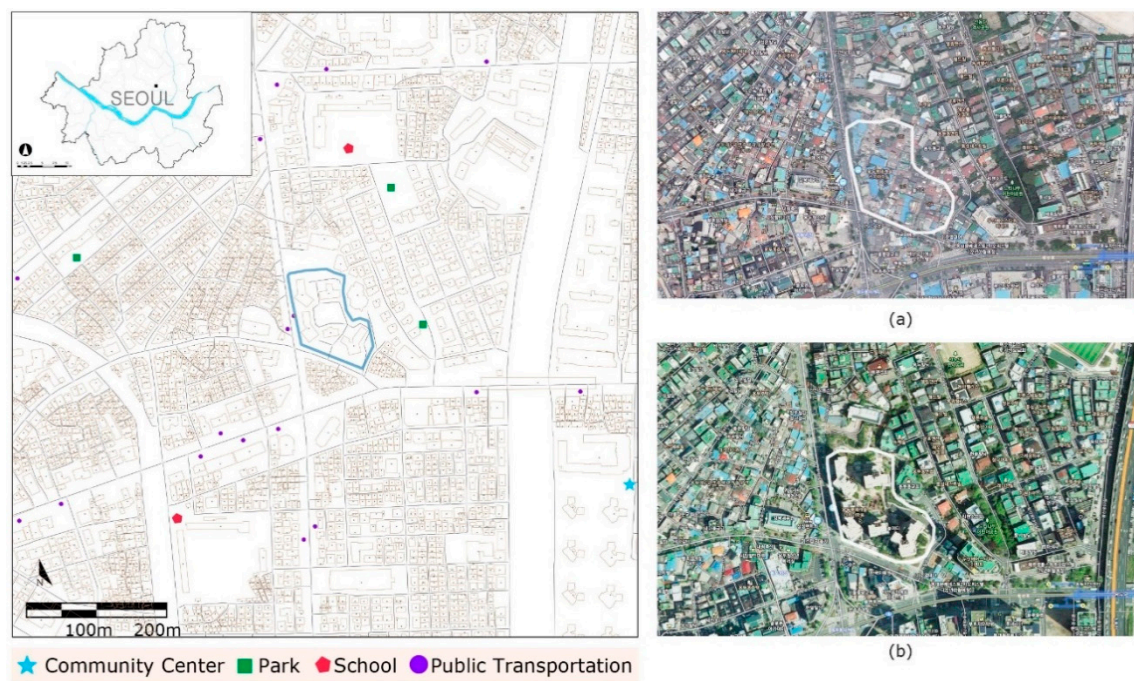
The purpose of this study was to analyze changes in walking environments due to the development of apartment complexes (ACs) in urban areas. To this end, we compared situations before and after the development of discrete apartment complexes by using data from the 2018 Seoul Improvement Project Progress report. Since 2000, 250 areas have been designated as “improvement business districts”, of which 144 have been built. As of June 2018, 111 districts have been completed in Seoul.

Among the 250 projects, we identified 30 areas in categories of new town, redevelopment, and reconstruction projects. For each of the projects, construction began after January 2011 and was finished before December 2017. Using Daum’s road view technology, we investigated features

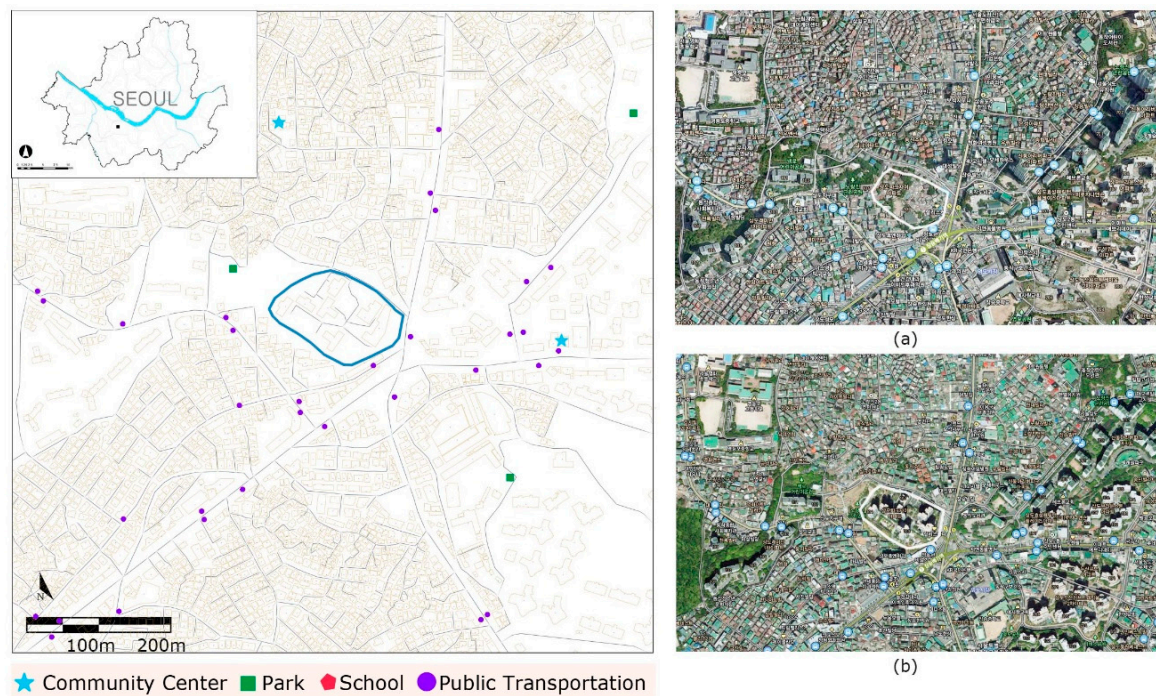
including development size, street networks, enclosure types, and surrounding neighborhoods. Then, we focused on three representative case study areas from among the most enclosed sites (Figures 3–5).



**Figure 3.** Bomun Park Apartment Complex, Seongbuk-gu, Seoul; (a) Satellite image in 2010 and (b) Satellite image in 2018.



**Figure 4.** Lotte Castle Apartment Complex, Dongdaemun-gu, Seoul; (a) Satellite image in 2010 and (b) Satellite image in 2018.



**Figure 5.** Sangdo Park Apartment Complex, Dongjak-gu, Seoul; (a) Satellite image in 2010 and (b) Satellite image in 2018.

This study used road network maps of Seoul in 2010 and 2018 to analyze the physical changes in pedestrian environments, comparing business districts where construction began before 2010 and was completed before 2017 to assess impacts before and after apartment complex development. Thirty apartment development sites are available for this analysis. Of the 30 apartment complex sites, three case study areas (from among the most highly gated communities) were selected as shown in Table 1. Analysis sites include the Bomun Park apartment complex in Seongbuk-gu, the Lotte Castle apartment complex in Dongdaemun-gu, and the Sangdo Park apartment complex in Dongjak-gu.

**Table 1.** Introduction of three case study sites in Seoul, South Korea.

| Case                  | Case 1: Bomun Park AC | Case 2: Lotte Castle AC | Case 3: Sangdo Park AC |
|-----------------------|-----------------------|-------------------------|------------------------|
| Location              | Seongbuk-gu           | Dongdaemun-gu           | Dongjak-gu             |
| Project area          | 52,246 m <sup>2</sup> | 15,380 m <sup>2</sup>   | 32,001 m <sup>2</sup>  |
| Project type          | Redevelopment         | Redevelopment           | Redevelopment          |
| Site perimeter length | 1400 m                | 520 m                   | 550 m                  |

Cities with high density development and well-connected urban streets have an opportunity to decrease transportation costs. However, the segregated urban fabrics due to the development of large-scale apartment complexes (ACs) might have negative impacts on walkability for the surrounding neighborhoods. This study focuses on the before-and-after analysis of the large-scale apartment complex development in terms of accessibilities to primary destinations such as community centers, parks, schools, and public transportation.

### 3.2. Method

Walking networks are important factors for initiating and sticking with walking behaviors. Various network analysis concepts are used to measure the integration of social and spatial networks. These concepts have been used in the designing and planning of cities for several decades. In particular,

the concepts have been used most commonly in areas of disaster planning, transportation planning, and facility planning.

One of the most applied concepts for investigating society-space relationships is the space syntax method. In establishing the now well-known space syntax methodology, Hillier and Hanson [33] applied the representation and analytic tools of graphs to street networks. From architectural building levels to city and country levels, plenty of work has been conducted with this methodology. Hillier and Hanson chose to represent streets with axial lines instead of street centerlines in their methodology [33]. This approach has led to some criticism, however, because the specification of axial lines is subjective (that is, there is more than one solution) and poorly applicable to sparsely built-up streets [34]. Space syntax studies (as well as most of the other spatial network studies to date) have represented networks using two types of elements—nodes and edges. Edges typically represent street segments and nodes represent the junctions where two or more edges intersect [35].

Contrary to deficiencies in space syntax and other network analysis methodologies, the urban network analysis (UNA) framework [36] has a useful modification. Urban network analysis adds buildings (housing or other infrastructures) to representations, adopting a tripartite system that consists of three basic elements: edges, nodes, and buildings. In the UNA method, each building connects to the nearest street segment (edge) with the shortest connection [37]. The standard three-level presentation of spatial networks in UNA methodology is well suited for mapping urban and regional networks of various typologies and scales. Table 2 includes key indicators and their formulas with descriptions in the UNA toolbox.

**Table 2.** Overview of accessibility and centrality indicators of the urban network analysis toolbox.

| Indicators             | Formula                                                                                  | Description *                                                                                                                                                                                                   |
|------------------------|------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility measures | $Reach[i]^r = \sum_{j \in G-i, d[i, j] \leq r} W[j]$                                     | The number of surrounding points (buildings, doorways, bus stops, etc.) that each building reaches within the radius specified in the network.                                                                  |
|                        | $Gravity[i]^r = \sum_{j \in G-i, d[i, j] \leq r} \frac{W[j]}{e^{\beta d[i, j]}}$         | The travel cost required to arrive at each of the destinations. Accessibility at the origin is proportional to the attractiveness (weight) of destinations and inversely proportional to the distances between. |
| Centrality measures    | $Straightness^r[i] = \sum_{j \in G-i, d[i, j] \leq r} \frac{\delta[i, j]}{d[i, j]} W[j]$ | Illustrates the extent to which the shortest paths from origins to destinations resemble straight Euclidian paths. The closer to 1, the more straight the path is.                                              |
|                        | $Betweenness^r[i] = \sum_{j \in G-i, d[i, j] \leq r} \frac{n_{jk}[i]}{n_{jk}} W[j]$      | The index divided by the number of paths passing through a specific point by the number of shortest paths between destinations within the set radius.                                                           |

\* This study used the radius of 600 m and the beta value of 0.00217 based on previous studies [37,38].

This study analyzes correlations between changes in walking networks and the design of apartment complexes in the typical residential style of Korea. Large-scale apartment complex development may destroy existing urban street networks, thereby obstructing the vitality of the whole city following completion. This study aims to examine changes in neighborhood walking environments following new apartment-style residential developments in existing urban fabrics. We assume that new apartment-style residential developments are highly likely to disrupt the well-connected small blocks

of existing urban areas. We use “before-and-after analysis” for the neighborhoods of three apartment complex developments that were constructed and completed from 2010 to 2017. To analyze the impacts of the new apartment complexes on surrounding walking environments, this study uses the urban network analysis (UNA) toolbox, developed by the City Form Lab at the Massachusetts Institute of Technology (MIT). Urban network analysis (UNA) is a spatial network analysis tool that analyzes five indicators of accessibility and centrality through network distances between departure and arrival points.

Changes in pedestrian environments in and around the apartment complexes were analyzed by measuring accessibility and centrality before and after apartment complex development. Table 2 shows the indicators measured in this study including gravity index, reach, straightness, and betweenness. Among these indicators, gravity index and reach comprise the accessibility index, while betweenness and straightness are the centrality index.

First of all, the reach variable is the number of origins in the network radius (based on path distance, not straight lines) at the destination. Thus, a large reach within the same street network means that many buildings are concentrated around the destination and that (building) access to the destination is high. Sevtsuk [37] demonstrates that a higher reach means a higher probability of a store being located there. In this study, we calculated the reach index using the radius of 600 m.

Second, the gravity index (a representative indicator of accessibility) is similar to the reach measure. Gravity index additionally measures factors in the spatial impedance required to travel to each of the destinations. Gravity index increases as distance increases, with an example of distance being the spatial resistance to reach a destination from a starting point within the set radius. Gravity measures factors in the travel costs required to arrive at each of the destinations. In this measurement, the beta value can be decided based on local and user characteristics. For walkability analysis, we used a beta value of 0.00217 based on the previous study [38].

Third, the straightness indicator (showing centrality) is an indicator of how close the network connection is to a straight line. The straight line distance from each source to each destination is divided by the network distance (that is, the distance based on the actual route).

To put it more clearly, straightness illustrates the comparison of the crow flies distance to the shortest path connection between each origin and destination [39]. When the distances between nodes get longer, the differences between the network distance and the crow flies distance start diminishing. The straightness indicator in the UNA toolbox has similarities with mean depth analysis in space syntax. A higher mean depth is the same as less straightness. In other words, the higher the integration of a node, the lower its depth [8]. To solve this problem, apartment complexes should not only be open to the outside environment, but the street network inside a complex must also comply with the street network outside.

Analyses performed by the UNA toolbox require three key inputs—a network, along which movement is analyzed, a trip origin, and a trip destination. Setting up a network and the appropriate origin and destination weights are typically the first steps in any UNA application [39]. First, the network and walking origin data used in this study were received from a source known as the “Road Name Address DB”, which was provided by the Ministry of Public Administration and Security. We conducted the generation of pedestrian networks based on street centerlines by using computer-aided design (CAD) software. Second, for walking origins, data about buildings were converted from shapefile formats (SHP) using ArcGIS geographic information software. Third, for the destination input, point shape data were created on Rhinoceros 3D (Rhino) software by checking elementary schools, parks, community centers, and transportation stops on Google Maps.

#### 4. Analysis

Apartment complexes are very common types of residence in Seoul, Korea. Apartments account for nearly half of total residential types in cities. According to data from the 2018 Housing Survey, apartments accounted for 49.2% (42.2% of housing types in the city of Seoul) of all housing types in



Korea [7]. Apartments allow more efficient use of development sites by accommodating a greater population per unit area than any other type of residence. In addition, many Korean people prefer to live in apartment complexes because of high levels of privacy and security in comparison to other types of housing. Despite the many advantages of apartments, however, the construction of large apartment complexes is criticized for reducing the continuity and accessibility of urban spaces by strictly restricting the inflow of cars and pedestrians due to partial or fully privatized networks.

Meanwhile, urban improvement projects are implemented in accordance with procedures based on “Urban and Residential Environment Improvement Law” in designated areas where urban functions need to be restored or where housing environments are poor, for the sake of improving and/or reconstructing buildings that are defective and old. During urban improvement projects, unlike other development activities, existing land is used without the purchase of new land. Thus, there is no change in land areas before and after these projects. In addition, urban improvement projects are implemented to improve and repair the physical and social conditions of residential areas and to improve areas where old and defective buildings are concentrated [40].

As such, improvement projects necessarily involve changes in physical environments centered on buildings, and can be classified according to the nature, purpose, and project promotion procedures of the improvement project. In the work of Kim [41], such improvement projects are classified as residential environment improvement projects, housing redevelopment projects, housing reconstruction projects, urban environment improvement projects, residential environment management projects, and street housing improvement projects according to the characteristics and forms of the project. The development of large apartment complexes causes changes in pedestrian accessibility around spatial sites. More specifically, the enclosed form of apartment complexes deactivates the short paths of pedestrian networks, thereby negatively affecting accessibility. In order to confirm this hypothesis, accessibility analysis of pedestrian networks before and after development was conducted by using UNA on Rhino software. Three inputs were implemented including a network, trip origins, and trip destinations.

Accessibility is comprised of indicators gravity and reach, while centrality includes the indicators of straightness and betweenness. Every accessibility and centrality indicator reflects a spatial property of a network. Gravity, straightness, and betweenness are used to explain how some places are places of shorter accessing time (gravity), how some places are accessible via a straight route to other places (straightness), and how some places are situated between two other pairs of places (betweenness).

The better a connection with a surrounding network, the higher the measured value. Our results compare characteristics before and after the development of apartment complexes at three sites. Having calculated these measurements in the networks before the development of the apartment complexes and after the development of the apartment complexes, we found significant differences between them.

This study analyzes the pedestrian accessibility and centrality of public facilities by neighborhood residents in cases of apartment complexes. Pedestrian accessibility was calculated from the location and pedestrian route of starting and destination points, and analysis was conducted by simplifying these factors into points and lines.

The radius value of the gravity index, betweenness, and straightness (used as an analytical index) was set to 500 m. Each of the indicators is based on the network distance within the radius set according to individual buildings (the starting points of walking environments) and public facilities (the destinations). The beta ( $\beta$ ) used in the gravity index was derived by applying a walking distance (m) criterion of 0.00217, following previous research, to obtain results. The distance strategy coefficient  $\beta$  is the effect of the reduction of the distance on each shortest path between the starting point and the destination point. The index was used as a control, and results were obtained by applying a walking distance (m) value of 0.00217 based on previous studies [42,43].

Table 3 shows the number of buildings—that is, the origins in accessibility and centrality indicators. “Inside” represents only the measurements for inside parts of the apartment complexes in each case study, while “outside” refers to areas excluding the apartment complexes themselves.

“Total” measurement refers to the whole apartment complex and surrounding area. Development of an apartment complex combines existing small-scale parcels and new construction of large-scale parcels and high-rise main buildings by dismantling and constructing low-rise, stand-alone buildings. To support this, it was observed that about 10.4%, 5.4%, and 3.96% of buildings are reduced by the effects of apartment development in the cases of Bomun Park, Lotte Castle, and Sangdo Park, respectively (Table 3).

**Table 3.** Number of origin points inside and outside the analysis site.

| Case Study Sites         | Before Development |        |         | After Development |        |         | Percent Change<br>(Inside Origin Points) |
|--------------------------|--------------------|--------|---------|-------------------|--------|---------|------------------------------------------|
|                          | Total              | Inside | Outside | Total             | Inside | Outside |                                          |
| Bomun Park AC (case 1)   | 3522               | 367    | 3155    | 3170              | 15     | 3155    | −10.4%                                   |
| Lotte Castle AC (case 2) | 2944               | 164    | 2780    | 2785              | 5      | 2780    | −5.4%                                    |
| Sangdo Park AC (case 3)  | 3230               | 135    | 3095    | 3102              | 7      | 3095    | −3.96%                                   |

Table 4 summarizes the distribution of public facilities (community centers, public parks, elementary schools, and public transportation stops) around the analysis sites. These public facilities, identified in every complete neighborhood, are primary destinations for pedestrians. In Korean cities, community centers and elementary schools are designed to be within walking distance for residents of any given area.

**Table 4.** Number of destination points around the analysis site.

|                          | Community Centers |      | Parks |       | Schools (Elementary) |      | Public Transport Station |       | Total Number of Destination Points |
|--------------------------|-------------------|------|-------|-------|----------------------|------|--------------------------|-------|------------------------------------|
|                          | No.               | %    | No.   | %     | No.                  | %    | No.                      | %     |                                    |
| Bomun Park AC (case 1)   | 2                 | 7.7% | 1     | 3.9%  | 2                    | 7.7% | 21                       | 80.8% | 26                                 |
| Lotte Castle AC (case 2) | 1                 | 4.2% | 3     | 12.5% | 2                    | 8.3% | 18                       | 75.0% | 24                                 |
| Sangdo Park AC (case 3)  | 2                 | 5.3% | 3     | 7.9%  | 1                    | 2.6% | 32                       | 84.2% | 38                                 |

The distance factor for these two destinations (community centers and elementary schools) is critical for pedestrians, especially for elderly people and children. With regard to the other two types of public facilities (parks and public transportation stations), accessibility is the main reason for residents to prefer walking. Alternatives to walking will be chosen if accessibility by walking is poor for pedestrians. Namely, the longer it takes to reach public facilities including community centers, parks, elementary schools, and transportation stations by walking, the more automobiles will be used.

Each building in each of the case study development sites and surrounding areas is the starting point for moving to the points of destination. The public facilities (community centers, parks, schools, and transportation stations) are the destination areas for analysis. The results of accessibility and centrality analyses are shown in Tables 5 and 6. According to these results, there are decreasing trends due to apartment complex redevelopment in all four measures, with the exception of some special conditions. The downward trend for these four measures can be explained as follows.

**Table 5.** Average results of accessibility and centrality analysis of surrounding facilities before and after development of apartment complex (all areas).

|                          |               | Before Development of Apartment Complexes, 2010 |        |                      |                           | After Development of Apartment Complexes, 2017 |        |                      |                           | Percent Change (2010–2017) |         |                      |                           |
|--------------------------|---------------|-------------------------------------------------|--------|----------------------|---------------------------|------------------------------------------------|--------|----------------------|---------------------------|----------------------------|---------|----------------------|---------------------------|
|                          |               | Community Centers                               | Parks  | Schools (Elementary) | Public Transport Stations | Community Centers                              | Parks  | Schools (Elementary) | Public Transport Stations | Community Centers          | Parks   | Schools (Elementary) | Public Transport Stations |
| Bomun Park AC (case 1)   | Gravity index | 0.285                                           | 0.112  | 0.320                | 3.082                     | 0.295                                          | 0.096  | 0.320                | 3.008                     | 3.41%                      | −14.72% | −0.01%               | −2.41%                    |
|                          | Reach         | 0.554                                           | 0.215  | 0.650                | 6.005                     | 0.558                                          | 0.169  | 0.659                | 5.681                     | 0.69%                      | −21.33% | 1.33%                | −5.39%                    |
|                          | Betweenness   | 15.079                                          | 7.247  | 16.660               | 172.238                   | 14.464                                         | 4.593  | 14.857               | 149.149                   | −4.08%                     | −36.62% | −12.13%              | −13.41%                   |
|                          | Straightness  | 0.411                                           | 0.109  | 0.475                | 4.423                     | 0.409                                          | 0.089  | 0.474                | 4.196                     | −0.40%                     | −18.99% | −0.02%               | −5.13%                    |
| Lotte Castle AC (case 2) | Gravity index | 0.028                                           | 0.533  | 0.420                | 3.723                     | 0.030                                          | 0.531  | 0.434                | 3.642                     | 5.71%                      | −0.35%  | 3.22%                | −2.18%                    |
|                          | Reach         | 0.054                                           | 1.070  | 0.876                | 7.445                     | 0.057                                          | 1.059  | 0.901                | 7.279                     | 5.71%                      | −1.04%  | 2.72%                | −2.23%                    |
|                          | Betweenness   | 0.854                                           | 26.851 | 22.000               | 176.615                   | 0.903                                          | 25.897 | 22.535               | 168.627                   | 5.71%                      | −3.55%  | 2.37%                | −4.52%                    |
|                          | Straightness  | 0.040                                           | 0.742  | 0.651                | 5.600                     | 0.042                                          | 0.752  | 0.672                | 5.478                     | 5.71%                      | 1.23%   | 3.12%                | −2.17%                    |
| Sangdo Park AC (case 3)  | Gravity index | 0.223                                           | 0.213  | 0.057                | 4.421                     | 0.217                                          | 0.142  | 0.059                | 4.097                     | −2.52%                     | −3.30%  | 3.96%                | −7.33%                    |
|                          | Reach         | 0.425                                           | 0.438  | 0.104                | 8.902                     | 0.405                                          | 0.294  | 0.108                | 8.220                     | −4.75%                     | −32.91% | 3.96%                | −7.67%                    |
|                          | Betweenness   | 13.347                                          | 12.693 | 4.307                | 222.428                   | 12.593                                         | 8.772  | 4.484                | 201.113                   | −5.65%                     | −30.89% | 3.96%                | −9.58%                    |
|                          | Straightness  | 0.285                                           | 0.286  | 0.065                | 6.388                     | 0.270                                          | 0.186  | 0.068                | 5.926                     | −5.15%                     | −34.82% | 3.96%                | −7.24%                    |

**Table 6.** Average results of accessibility and centrality analysis of surrounding facilities before and after development of apartment complexes (outside).

|                          |               | Before Development of Apartment Complexes, 2010 |        |                      |                           | After Development of Apartment Complexes, 2017 |        |                      |                           | Percent Change (2010–2017) |         |                      |                           |
|--------------------------|---------------|-------------------------------------------------|--------|----------------------|---------------------------|------------------------------------------------|--------|----------------------|---------------------------|----------------------------|---------|----------------------|---------------------------|
|                          |               | Community Centers                               | Parks  | Schools (Elementary) | Public Transport Stations | Community Centers                              | Parks  | Schools (Elementary) | Public Transport Stations | Community Centers          | Parks   | Schools (Elementary) | Public Transport Stations |
| Bomun Park AC (case 1)   | Gravity index | 0.296                                           | 0.098  | 0.320                | 3.100                     | 0.296                                          | 0.096  | 0.319                | 3.017                     | 0.00%                      | −2.17%  | −0.20%               | −2.67%                    |
|                          | Reach         | 0.560                                           | 0.176  | 0.659                | 5.908                     | 0.561                                          | 0.170  | 0.658                | 5.694                     | 0.11%                      | −3.42%  | −0.14%               | −3.62%                    |
|                          | Betweenness   | 16.191                                          | 7.040  | 15.006               | 175.723                   | 14.532                                         | 4.615  | 14.917               | 149.836                   | −10.25%                    | −34.44% | −0.59%               | −14.73%                   |
|                          | Straightness  | 0.411                                           | 0.092  | 0.476                | 4.364                     | 0.411                                          | 0.089  | 0.474                | 4.208                     | 0.10%                      | −3.67%  | −0.38%               | −3.55%                    |
| Lotte Castle AC (case 2) | Gravity index | 0.030                                           | 0.531  | 0.434                | 3.641                     | 0.030                                          | 0.531  | 0.434                | 3.642                     | 0.00%                      | 0.04%   | 0.07%                | 0.02%                     |
|                          | Reach         | 0.057                                           | 1.059  | 0.902                | 7.277                     | 0.057                                          | 1.059  | 0.903                | 7.278                     | 0.00%                      | 0.03%   | 0.04%                | 0.01%                     |
|                          | Betweenness   | 0.904                                           | 27.272 | 23.036               | 174.562                   | 0.904                                          | 25.940 | 22.575               | 168.906                   | 0.00%                      | −4.88%  | −2.00%               | −3.24%                    |
|                          | Straightness  | 0.042                                           | 0.752  | 0.673                | 5.478                     | 0.042                                          | 0.752  | 0.673                | 5.480                     | 0.00%                      | 0.02%   | 0.04%                | 0.02%                     |
| Sangdo Park AC (case 3)  | Gravity index | 0.219                                           | 0.196  | 0.059                | 4.209                     | 0.218                                          | 0.143  | 0.059                | 4.101                     | −0.68%                     | −27.38% | 0.00%                | −2.56%                    |
|                          | Reach         | 0.410                                           | 0.411  | 0.109                | 8.481                     | 0.406                                          | 0.294  | 0.109                | 8.227                     | −1.02%                     | −28.38% | 0.00%                | −3.00%                    |
|                          | Betweenness   | 13.588                                          | 10.816 | 4.494                | 214.937                   | 12.622                                         | 8.791  | 4.494                | 201.551                   | −7.11%                     | −18.72% | 0.00%                | −6.23%                    |
|                          | Straightness  | 0.274                                           | 0.267  | 0.068                | 6.111                     | 0.271                                          | 0.187  | 0.068                | 5.933                     | −1.05%                     | −30.12% | 0.00%                | −2.92%                    |

A decrease in the measures of gravity and reach means an increased time required to arrive at destinations. With some exceptional cases, the longer it takes to arrive at a destination, the less favorable the environment is for walking [43]. Thus, we can say walkability is worsened by apartment complex development because of the deterioration of accessibility. Second, a decrease in the measure of straightness does not necessarily mean a decrease in walking intentions on the part of pedestrians. For transportation purposes, the shortest path (representing the straightness measure) is always desirable. In some conditions of walking for recreation, however, curving and/or non-linear paths are more desirable [43].

In brief, the overall results of analysis support our hypothesis that the development of apartment complexes has negative effects on pedestrian environments. In addition, however, the results also suggest that other spatial conditions need to be considered in terms of their effects on pedestrian environments. Table 5 shows the overall results of changes in the accessibility and centrality of all origins, including both apartment complexes and surrounding areas, to public facilities (community centers, parks, elementary schools, bus stops, and subway entrances) due to the construction of apartment complexes.

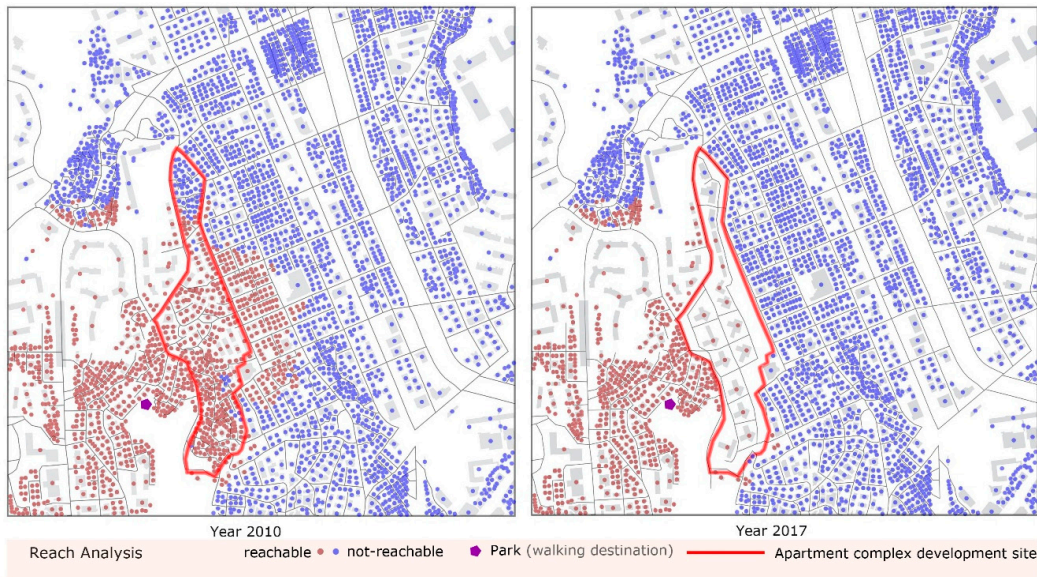
Even though the gravity index, reach, straightness, and betweenness indicators appear to be decreasing in most situations, there are some exceptions. For example, average measurements for school destinations in case 2 and case 3 are increasing, as is the measurement for the destination of the community center in case 2. In the analysis results in Table 5, however, the number of origins (as a building unit in this analysis) is not the same in 2010 and 2017. Also included in the measurements are origins inside the development sites.

In order to determine the effects of redevelopment on the accessibility and centrality of surrounding areas only, we excluded origins in apartment redevelopment sites and conducted analysis again. Table 6 shows the average accessibility and centrality analysis results for the surrounding areas, excluding the apartment redevelopment area itself. According to the results, the construction of apartment complexes generally reduced the gravity index, reach, straightness, and betweenness in the areas of analysis.

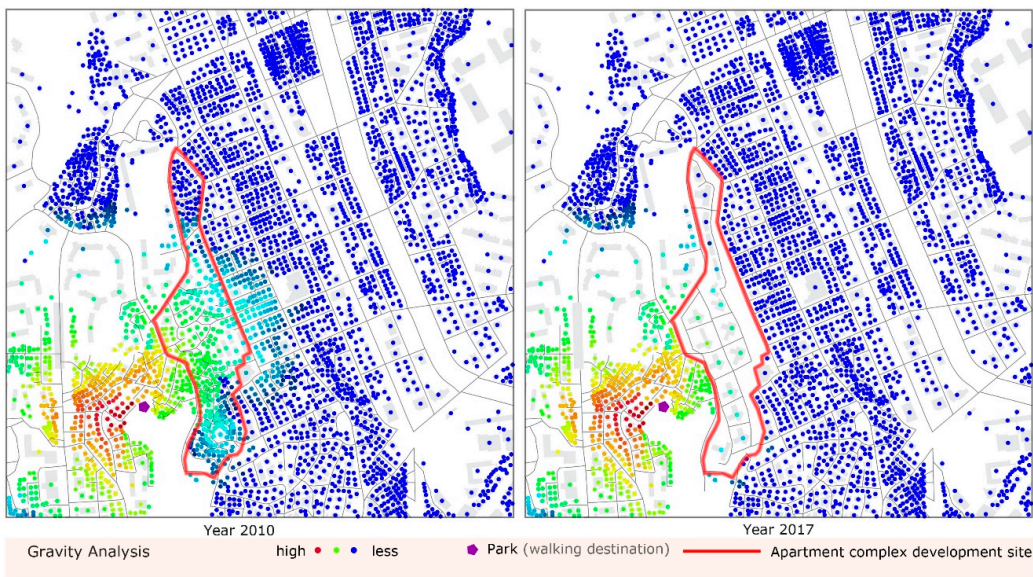
Unlike the results in Table 5, the average measurements for the destinations of schools in case 2 and case 3 and the destination of the community center in case 2 do not change, or change very slightly, in the results in Table 6. The reason for this is that improvements in accessibility and centrality measurements on these occasions are only for the inside of apartment complexes, while the areas around the apartment complexes are not significantly improved by development.

One of the most interesting results of this analysis is that even though case 2 (Lotte Castle Apartment Complex) is the most “gated community” apartment complex plan based on the perimeter-per-gate value (1 gate to every 550 m boundary), case 2 has the lowest change of decrease in the values of accessibility and centrality measurements among the three cases. This can be explained because the pedestrian network in case 2 was not well connected before development of the apartment complex. Further, in comparison to the other two cases, the smaller area of the apartment complex in case 2 lessens the surrounding effects.

Figures 6–9 illustrate the visual explanation of the change in Reach, Gravity, Straightness, and Betweenness with 4 samples, chosen from situations in which there are significant changes before and after apartment complex development. In these visualizations, the red color indicates places where gravity, straightness, and betweenness are the highest, followed by yellow, green, and light blue. On the other hand, the dark blue color depicts the lowest values. It is clearly seen, both by the numerical results in Tables 5 and 6 and by the depiction of gravity, straightness, and betweenness in Figures 6–9, that apartment complex development negatively affects accessibility.



**Figure 6.** Before-and-after visualization of reach values for the park destination (case 1: Bomun Park AC).



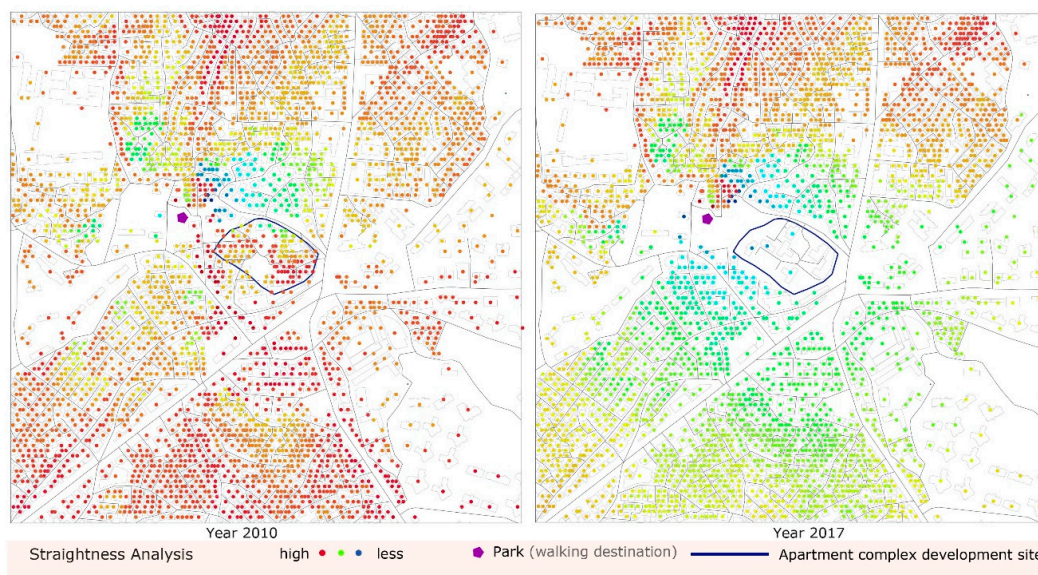
**Figure 7.** Before-and-after visualization of gravity values for the park destination (case 1: Bomun Park AC).

Figure 6 shows the visualization of reach for the destination of park in the case 1 (Bomun Park AC). In this visualization, it is seen that a number of buildings on the right side of the apartment complex are becoming unreachable for the nearby park destination after the development of the apartment complex. The long form of Bomun Park AC (case 1) stays as a barrier between the neighborhood and the destination.

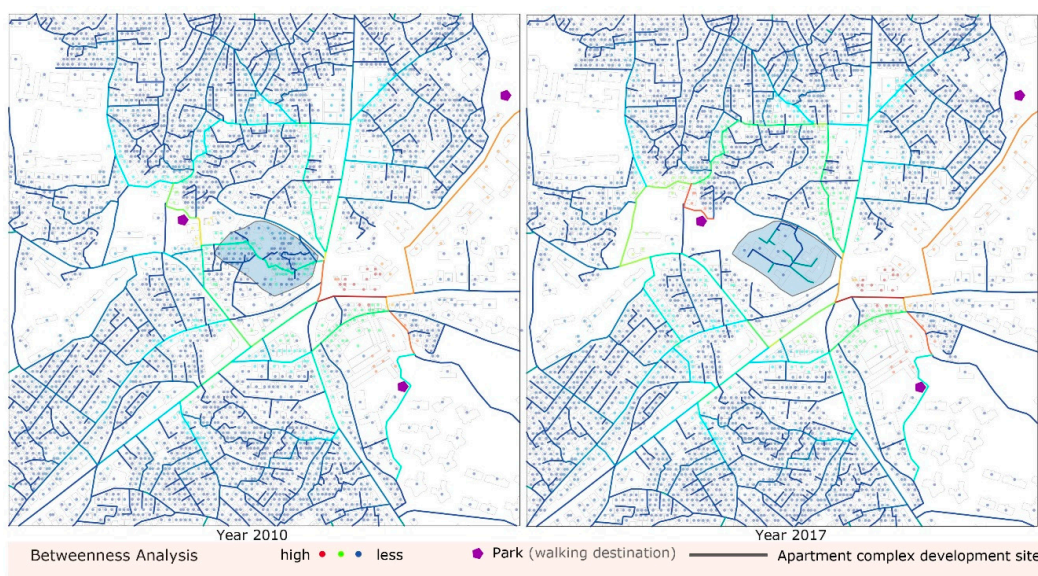
In Figure 7, gravity analysis of the case 1 (Bomun Park AC) is exhibited. The colors on the right side of the apartment development site are changing from green to blue, which can be interpreted as a sign of worsening accessibility to the park.

Figure 8 shows the visualization of straight accessibility to the destination of park in case 3 (Sangdo Park AC). The change in colors clearly depicts that the south part of apartment development site is experiencing deteriorating direct access to the park.

Lastly, Figure 9 shows betweenness analysis for the destination of park in case 3 (Sangdo Park AC). Different than the first 3, visualization was done in this case by coloring the lines, and this depicts the concentration of connection between origins and destinations. Red and yellow color respectively exhibit where the street is used the most for the trips between origin and destinations. According to this visualization, some of the main streets on the south west of the apartment complex are losing pedestrian weight after the development. In other words, these streets are becoming less commonly used now.



**Figure 8.** Before-and-after visualization of straightness values for one park destination (case 3: Sangdo Park AC).



**Figure 9.** Before-and-after visualization of betweenness values for the park destination (case 3: Sangdo Park AC).

## 5. Conclusions

This study examines changes in neighborhood walking environments before and after apartment complex development in existing urban fabrics in Seoul, Korea. We analyzed three apartment complexes according to accessibility and centrality in terms of changes in walking networks for pedestrians.

The development of apartment complexes was shown to decrease the walkability of surrounding areas for the average pedestrian after development of the complex. This finding indicates that organic links between apartment complexes and surrounding neighborhoods are disconnected. Residents who live in surrounding areas are more likely to make longer walking trips within the neighborhood as a result of development. An apartment complex has a closed and private character because many households share and own parcels within facilities. For outsiders, this restricts accessibility to the inside of the apartment complex, while heightening convenience for apartment complex residents. Consequently, the safety and convenience of walking for elementary school students and elderly people (who are highly dependent on walking) is hindered in surrounding areas [44]. This increase in private apartment complexes stands to worsen organic linkages in urban space.

While the development of an apartment complex provides high-quality living conditions and safety for residents, this study confirms that large-scale apartment complexes are likely to undermine walking conditions for pedestrians in surrounding areas. This finding indicates that urban redevelopment and readjustment policies should consider the negative impacts of apartment complex development on surrounding neighborhoods. To greater or lesser extents, the form of new streets inside an apartment complex may positively affect accessibility, such as in case 2 herein. The nuance of this finding indicates that the development of a large-scale apartment complex will not necessarily deteriorate walkability for pedestrians if the inner street networks of the complex are well connected to the outside neighborhoods.

Based on this study alone, findings are insufficient for conclusions on the effects on walking behaviors due only to changes in physical walking networks following the construction of apartment complexes. In particular, distance is not the only factor that impacts people's selection of walking paths. Other factors such as aesthetics, shade, safety, and familiarity may play significant roles in pedestrians' walking path choices. Therefore, it is expected that this limitation will be overcome in future research by adding more data related to other factors to measure changes in physical walking environments due to the construction of large-scale apartment complexes. Furthermore, future studies should address the impacts of large-scale apartment complexes on other planning issues such as housing segregation, income inequality, vernacular architecture, and historic preservation.

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