Abstract

This study is based on the assumption that there is a problem in the existing approach of introducing and applying the concept of metric weighting to space syntax. In this study, we discussed relevant previous studies to comprehend the problems and limits, established several new approaches for introducing and applying the metric weighting, and verified their validities by applying them to actual built spaces. We proposed the metric weighting functions of the distance itself, the square root function of the distance, the square function of the distance, the exponential function of the distance, and the logarithmic function of the distance to introduce and apply the metric weighting. We designated Myeong-dong, Insa-dong, and Seoul City Hall as the three target sites for analysis, and drew the respective segment axial maps representing the sites. Subsequently, we conducted metric segment analyses and correlation tests between the results and the pedestrian densities for the three sites, thus examining the predictive power against the human-movement behaviors.

Keywords: space syntax; metric weighting; weighting function; segmented axial map; human movement behavior

1. Introduction

Space syntax was proposed by Hillier and Hanson in the early 1980s, and since then there has been a steady increase in the utilization of quantitative spatial analysis methodology in analytic studies of architectural and urban spaces. Researchers have accomplished significant achievements by applying the spatial analysis methodology to interior spaces, underground spaces, and urban street spaces. In addition, as space syntax was found to suitably predict the movement behavior of people, this methodology now also applies to predicting human behavior, with spatial analysis being regarded as a tool for evaluating architectural and urban planning.

The development of spatial analysis methodology and space syntax models is continuously expanding. For example, all-line maps, segmented axial maps, and visibility graph analysis (VGA) were proposed as representation methods that were developed from initial methods such as axial map and convex map. While these methods represent developments in the representation of space, there are also developments in the calculation of analysis indices. For example, choice value, standardized integration (Tecklenburg et al., 1999), etc. were introduced and applied. Furthermore, the concept of angular weighting onto the depth, which is the basic concept of the distance inside a network structure (Dalton, 2001; Turner, 2001) as well as the concept of metric weighting (Hillier & Iida, 2005) were developed. Of these approaches, the concept of angular weighting resulted in the angular segment analysis (ASA) methodology by combining it with a segmented axial map.

The analysis results obtained using the ASA methodology indicated high predictive power for human-movement patterns (Turner, 2007). As a result, the researchers also attempted to introduce the concept of metric weighting to the analysis of a segmented axial map, but unlike the angular weighting approach, this had unsatisfactory results and led to the tentative conclusion that the distance is meaningless as a weighting. However, rather than making such conclusion, the approach should focus on the method of introduction and the application of the concept, rather than the concept of distance itself. In another recent study, the authors introduced metric weighting to the eigenvector ratio of adjacency matrix (ERAM) model, which is a spatial analysis methodology, by varying the metric weighting function (Park, Kim, Choi, 2014).

In this study, to better understand the limitations of previous studies, we discuss previous studies that introduce the concept of metric weighting to space
syntax, and in order to overcome the limitations propose new approaches to metric weighting. Finally, we applied the approaches to an actual existing space for verification. We confirm the significance of the metric weighting concept in space syntax, and aim to determine the metric weighting approach that is most effective for human-movement pattern prediction.

2. Discussion on Relevant Theories and Previous Studies Introduction

Space syntax is a quantitative spatial analysis methodology proposed by Hillier et al. at University College London. The methodology quantitatively comprehends and analyzes the social logic inherent to architectural and urban spaces, focusing on interconnections between unit spaces. The interconnections between unit spaces are expressed by a mathematical approach called a graph or network, while the characteristics of each unit space are numerically derived by performing an analysis of the network. The analysis of space syntax comprises the representation of space step, which expresses a target architectural or urban space as a network, and the calculation of index (measure) step, where the represented network is numerically analyzed to derive the quantitative properties of each unit space. In the earlier days of space syntax, axial map and convex map were mainly used to represent space, while connectivity, control, mean depth, and integration were mainly used as analysis indices.

### Table 1. Analysis Indices of Space Syntax

<table>
<thead>
<tr>
<th>Index</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connectivity</td>
<td>$Cn_i = k_i =</td>
</tr>
<tr>
<td>Control</td>
<td>$CV_i = \sum_{j \in N_i} 1/Cn_j$</td>
</tr>
<tr>
<td>Mean Depth</td>
<td>$MD_i = \frac{1}{n-1} \sum_{j=1}^{n} d_{ij}$ $(d_{ij}: depth \ of \ shortest \ path \ from \ node \ i \ to \ node \ j)$</td>
</tr>
<tr>
<td>Integration</td>
<td>$Intg_i = \frac{2(MD_i - 1)}{n-2} \times D_n$ $(D_n = \frac{6.44n \times \log(n+2) - 5.17n + 2}{(n-1)(n-2)})$</td>
</tr>
</tbody>
</table>

Initially, notable achievements of space syntax included a correlation study between the analysis results of space syntax and human behavioral patterns. According to the study, the distribution of local integration derived from the analysis of a specific urban space through space syntax showed a high correlation with human-movement patterns in the same urban space (Hillier et al., 1993). Space syntax became a well-known tool for predicting actual human behaviors in a specific architectural or urban space, and its application rapidly expanded to other areas.

Thereafter, numerous follow-up studies proposed new analysis methodologies in order to increase the degree of correlation between analysis results and actual human behaviors, in order to increase the prediction of human behaviors. These studies can be divided into those that focused on the representation of space, and those that focused on the calculation of index. Based on former studies, the authors proposed representation methods such as all-line map, visibility graph, and segmented axial map. Indices such as choice value, standardized integration, and ERAM value were proposed by the latter group. From studies of the former group, methods of space representation that actively reflect the physical or human-behavioral properties originally possessed by space were proposed. A typical case would be the axial segment analysis.

Axial segment analysis methodology is an upgraded version of the existing axial map. It started out based on the assumption that the degree of connection between two adjacent axial lines depends on the angle made by the two axial lines. Here, a human-behavioral point of view is reflected by stating that for a person who moves along the two axial lines, it becomes easier to move as the angle between the two axial lines increases, and as the angle decreases, it becomes harder to move. In other words, the physical and human-behavioral properties of space, which were not present in the original axial map, were introduced to the representation of space. According to the study, when this methodology was applied to an actual urban space, the correlation was very high (Hillier & Iida, 2005; Turner, 2007).

The core of axial segment analysis methodology is that it deviates from the dichotomous viewpoint of the original space syntax, where the connection between two adjacent axial lines is viewed as either connected=1 or disconnected=0, and instead, it uses the angle to distinguish the degree of connection. This can be paraphrased as the introduction and application of a concept of weighting to the degree of connection. The degree of connection between two adjacent axial lines can be viewed as the function, namely the weighting function of the connection angle. The degree of connection between two adjacent axial lines can be substituted by the distance between two nodes connected by a link in a network, which is the depth. Hence, the depth can be expressed as a weighting function of the connection angle.

$$Depth = W(\theta)$$  \hspace{1cm} (1)

Encouraged by this achievement, researchers proposed the metric distance as another factor that influences the depth from both a physical and human-behavioral viewpoint. The typical case of the proposal is the study of Hillier and Iida (2005). In their study, they applied three weighting concepts, namely the topological approach, geometric approach, and metric approach, in which they compared the results. Herein,
the topological approach refers to the original style of space syntax, where the depth is referred as \( l \), meaning that it is connected, while the geometric approach refers to the style in which the depth is viewed as a weighting function of the connection angle. The metric approach views the depth as a weighting function of the metric distance, where the depth varies depending on the metric distance between the two axial lines. As a consequence, both the topological and geometric approaches show excellent predictions of human-movement patterns, while the metric approach shows a relatively lower prediction performance.

Alternately, Park et al. (2014) considered that the results were caused not by a problem of the concept of metric weighting itself, but by a problem of how to introduce and apply the concept of metric weighting. They reported that the existing studies viewed the degree of effort required to move across two adjacent axial lines as being simply proportional to the distance between the two axial lines, which implies that the degree of connection between two adjacent axial lines is inversely proportional to the distance between the two axial lines. Park et al. stated that this scenario should be considered from a more diverse viewpoint. Based on the ERAM model, which is a network-based spatial analysis methodology similar to space syntax, they set three more weighting functions of the distance\( D \) between two adjacent axial lines, as shown below, in addition to the weighting function \( '1/D' \), which was obtained from the existing studies. Then, they compared the predictive powers of the four functions for actual human-movement behaviors.

\[
W_1(D) = (D/D_{\max} - 1)^2
\]

\[
W_2(D) = 1 - D/D_{\max}
\]

\[
W_3(D) = 1 - (D/D_{\max})^2
\]

As a result, the case in which the weighting function was set as \( W_2 \) showed higher predictive power for human-movement behaviors when compared to the cases involving the use of the weighting function in existing studies as well as the other weighting functions. Further, the case of \( W_2 \) showed higher prediction power than the case in which the concept of metric weighting was not applied. From the results, it became clear that the reason for the problems associated with the introduction of the metric weighting concept to spatial analysis methodologies was because of the method used to apply the concept of metric weighting, and it was not a flaw of the concept itself.

As expected, the metric weighting functions established by Park et al. cannot be directly introduced to space syntax because the perspectives on the degree of connection between two adjacent axial lines are different for the ERAM model and space syntax. More specifically, space syntax considers the degree of connection between two adjacent axial lines from the perspective of the difficulty of passing, namely the resistance, while the ERAM model considers it from the perspective of the intensity of adjacency. The higher the intensity of adjacency between the two axial lines, the lower the difficulty of passing the two axial lines. Therefore, the two concepts are in conflict with each other, and the aim is to find a way of introducing and applying the concept of metric weighting, that is, a metric weighting function that is appropriate for space syntax.

3. Application of Metric Weighting

In this study, we propose various approaches of applying metric weighting, and compare the predictive power of each approach against actual human-movement behaviors with the approach of existing studies to determine the significance of the metric weighting concept.

Fig.1. shows the representations of an identical urban space in an original axial map and a segmented axial map, including the networks extracted from the two representations. Hillier & Iida (2005) and Turner (2007) used the segmented axial map instead of the original axial map as a representation method for applying the metric and angular weighting, because the application of weighting is possible in the segmented axial map. For example, in Fig.1.(a), as axial line b and axial line c cross, four included angles are formed. Among the included angles, it is unclear which one should be chosen as the connection angle between the axial line c and axial line b. On the other hand, in Fig.1.(b), there is only one included angle between segment \( c_i \) and segment \( b_i \), and this then becomes the connection angle between the two. Thus, the application of angular weighting becomes clear in later cases.

![Fig.1. Axial Map and Segmented Axial Map](Hillier et al., 2005)

The same can be said regarding the application of metric weighting. In Fig.1.(a), it is not easy to
determine how to measure the distance between axial line \(c\) and axial line \(b\). On the other hand, in Fig.1.(b), the distance between segment \(c_1\) and segment \(b_2\) can be clearly set as the physical displacement from the center of \(c_1\) to the center of \(b_2\). Earlier researchers also set the distance between two adjacent segments in this manner. For instance, if the lengths of \(c_1\) and \(b_2\) are respectively 150 m and 120 m, the distance from \(c_1\) to \(b_2\) is equal to 135 m \((= 150/2 + 120/2)\). Therefore, the segmented axial map is adopted for this study, and the method employed to calculate the distance between the two adjacent segments also refers to the method mentioned above.

However, earlier researchers did not propose a predetermined metric weighting function, but simply assumed the physical distance between two segments as the depth between the two segments. This study poses a problem regarding the scenario by proposing a new metric weighting function that is different from the metric weighting function proposed by earlier researchers. For more diverse approaches, in this study, we propose five types of metric weighting functions, as shown below.

### Table 2. Five Types of Metric Weighting Functions

<table>
<thead>
<tr>
<th>Type</th>
<th>Metric Weighting Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>(W(D) = D/D_{mean})</td>
</tr>
<tr>
<td>Case 2</td>
<td>(W(D) = \sqrt{D/D_{mean}})</td>
</tr>
<tr>
<td>Case 3</td>
<td>(W(D) = (D/D_{mean})^2)</td>
</tr>
<tr>
<td>Case 4</td>
<td>(W(D) = \exp(D/D_{mean} - 1))</td>
</tr>
<tr>
<td>Case 5</td>
<td>(W(D) = \log(D/D_{mean}) + 1)</td>
</tr>
</tbody>
</table>

Fig.2. Graph of Metric Weighting Functions

In the above five functions, \(D\) refers to the distance between the two adjacent segments, while \(D_{mean}\) refers to the average of \(D\). Dividing \(D\) by \(D_{mean}\) enables us to obtain valid results by appropriately dealing with the exponential and logarithm functions, which are sensitive to even the smallest changes. From this perspective, \(D/D_{mean}\) can be thought of as a corrected value of distance. The metric weighting function of the existing studies is referred to as Case 1. Case 2 refers to the metric weighting function, which is set as the square root of the distance, Case 3 refers to the metric weighting function as the square of the distance, and Case 4 refers to the metric weighting function as the natural exponential function of the distance. Here, a deduction of 1 from the distance is performed to ensure that the depth, i.e., the value of the metric weighting function, is 1 when the distance is 1. Case 5 refers to the metric weighting function as the logarithm function of the distance. Here, 1 is added to the logarithm of the distance to ensure that the depth is 1 when the distance is 1. By setting the five metric weighting functions as the depth between the two segments, and by applying them to segmented axial map, we propose and perform the metric segment analysis.

### 4. Spatial Analysis Applied with Metric Weighting Function

#### 4.1 Spatial Analysis

The target sites for the analysis are the three areas of Myeong-dong, Insa-dong, and City Hall in Seoul. The pedestrian densities of these three areas were derived from existing data (Kwon, 2001), which were measured up to 250 m from the center of each area. The spatial scope for drawing segmented axial maps for these three areas was set at 2,200 m in diameter. The edge effect could be overcome by covering a sufficient range around the area where the pedestrian density was measured in each target site as the scope for drawing segmented axial maps.

After drawing the segmented axial maps for each site, we performed the metric segment analysis by using a spatial analysis tool. The main index of the analysis was the closeness centrality index, which is the inverse of the mean depth, and it has nearly the same meaning as the existing integration index, although the method of calculating it is slightly different. In the existing studies of Hillier, Iida (2005), and Turner (2007), the closeness centrality index was also used instead of the integration index.

When calculating the closeness centrality index, we also calculated both of the global closeness centrality and local closeness centrality indices. The local closeness centrality index is generally known to be better for predicting the human-movement pattern than the global closeness centrality. Researchers of spatial analysis have reported that the radius for calculating the local closeness centrality can vary depending on the types of movement behaviors that are to be observed. Further, they noted that the radius for the pedestrian movement pattern should range between 400 m and 800 m, while the movement pattern of vehicles requires a much larger scale (Al-Sayed et al., 2014, p. 450).
In this study, because we utilized the pedestrian density data, setting the radius was based on a range of 400 m to 800 m for calculating the local closeness centrality. The range was again varied and diversified into the values of 200 m, 400 m, 600 m, 800 m, 1,000 m, 1,200 m, 1,400 m, and 1,600 m.

In short, we drew segmented axial maps for the three target sites, and conducted the metric segment analysis, which was applied with five metric weighting functions. As the control group, we also conducted analysis that did not apply the concept of weighting. From the analysis results, we calculated the global closeness centrality index, as well as the local closeness centrality indices for each 200 m interval along with the radius for the range of 200m to 1,600m.

### 4.2 Correlation Analysis between Global Closeness Centrality and Pedestrian Density

First, we carried out correlation tests between the distributions of the global closeness centrality index from the results of the metric segment analyses, and the distribution of pedestrian density for the three target sites each. It is important to note that the distribution of the logarithm of the pedestrian density is applied to the correlation test. The pedestrian densities of the three target sites all show strong trends of exponential distributions (Table 3.), while the closeness centrality shows a trend of linear distribution, and applying logarithm function is needed to match the two distribution trends. In previous studies, the logarithm of the pedestrian density was applied as well to conduct the correlation test dealing with the same problem above. (Hillier et al., 1993; Kim, 2003; Raford, 2003)

The correlations between the metric segment analysis results applied with the five respective metric weighting functions and the pedestrian density were mostly low in the case of Myeong-dong, as seen from the data in Table 4.

#### Table 5. shows the results of the correlation test dealing with the same problem above. (Hillier et al., 1993; Kim, 2003; Raford, 2003)

### 4.3 Correlation Analysis between Local Closeness Centrality and Pedestrian Density

Table 5. shows the results of the correlation test between the pedestrian density and the local closeness centrality calculated while varying the metric radius. We extracted the local closeness centrality values from the results of metric segment analyses when applying the five metric weighting functions as well as when not applying them for the three target sites.

For the case of Myeong-dong, the correlation is generally highest when the metric radius ranges from 400 m to 600 m. The correlation is high when the metric radius is 400 m, while the correlation is lower when the metric radius is 800 m. Applying the metric radius of 600 m to 800 m, the correlation is high when the metric radius is 600 m, while the correlation is lower when the metric radius is 800 m. These results show that the predictive power for human-movement behaviors is higher when applying the metric weighting functions proposed in this study, than when it is not applied. However, the statistical significance of these results could be somewhat lowered by the fact that the correlation coefficients were mostly low in the case of Myeong-dong, as seen from the data in Table 4.

### Table 3. Distribution of Pedestrian Densities and Log (Pedestrian Densities) for the Three Target Sites

**Table 4. The Correlations between the Global Closeness Centrality(C.C.) and the Pedestrian Density (*, **: Statistically Significant)**

<table>
<thead>
<tr>
<th>Areas</th>
<th>C.C</th>
<th>C.C. Case 1</th>
<th>C.C. Case 2</th>
<th>C.C. Case 3</th>
<th>C.C. Case 4</th>
<th>C.C. Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myeong-dong</td>
<td>.173</td>
<td>.245</td>
<td>.220</td>
<td>.140</td>
<td>.242</td>
<td>.077</td>
</tr>
<tr>
<td>Insa-dong</td>
<td>.318*</td>
<td>.241</td>
<td>.351**</td>
<td>.092</td>
<td>.369**</td>
<td>.051</td>
</tr>
<tr>
<td>Seoul City Hall</td>
<td>-.052</td>
<td>.191</td>
<td>.033</td>
<td>.337*</td>
<td>.194</td>
<td>.221</td>
</tr>
</tbody>
</table>
For the case of Insa-dong, the consequences are somewhat different. At this site, for a metric radius of around 400 m to 800 m, the analysis results applied with the metric weighting functions generally show a higher correlation than the analysis result that is not applied with the metric weighting function. On the other hand, when the metric radius is greater than 1,000 m, the analysis result that is not applied with the metric weighting function shows a higher correlation than the analysis results that are applied with the metric weighting functions. When the metric radius ranges from 400 m to 800 m, Case 4 generally shows the highest correlation, while Case 2 ranked second. Both results of Case 4 and Case 2 show a higher correlation than when the metric weighting function is not applied.

For the case of the Seoul City Hall, the analysis results applied with the metric weighting functions largely show a high correlation when the metric radius ranges from 200 m to 400 m. Generally, Case 3 shows a high correlation followed by Case 1, Case 4, and Case 5. At this site, the analysis results of Case 2 show a low correlation, while those of Case 3 show a high correlation, unlike the cases of Myeong-dong and Insa-dong.

From the results above, we can determine that the analysis results applied with the metric weighting functions of Case 2 (Myeong-dong, Insa-dong), and Case 3 (Seoul City Hall) show a higher correlation compared to those that are not applied with the metric weighting function and applied with Case 1. This implies that Case 1, which refers to the existing style of applying the metric weighting, is problematic, and the newly proposed method of applying the concept of metric weighting can be used to overcome this problem.

In addition, in the results above, all three sites show a fairly high correlation when applied with the metric weighting functions for a metric radius of 200 m to 800 m. This means that in a relatively localized area within the radius of 1,000 m, the significance of the metric segment analysis is high, which is supported by the study by Hillier et al. (2009), who noted that urban space is globally topological and geometric, but is locally metric from the perspective of predicting the human-movement behaviors.

For a closer examination on the predictive power in a localized area, we conducted additional analyses for the metric radii of 250 m, 300 m, 350 m, 400 m, 450 m, 500 m, and 550 m, which were set by starting from 400 m and fluctuating upwards and downwards in 50 m intervals (Table 6.). The results of the additional analyses reconfirm that for all three sites, the analysis results applied with the metric weighting functions show a higher correlation than the result that is not applied with the function, and the result of Case 1 shows a lower correlation than the others. However, the area of Seoul City Hall shows a somewhat different perspective compared to those of Myeong-dong and Insa-dong, of which we should be aware. In Myeong-dong and Insa-dong, the model applied with the Case 2 metric weighting function shows high predictive powers for human-movement behaviors, while in the area of Seoul City Hall, the model applied with the Case 3 metric weighting function shows high predictive powers.

Table 5. The Correlations between the Local Closeness Centrality and the Pedestrian Density for the Metric Radius of 200m~1,600m (*,** : Statistically Significant)

<table>
<thead>
<tr>
<th>Areas</th>
<th>Metric Radius (m)</th>
<th>C.C</th>
<th>C.C Case 1</th>
<th>C.C Case 2</th>
<th>C.C Case 3</th>
<th>C.C Case 4</th>
<th>C.C Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myeong-dong</td>
<td>200</td>
<td>.240</td>
<td>-.134</td>
<td>.214</td>
<td>-.179</td>
<td>-.068</td>
<td>-.281</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>.625*</td>
<td>.243</td>
<td>.686**</td>
<td>-.120</td>
<td>.166</td>
<td>.078</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>.474**</td>
<td>.142</td>
<td>.420**</td>
<td>-.195</td>
<td>.091</td>
<td>-.047</td>
</tr>
<tr>
<td></td>
<td>800</td>
<td>.332*</td>
<td>.006</td>
<td>.214</td>
<td>-.264</td>
<td>.015</td>
<td>-.189</td>
</tr>
<tr>
<td></td>
<td>1,000</td>
<td>.198</td>
<td>-.158</td>
<td>-.018</td>
<td>-.260</td>
<td>-.093</td>
<td>-.256</td>
</tr>
<tr>
<td></td>
<td>1,200</td>
<td>.72**</td>
<td>-.168</td>
<td>-.088</td>
<td>-.203</td>
<td>-.059</td>
<td>-.225</td>
</tr>
<tr>
<td></td>
<td>1,400</td>
<td>.67**</td>
<td>-.142</td>
<td>-.118</td>
<td>-.110</td>
<td>.013</td>
<td>-.184</td>
</tr>
<tr>
<td></td>
<td>1,600</td>
<td>.019</td>
<td>-.073</td>
<td>-.094</td>
<td>-.043</td>
<td>.047</td>
<td>-.141</td>
</tr>
<tr>
<td>Insa-dong</td>
<td>200</td>
<td>.101</td>
<td>-.335**</td>
<td>-.042</td>
<td>-.321*</td>
<td>-.061</td>
<td>-.343**</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>.337**</td>
<td>.182</td>
<td>.404**</td>
<td>-.090</td>
<td>.422**</td>
<td>-.142</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>.406**</td>
<td>.304*</td>
<td>.459**</td>
<td>.008</td>
<td>.575**</td>
<td>-.038</td>
</tr>
<tr>
<td></td>
<td>800</td>
<td>.396**</td>
<td>.502**</td>
<td>.383**</td>
<td>.012</td>
<td>.528**</td>
<td>-.021</td>
</tr>
<tr>
<td></td>
<td>1,000</td>
<td>.470**</td>
<td>.358**</td>
<td>.444**</td>
<td>.039</td>
<td>.429**</td>
<td>-.010</td>
</tr>
<tr>
<td></td>
<td>1,200</td>
<td>.462**</td>
<td>.362**</td>
<td>.459**</td>
<td>.025</td>
<td>.426**</td>
<td>.021</td>
</tr>
<tr>
<td></td>
<td>1,400</td>
<td>.383**</td>
<td>.481**</td>
<td>.431**</td>
<td>.033</td>
<td>.472**</td>
<td>.021</td>
</tr>
<tr>
<td></td>
<td>1,600</td>
<td>.344**</td>
<td>.453**</td>
<td>.391**</td>
<td>.051</td>
<td>.449**</td>
<td>.039</td>
</tr>
<tr>
<td>Seoul City Hall</td>
<td>200</td>
<td>-.167</td>
<td>.581**</td>
<td>.031</td>
<td>.562**</td>
<td>.542**</td>
<td>.380*</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>-.058</td>
<td>.452**</td>
<td>-.002</td>
<td>.535**</td>
<td>.416**</td>
<td>.369*</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>-.079</td>
<td>.277</td>
<td>-.124</td>
<td>.459**</td>
<td>.297</td>
<td>.229</td>
</tr>
<tr>
<td></td>
<td>800</td>
<td>-.121</td>
<td>.281</td>
<td>-.040</td>
<td>.430**</td>
<td>.311*</td>
<td>.199</td>
</tr>
<tr>
<td></td>
<td>1,000</td>
<td>-.153</td>
<td>.191</td>
<td>-.062</td>
<td>.403**</td>
<td>.277</td>
<td>.177</td>
</tr>
<tr>
<td></td>
<td>1,200</td>
<td>-.211</td>
<td>.075</td>
<td>-.245</td>
<td>-.245</td>
<td>.138</td>
<td>.093</td>
</tr>
<tr>
<td></td>
<td>1,400</td>
<td>-.143</td>
<td>.240</td>
<td>-.107</td>
<td>.262</td>
<td>.250</td>
<td>.132</td>
</tr>
<tr>
<td></td>
<td>1,600</td>
<td>-.116</td>
<td>.243</td>
<td>-.061</td>
<td>.346*</td>
<td>.248</td>
<td>.284</td>
</tr>
</tbody>
</table>
All three areas are active commercial areas. However, the area of Seoul City Hall is encumbered with physical factors such as main roads with heavy traffic and a large square. Meanwhile, the areas of Myeong-dong and Insa-dong are pedestrian-centered commercial areas, and are comprised of pedestrian-only roads and small public areas. In addition, Insa-dong has more pedestrian-centered road characteristics than Myeong-dong. Such differences in the physical characteristics are assumed to be the reasons for the different results. In other words, the application of metric weighting may differ depending on the characteristics of the target site. Additional studies are required of more diverse areas in order to verify such reasoning.

5. Conclusions

This study was conducted based on the assumption that there is a problem in the existing approach of introducing and applying the concept of metric weighting to space syntax. In this study, we discussed relevant previous studies to comprehend the problems and limits, established several new approaches for introducing and applying the metric weighting, and verified their validities by applying them to actual built spaces. We proposed the metric weighting functions of the distance itself, the square root function of the distance, the square function of the distance, the exponential function of the distance, and the logarithmic function of the distance to introduce and apply the metric weighting. We designated Myeong-

<table>
<thead>
<tr>
<th>Areas</th>
<th>Metric Radius (m)</th>
<th>C.C Case 1</th>
<th>C.C Case 2</th>
<th>C.C Case 3</th>
<th>C.C Case 4</th>
<th>C.C Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myeong-dong</td>
<td>250</td>
<td>0.300</td>
<td>-0.010</td>
<td>.342*</td>
<td>0.162</td>
<td>-0.004</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>.467**</td>
<td>0.200</td>
<td>.567**</td>
<td>0.112</td>
<td>0.120</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>.571**</td>
<td>0.253</td>
<td>.672**</td>
<td>-0.108</td>
<td>0.169</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>.625**</td>
<td>0.243</td>
<td>.686**</td>
<td>-0.120</td>
<td>0.166</td>
</tr>
<tr>
<td></td>
<td>450</td>
<td>.582**</td>
<td>0.153</td>
<td>.576**</td>
<td>-0.152</td>
<td>0.111</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>.577**</td>
<td>0.074</td>
<td>.489**</td>
<td>-0.189</td>
<td>0.060</td>
</tr>
<tr>
<td></td>
<td>550</td>
<td>.537**</td>
<td>0.124</td>
<td>.462**</td>
<td>-0.185</td>
<td>0.097</td>
</tr>
<tr>
<td>Insa-dong</td>
<td>250</td>
<td>0.144</td>
<td>-0.235</td>
<td>0.068</td>
<td>-0.271*</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>0.197</td>
<td>-0.113</td>
<td>0.174</td>
<td>-0.234</td>
<td>0.170</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>.256*</td>
<td>0.034</td>
<td>0.236</td>
<td>-0.184</td>
<td>.270*</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>.337**</td>
<td>0.182</td>
<td>.404**</td>
<td>-0.090</td>
<td>.422**</td>
</tr>
<tr>
<td></td>
<td>450</td>
<td>.361**</td>
<td>0.246</td>
<td>.446**</td>
<td>-0.036</td>
<td>.497**</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>.371**</td>
<td>0.246</td>
<td>.439**</td>
<td>-0.014</td>
<td>.507**</td>
</tr>
<tr>
<td></td>
<td>550</td>
<td>.400**</td>
<td>0.238</td>
<td>.458**</td>
<td>0.000</td>
<td>.522**</td>
</tr>
<tr>
<td>Seoul City Hall</td>
<td>250</td>
<td>-0.081</td>
<td>.527**</td>
<td>0.114</td>
<td>.576**</td>
<td>.520**</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>-0.068</td>
<td>.509**</td>
<td>0.068</td>
<td>.572**</td>
<td>.489**</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>-0.021</td>
<td>.517**</td>
<td>0.065</td>
<td>.549**</td>
<td>.467**</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>-0.058</td>
<td>.452**</td>
<td>-0.002</td>
<td>.535**</td>
<td>.416**</td>
</tr>
<tr>
<td></td>
<td>450</td>
<td>-0.059</td>
<td>.401**</td>
<td>0.003</td>
<td>.542**</td>
<td>.385*</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>-0.056</td>
<td>.383*</td>
<td>-0.032</td>
<td>.533**</td>
<td>.356*</td>
</tr>
<tr>
<td></td>
<td>550</td>
<td>-0.063</td>
<td>0.284</td>
<td>-0.097</td>
<td>.485**</td>
<td>.326*</td>
</tr>
</tbody>
</table>

Table 7. Three Target Areas and its Pedestrian Density Distribution and Local Closeness Centrality Distribution

<table>
<thead>
<tr>
<th>Category</th>
<th>Myeong-dong (明洞)</th>
<th>Insa-dong (仁寺洞)</th>
<th>Seoul City Hall (首爾市廳)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian Density Distribution</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
</tr>
<tr>
<td>Local Closeness Centrality Distribution</td>
<td><img src="image4" alt="Image" /></td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
</tbody>
</table>
dong, Insa-dong, and Seoul City Hall as the three target sites for analysis, and drew the respective segment axial maps associated with the sites. Subsequently, we conducted metric segment analyses and correlation tests between the results and the pedestrian densities for the three sites, thus examining the predictive power against the human-movement behaviors.

As a consequence, Myeong-dong showed the highest prediction when applied with the Case 2 metric weighting function for the metric radius of 400 m. Insa-dong showed the highest prediction when applied with the Case 4 metric weighting function for the metric radius ranging from 400 m to 800 m, while Case 2 also showed relatively high prediction. On the other hand, Seoul City Hall constantly showed high prediction when applied with the Case 3 metric weighting function. We noted that for all three sites, the models applied with Case 2 (Myeong-dong, Insa-dong), or Case 3 (Seoul City Hall) metric weighting functions showed higher prediction than when applied with Case 1 or when the weighting function was not applied. This means that the existing method of applying the metric weighting is problematic, and that differentiating the method of application is effective for improving the predictive power of the spatial analysis methodology. Yet, the results differ between the area of Seoul City Hall and the areas of Myeong-dong and Insa-dong, and this appears to have stemmed from the differences in the regional characteristics. This will require further verification by performing additional studies of more diverse target sites. In addition, more follow-up studies are required to determine which metric weighting function stands out as the most suitable, or how the metric weighting function changes depending on regional characteristics.

Acknowledgements
This research was supported by the Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning(NRF-2016R1C1B1011374).

References