Proceedings of the Ninth International Space Syntax Symposium
Edited by Y O Kim, H T Park and K W Seo, Seoul: Sejong University, 2013

# A REVISED REPRESENTATION FOR SPACE SYNTAX ANALYSIS BASED ON URBAN STREET SPATIAL ATTRIBUTES

052

**Sang Kyu Jeong**
Chungbuk National University
e-mail: neoshaky@daum.net

**Yong Un Ban**
Chungbuk National University
e-mail: byubyu@cbnu.ac.kr

## Abstract

*Although space syntax is a well-known technique for spatial analysis in architectural and urban space, the effects of the axial map as the key representation of the raw space syntax have been questioned among some researchers because of a lack of consideration about metric and geometric information. Therefore, extended representations to solve problems of the conventional space syntax theory have been introduced to the space syntax community.*

*However, these methods still cannot deal with the street width (capacity) and continuous spatial attributes based on the metric information in an urban street network because they have focused on topological information.*

*Accordingly, in order to conduct a more precise space syntax analysis, this study aims to develop an extended representation that can take into account the street width in addition to street length and turning angle and also accounts for continuous spatial attributes in the path segments connected by nodes (i.e., turning points or junctions in the street network).*

*To reach this goal, this study has developed algorithms to add metrical and continuous attributes into the linear and discontinuous representation of the existing space syntax, and has implemented them in a computational application called "J-Street Syntax Analyzer" (J-SSA).*

*As a result, the application developed here is able to consider the effects of not just topological properties but also metric properties such as length and width of path segments in a street network during space syntax analysis.*

*Furthermore, the proposed representation enables the visualization of continuous spatial properties in an urban street system by finely subdividing a path segment at regular intervals and then applying grayscale or spectrum scale to the subdivided sections.*

*In conclusion, we hope that the methods developed in this study will be a useful tool for planning urban streets by analyzing spatial configurations on the basis of the spatial and social relationships in urban street networks.*

**Keywords:** *space syntax, urban street network, metrical attributes, street width, continuous spatial properties*

**Theme:** *Modelling and Methodological Developments*

## 1. Introduction

Space syntax based on graph theory is a well-known technique for the quantitative analysis of spatial configurations in buildings and urban systems (Hillier & Hanson, 1984; Hillier, 2004). The theory of space syntax deals with accessibility based on the relationships that each space has with the other spaces in a system. This accessibility is used in a number of fields such as architectural planning, urban planning, and geography, and can be measured by analyzing the relationships among spaces in a street system.

According to conventional space syntax, an axial line is a representation that is used as a unit of space to analyze spatial configurations at the urban level. The definition of the axial line is based on the concept of a convex space. Hillier et al. (1987) suggested a topological representation called as “axial map” consisting of axial lines in an urban space. Space syntax has provided computational support for the development of urban morphological studies based on defining space by the axial map.

Jiang et al. (1999) showed how space syntax can be used to develop ideas of accessibility based on the connectivity of segments in a street network within a geographic information system (GIS). However, because of several problems caused by the lack of metric and geometric considerations in conventional space syntax analysis, some researchers have questioned the effects of the axial map (Ratti, 2004; Batty, Jiang, & Thurstain-Goodwin, 1998).

Consequently, there have been many studies to enhance conventional space syntax theory within the space syntax community, and new methodologies for a more precise space syntax analysis have been proposed (Turner, 2007; Ratti & Richens, 2004; Batty, 2001).

Despite the introduction of these new methodologies, the amount of geometric information for space syntax analysis about the complex urban environment is still lacking because the analysis using such methodologies mainly depends on a one-dimensional line segment. Therefore, to elaborate on the existing methods of space syntax analysis and differentiate our approach from them, we develop a new representation for a more precise space syntax analysis that takes into account street width in addition to street length and angular turn, and can express continuous spatial properties on a path segment connected to a node as turning point or junction at the street network level in an urban environment.

To reach this goal, this study has developed algorithms to add metric and continuous attributes into linear and discontinuous representation of conventional space syntax, and has implemented them in a computational application called "J-Street Syntax Analyzer” (J-SSA).

In the next section, we introduce the existing models of space syntax and present their limitations and problems. We then suggest ideas to conduct more precise space syntax analysis by considering street width and continuous spatial attributes in a street network. We then explain the J-SSA algorithms developed from our ideas. To demonstrate our algorithms, we present two case studies analyzed by J-SSA. The final section concludes with a summary of results and directions for further study.

## 2. Existing models of space syntax

### 2.1 The raw space syntax

Space syntax based on topology and graph theory can measure the properties of spatial configurations by mapping the depth of all of the spaces in a pattern from a particular point in buildings or urban systems (Hillier & Hanson, 1984; Hillier, 2007). In the space syntax analysis, axial lines as routes or movement paths are the longest straight lines that go through all convex spaces. The axial map of an urban space is mapped using the axial lines (Hillier et al, 1987).

Some studies have reported that the axial map has a number of inconsistencies during space syntax analysis. Much of the criticism derives from the fact that the information contained in the axial map of the raw space syntax is insufficient. In particular, Ratti (2004) pointed out that the limitations and inconsistencies associated with axial lines in space syntax were caused by the fact that the axial map, as a topological representation, discards precise metric information. According to his arguments, two similar urban configurations (shown in Fig.1) show how a small deformation of the urban grid can produce an abrupt change in its axial map. In other words, there may be a change of phase where one axial line suddenly becomes many axial lines due to a minor change in part of the street network.

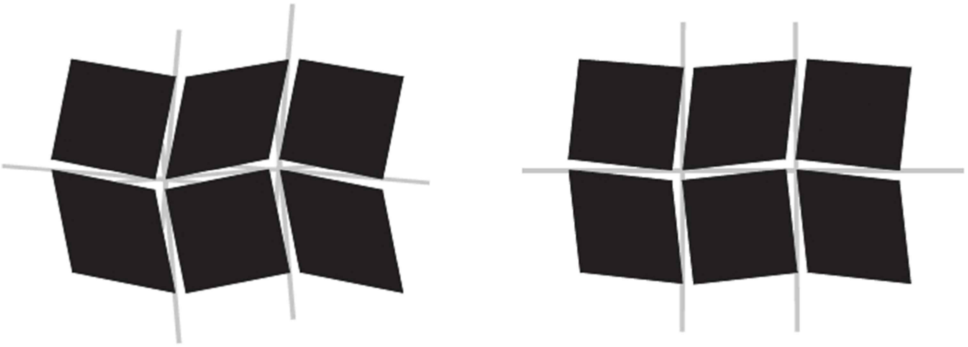


**Figure 1** Urban configurations and their axial maps.
(Source: Ratti, 2004, p. 495)

### 2.2 Angular segment analysis

In an effort to resolve the problems of the raw space syntax, angular segment analysis (ASA) has been introduced into the space syntax community (Dalton, 2001; Turner, 2001). ASA breaks axial lines into segments and then records the sum of the angles turned from the starting segment to any other segment within the system. As shown in Fig. 2, the ASA calculates the measurements by applying values weighted in the range of 0 (no turn) to 2 (180° turn) according to the turning angle from one segment to another. Therefore, ASA does not suffer from the representational problems highlighted by Ratti in the previous section.

Dalton et al. (2003) demonstrated the possibility that ASA may be applicable to more than axial maps. Hiller and Iida (2005) demonstrated a strong correlation between ASA measurements and movement, and used ASA within space syntax.

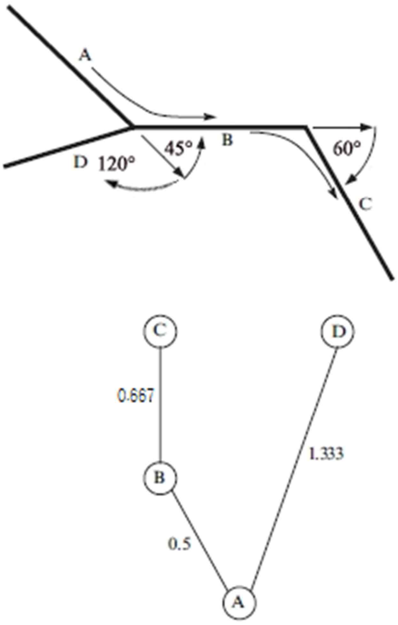


**Figure 2** ASA considering turning angles of path segments through a network.
Source: Turner, 2007, p. 542. (The above picture was adapted by the authors.)

In order to consider the length (metric distance) of a path segment in ASA, Turner (2007) suggested a new algorithm that can conduct ASA of road-center lines as axial lines through a length-weighted normalization procedure.

Although urban streets have a linear (one-dimensional) characteristic, on maps they are represented as two-dimensional segments of various widths. Therefore, even the extended ASA cannot take into account the impact of the street capacity based on width, because it still focuses on a line-based representation using one-dimensional segments. This may create limitations for the representation of the street network for space syntax analysis.

## 3. Methods for a new representation

This section provides an overview of the methods to conduct space syntax analysis by considering the attribute of street capacity and represent continuous spatial properties in a street network.

### 3.1 Street capacity attribute

In order to overcome the limitations of a linear representation, we propose a methodology to incorporate the attribute of street capacity into the existing metrics of space syntax.

Space syntax for the analysis of spatial configuration measures the properties of the patterns of spaces through which vehicles and pedestrians move. In a street network, the amount of movement a space will attract can be measured as the degree of spatial integration based on the relative accessibilities of streets (Penn et al., 1998; Hillier and Hanson, 1984).

Penn and Dalton (1994) found a strong correlation between traffic flows and configurational measures of the street network through a simultaneous study of vehicular and pedestrian movement.

Street width is a major factor that influences the movement in the route structure of an urban area (Krishnamurthy & Thamizh Arasan, 2012; Penn et al., 1998). Penn et al. (1998) suggested the possibility of using street width and building height as urban design parameters to arrive at a better controlled relationship between vehicles and pedestrians in urban areas. Using statistical techniques, they found that in addition to the degrees of integration as configurational measures, street width (capacity) and building height (development density) are major factors affecting flow. According to their research, vehicular flow rates are strongly related to the capacity of the streets as measured by street width and pedestrian flow rates depend on the development density as measured by the average of the maximum building heights for each street segment.

Therefore, we selected street width as an attribute of street capacity and constructed an algorithm that uses weights derived from the ratio of the width of each path segment to the maximum street width of the street system. Details of the algorithm are described in Section 4.2 of this paper.

In the case of a multi-lane carriageway, the number of lanes is also an important attribute that significantly affects vehicular flows (Tang et al., 2012). On the other hand, in the case of pedestrian zones (i.e., car-free zones reserved for pedestrian use only), the building height indicates the development density and has a strong effect on pedestrian movement (Penn et al., 1998).

Therefore, vehicle-only multi-lane carriageways outside an urban district and pedestrian-only zones are excluded from the scope of this study. Instead, only streets used by both vehicles and pedestrians lying inside an urban district are included.

Incorporating the number of lanes as a measure of road capacity and building height as a measure of development density in space syntax analysis is another task to be addressed in a future study.

### 3.2 Continuous representation of spatial properties in a street network

Lu, Chen and Hancock (2009) used concepts of graph theory to detect abnormal paths in the large spatial graphs that typically represent a transportation networks and to assist with identifying abnormal events that occur during a trip in urban street system. In their study, a path segment is considered to be a sequence of vertices in a spatial graph with one additional constraint that the physical connectivity is kept between two consecutive vertices. Similarly, in this study, the path segment in a street network is considered to be an edge connecting two vertices (i.e., turning points or junctions in the street network) in the spatial graph.

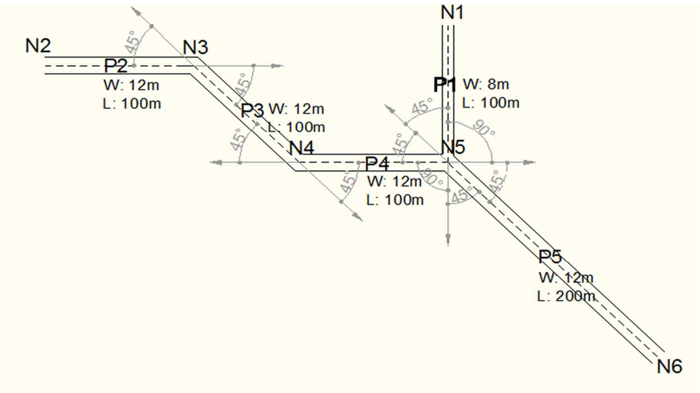
The following assumptions have been made in order to measure and represent continuous details of spatial configurations and the properties of a street network on a spatial graph.

(1) A node represents turning point or junction in a street network.

(2) A path segment is a two-dimensional space with length and width and exists between two consecutive nodes.

(3) A street network is a combination of nodes and path segments.

(4) The space unit for space syntax analysis is the node.



Where, N1, N2…, Nn: nodes, P1, P2…, Pn: path segments, W: width of the path segment, L: length of the path segment, Dashed line: road-center line

**Figure 3** Nodes and path segments in the street network.

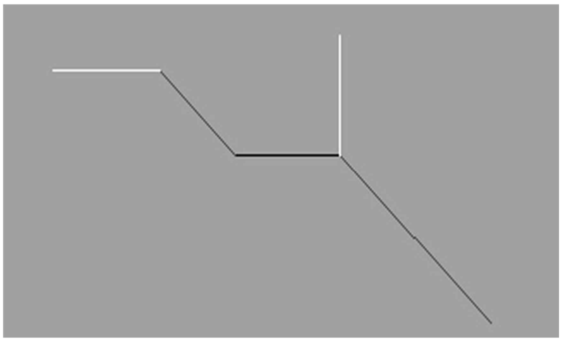
Jiang and Claramunt (2002) proposed point-based space syntax as an alternative approach to integrate space syntax into GIS, which can model large-scale spaces as a finite set of small spaces. Through the calculation of space syntax parameters assigned to characteristic points including junctions or turning points where people make navigation decisions, their study illustrated that pointed-based analysis results are very similar to those of line-based analysis.

The line-based approach that assigns the same spatial property to a path segment is inappropriate for street networks, because the accessibility of one end of a path segment may differ from that of the other end. On the other hand, the point-based approach is more appropriate for deriving the continuous spatial properties between the nodes at the ends of a path segment. Therefore, using a point-based approach, we propose a method to represent continuous changes in space syntax values between two consecutive nodes.

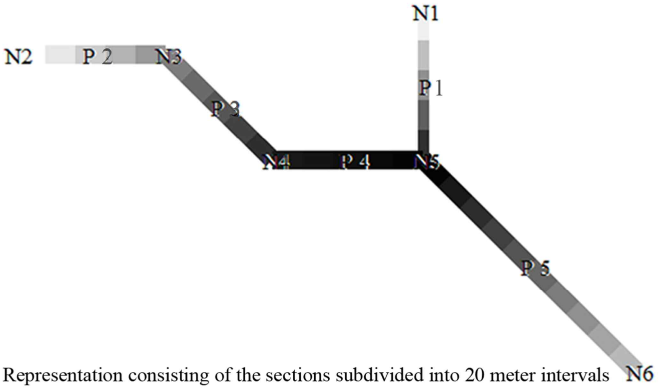
As shown in Fig. 4(a), because only one spatial property is assigned to a path segment in conventional space syntax analysis, the representation of a street network is discontinuous.

In order to smooth the discontinuities and thereby more precisely represent continuous spatial properties in a street network, the path segment with an elongated shape in a street network should be subdivided into regular intervals and the correct spatial properties for each subdivided section should be assigned.

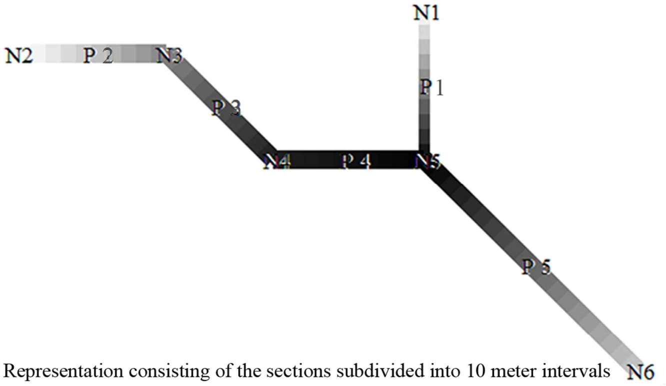
To do this, the node rather than the path segment should become the space unit for space syntax analysis. As shown in Fig. 4(b), the spatial properties of nodes forming a path segment can then be dispersed and represented more precisely on the path segment.



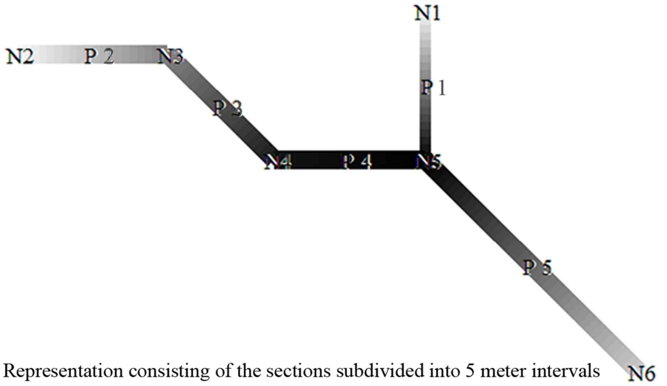
(a) The existing discrete and linear representation.



Representation consisting of the sections subdivided into 20 meter intervals



Representation consisting of the sections subdivided into 10 meter intervals



Representation consisting of the sections subdivided into 5 meter intervals

b) Continuous representation proposed in our methodology.

**Figure 4** The continuous representation of spatial properties on the path segment.

Though our representation is, in reality, discontinuous, it approximates a continuous system by finely subdividing the path segment at regular intervals and then applying grayscale values to the subdivided sections. Therefore, it can include continuously varying spatial properties and can be easily recognized.

When the spatial property of node at one end of a path segment is different to that of the node at the other end, a continuous representation of spatial properties in the street network can be obtained by assigning changing property values at regular intervals along the path segment. The more narrowly the intervals are set, the more finely the gradation is represented. Details of the algorithm are described in Section 4.3 of this paper.

## 4. Construction of algorithms

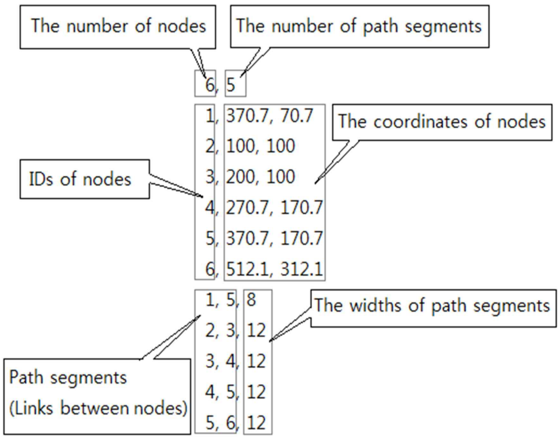
This section details the algorithms to create the data file of a street network, calculate mean depths and visualize the analysis results using the continuous representation of a path segment.

### 4.1 The development of computational application and the composition of a data file

To demonstrate the algorithms proposed in this study, we developed the J-SSA written in Visual Basic.NET, which can analyze the spatial information of a street network converted to graph data.

As shown in Fig. 5, the data file of the street network sample illustrated in Fig. 3 is composed of the number of nodes and path segments, the node identifiers (IDs) and their coordinates, the path segments, and the widths of the path segments.

Algorithms developed here can numerically derive the analysis results and express them visually by loading and analyzing the network data from the file with the “SSA” extension.



```
6, 5
1, 370.7, 70.7
2, 100, 100
3, 200, 100
4, 270.7, 170.7
5, 370.7, 170.7
6, 512.1, 312.1
1, 5, 8
2, 3, 12
3, 4, 12
4, 5, 12
5, 6, 12
```

**Figure 5** The composition of data files of a street network

## 4.2 Algorithm for numerical analysis

According to the raw space syntax, the total depth (*TD*) can be calculated by summing the depths via each of the shortest paths between one node and all others in a street network. After calculating the *TD*, the mean depth (*MD*) can be calculated by

$$MD_x = \frac{\sum_{i \in S, i \neq x} D(x,i)}{k-1}$$

where $MD_x$ represents the mean depth of space *x*, *D(x, i)* represents the depth on the shortest route between two spaces, space *x* and space *i*, in a network system *S*, and *k* is the number of space units in the system *S*. The *MD* is an indicator of the integrating/segregating effects of space in buildings or urban environments. If the *MD* value of a space in street network is low, it indicates that the space tends to have a more integrated property in the system.

In the raw space syntax, the depth value is not the actual distance, but the step number between space units on the street network. ASA computes depths by considering the angles turned from the starting space to any other space instead of the step number between space units within the system.

Because the feature focusing only on topological distance has created the limitation of space syntax analysis, Turner (2007) suggested a supplemented *MD* for a segment *x* to consider turning angle and the length of a path segment in a street system as follows

$$MD_x = \frac{\sum_{i \in S, i \neq x} D_\theta(x,i) L(i)}{L_{total}}$$

where *L(i)* indicates the length of path segment *i* in the metric system, $L_{total}$ indicates total length of path segments in a street network, and $D_\vartheta(x, i)$ represents the depth obtained by considering angle ($\vartheta$) for each turn from segment *x* to segment *i* via the shortest angular route, which ranges from 0 (no turn) to 2 (180° turn). However, Eq. (2) cannot take into account the effect of street width as an attribute of street capacity. Therefore, we propose a further complemented equation that considers not only the turning angles and lengths but also the street widths as follows

$$MD_x = \frac{\sum_{i \in S, i \neq x} D_\theta(x,i) L(x,i) (2 - W(x,i)/W_{\max})}{L_{total}}$$

where *L(x, i)* indicates the length of each path segment on the shortest route from node *x* to node *i, W(x, i)* indicates the width of each path segment on the shortest route from node *x* to node *i,* and $W_{max}$ indicates the maximum width of the path segment in a system S.

In Eq. (3), in addition to turning angle and length, the weighted value of the street width is added, which ranges from 1 (the maximum width) to 2 (that of a street of 0m width, which is practically impossible). Recall that, unlike the existing methods, the space unit for space syntax analysis is a node, not a path segment.

On the basis of the above equations, we construct the algorithm to numerically analyze a street network by loading the network data, selecting one from the options, and then calculating the *MD*s. Table 1 shows the pseudo code of the algorithm.

**Table 1** Pseudo code of the algorithm for numerical analysis

**Pseudo code** / **Remarks**

```
P: path segment
TL: total length of paths in the street network
$W_{max}$: the maximum width of path segment
k: the number of nodes
$N_R$: node as root
$N_D$: node as destination
$N_S$: a node on the shortest route between $N_R$ and $N_D$
N (1 to 3): three consecutive nodes forming two path segments
i: ID of the above three nodes.
Op: the option selected from the list of options
A: the angle among three consecutive nodes (two path segments) on the shortest route
TA: the turning angle assigned in the range of 0 (no turn) to 2 (180°turn)
D: the depth between two consecutive nodes on the shortest route
TD: the total depth of each node
MD: the mean depth of each node
```

Declare variables.

```
O1 = “Topological analysis based on the raw space syntax"
O2 = “Analysis considering the turning angles of path segments"
O3 = “Analysis considering the turning angles and length of path segments"
O4 = “Analysis considering the turning angles, lengths, and widths of path segments”
```

Declare constants as options for space syntax analysis.

```
Load the network data.
```

Read the network data from SSA file.

```
For Each P In the list of path segments
  TL = TL + Length of P
Next P
```

Calculate total length of the street network.

```
For Each $N_R$ In members of node collection
  For Each $N_D$ In members of node collection
    Find the shortest route from $N_R$ (root) to $N_D$ (destination).
    Read the option selected from the list of options for space syntax analysis.
```

Execute the For...Next loops to specify root and destination, and to find the shortest route between them.

```
    If Op = O1 Then
      D = the number of the path segments on the shortest route between $N_R$ and $N_D$
    End If
```

Determine topological depth from root to destination when conducting the topological analysis.

```
    $N_S$ = $N_D$
    i = 1
```

Initialize $N_S$ and *I*.

```
    Do Until $N_S$ Is $N_R$
      $N_S$ = the other node connected to $N_S$ on the shortest route
      i = i + 1
      N(i) = Ns
      If Not (N(3) Is Nothing) Then
```

Execute the loop to examine nodes by going backward from the destination to the root.

```
        If Op = O3 Or Op = O4 Then D = length between N(2) and N(3)
```

Determine depth of a path segment corresponding to the length between *N(2)* and *N(3)* when conducting analysis considering the length of the path segment,

```
        A = |angle among three consecutive nodes on the shortest route|
        TA = (180 - A) / 90
```

Calculate the turning angle assigned in the range of 0 to 2 among three nodes (two path segments) on the shortest route.

```
        If Op = O1 Then TD = TD + D
        If Op = O2 Then TD = TD + TA
        If Op = O3 Then TD = TD + D *TA
        If Op = O4 Then TD = TD + D * TA * ( 2 - ( width of path between N(2) and N(3) / $W_{max}$ ) )
        N(3) = Nothing
      End If
      If i = 3 then i = 1
    Loop
  Next $N_D$
```

Calculate the *TD of each node* according to the option selected.

```
  If Op = O1 Or Op = O2 Then MD = TD / k - 1
  If Op = O3 Or Op = O4 Then MD = TD /TL
  Record the TD and MD of each node ($N_R$) in data grid.
Next $N_R$
```

Calculate the *MD* of each node according to the option selected and record the calculated results.

## 4.3 Algorithm to visualize the analysis results

We constructed an algorithm to visualize the analysis results obtained by the algorithm described above. We assume that the spatial property has a different value at each location on a path segment, influenced by the nodes at both ends. To represent this, the algorithm subdivides the path segment into small discrete subsections, and then fills each subsection with a grayscale or a spectrum scale corresponding to each *MD*.

The pseudo code for the algorithm is shown in Table 2.

**Table 2** Pseudo code of the algorithm to visualize the analysis results

| Pseudo code | Remarks |
|---|---|
| *P*: path segment<br>*L*: the length of the path segment<br>*N*: node<br>  *N1*: the node at one end of *P*<br>  *N2*: the node at the other end of *P*<br>  *x1*: x-coordinate of *N1*<br>  *y1*: y-coordinate of *N1*<br>  *x2*: x-coordinate of *N2*<br>  *y2*: y-coordinate of *N2*<br>*MD*: the mean depth of each node<br>  $MD_{max}$: the maximum *MD*<br>  $MD_{min}$: the minimum *MD*<br>*Grayscale*: the grayscale value specified in the range from 0 (black) to 255 (white)<br>*Interval*: the interval subdividing the path segment<br>*i*: the variable increasing at regular intervals in the range from 0 to L<br>*Pen*: pen to draw the street network<br>  *Pen*.Color: color of the pen<br>  *Pen.Width* = width of the pen<br>*ID*: identifier | Declare variables. |
| For Each *N* In members of node collection<br>  If *MD* of *N* >= *MD*s of the other nodes Then $MD_{max}$ = *MD* of *N*<br>  If *MD* of *N* <= *MD*s of the other nodes Then $MD_{min}$ = *MD* of *N*<br>Next *N* | Seek the maximum and minimum values of the *MD*s obtained using the numerical analysis algorithm described in the previous section. |
| Input *Interval* | Input the interval to subdivide *P.* |
| For Each *P* In members of path collection | Execute the loop to examine each path segment. |
|   Grayscale = ( (MD of *N2* - $MD_{min}$) / ($MD_{max}$ - $MD_{min}$) ) * 255 | Seek grayscale value of the MD of N2 in the range from 0 (grayscale value of $MD_{max}$) to 255 (that of $MD_{min}$). |
|   For *i* = 0 To *L* Step *Interval* | Execute the loop to generate values  increasing at regular intervals in the range from 0 to L. |
|    *Grayscale* = *Grayscale* + (*Grayscale* of *N1* - *Grayscale* of *N2*) * (Interval / *L*) | Assign grayscale values in the range between the grayscale value of the *MD of N1 and that of N2,* along each section of the path segment subdivided by intervals, |
|    *Pen*.Color = *Grayscale* | Set the pen color corresponding to the grayscale value, |
|    *Pen*.Width = Width of *P* | Set the width of pen corresponding to the width of *P*. |
|    DrawLine (*Pen*, *x1*, *y1*, *x2* - (*x2* - *x1*) * *i* / *L*,  *y2* - (*y2* - *y1*) * *i* / *L*)<br>  Next *i*<br>Next *P* | Draw each section of the path segment using the grayscale pen with the thickness corresponding to the width of path segment. |
| For Each *N* In members of node collection<br>  Display *ID* of each *N* at its x and y coordinates.<br>  For Each *P* In members of path collection<br>    Display the width and length of each *P* at the bottom of the middle of the path.<br>  Next *P*<br>Next *N* | Display ID of each node and the width and length of each path segment on the street network by examining nodes and path segments using the For,,.Next loops. |

## 5. Application

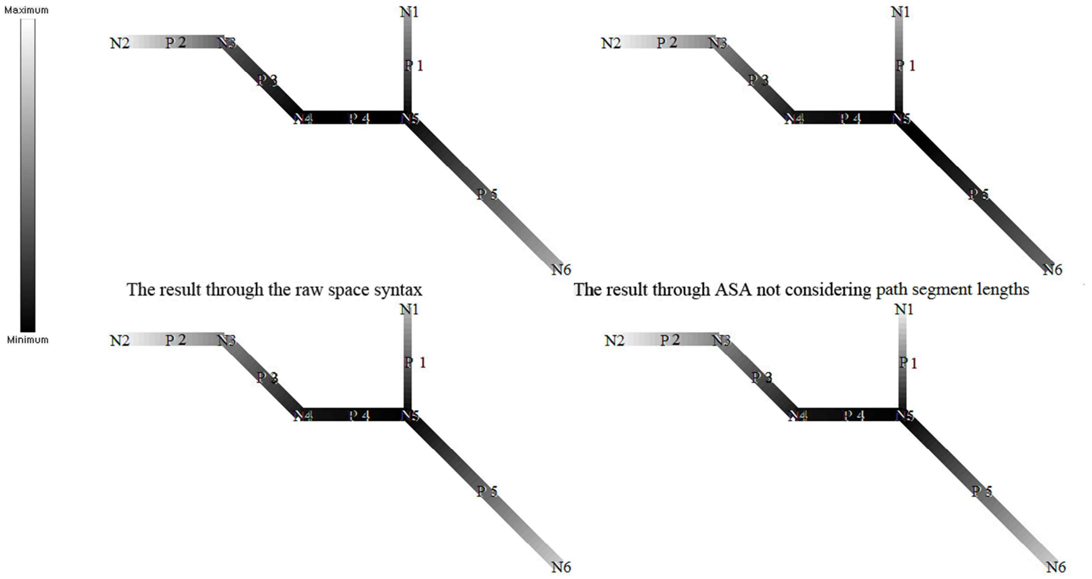
This section presents two case studies analyzed by J-SSA developed in this study.

### 5.1 Case study 1

To illustrate the applicability of our methodology, we analyzed the street network sample shown in Fig. 3 with J-SSA. Table 3 shows the *TD*s and *MD*s of the nodes forming the street network for several methods: the raw space syntax analysis, ASA not considering path segment lengths, ASA considering path segment lengths, and our method.

**Table 3** *TD*s and *MD*s calculated by each method.

| **Node's ID** | **The raw space syntax** | | **ASA not considering path segment lengths** | | **ASA considering path segment lengths** | | **Our method** | |
|---|---|---|---|---|---|---|---|---|
| | ***TD*** | ***MD*** | ***TD*** | ***MD*** | ***TD*** | ***MD*** | ***TD*** | ***MD*** |
| N1 | 12 | 2.400 | 5.0 | 1.000 | 499.992 | 0.833 | 616.659 | 1.028 |
| N2 | 14 | 2.800 | 6.5 | 1.300 | 649.962 | 1.083 | 649.962 | 1.083 |
| N3 | 10 | 2.000 | 4.0 | 0.800 | 399.962 | 0.667 | 399.962 | 0.667 |
| N4 | 8 | 1.600 | 2.0 | 0.400 | 199.993 | 0.333 | 199.993 | 0.333 |
| N5 | 8 | 1.600 | 1.5 | 0.300 | 149.992 | 0.250 | 149.993 | 0.250 |
| N6 | 12 | 2.400 | 3.5 | 0.700 | 549.932 | 0.917 | 549.932 | 0.917 |

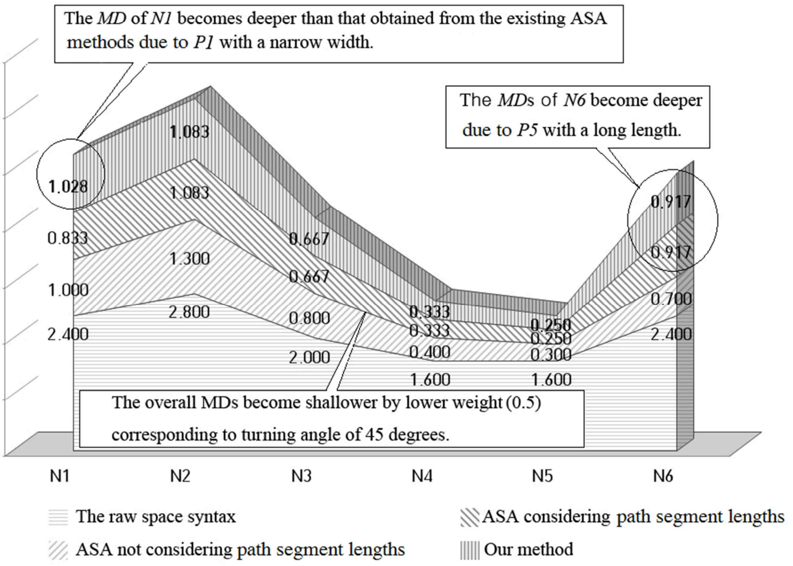


The result through the raw space syntax

The result through ASA not considering path segment lengths

The result through ASA considering path segment lengths

The result through our method



The *MD* of *N1* becomes deeper than that obtained from the existing ASA methods due to *P1* with a narrow width.

The *MD*s of *N6* become deeper due to *P5* with a long length.

The overall MDs become shallower by lower weight (0.5) corresponding to turning angle of 45 degrees.

**Figure 6** The results obtained from each method

Fig.6 compares the results obtained from each method. As shown in Table 3 and Fig. 6, when compared with the raw space syntax analysis, the overall *MD*s calculated by ASA become shallower because four pairs of path segments (*P2–P3*, *P3–P4, P1–P5*, and *P4–P5*) have a lower weight (0.5) corresponding to a turning angle of 45 degrees, half of the weight (1.0) of a 90 degree turning angle between *P1–P4*.

The *MDs* of node *N6* calculated by ASA considering path segment lengths and our method become deeper than the *MD* obtained from ASA not considering path segment lengths because of the weight of *N6* adjacent to *P5* that has longer length (200 m) than the lengths of the other segments in the street network.

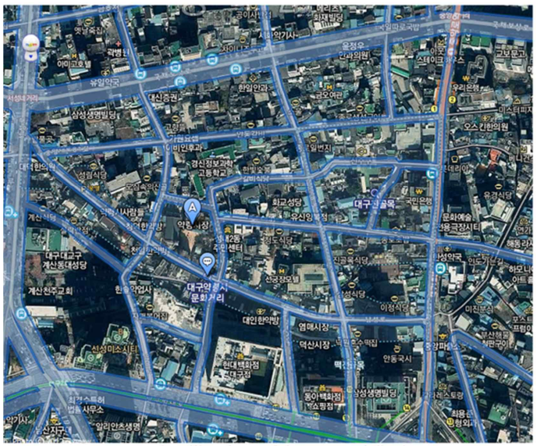
In addition, when applying our methodology that considers street width during space syntax analysis, the *MD* (1.028) of *N1* becomes deeper than the *MD* (0.833) obtained from the existing ASA methods because node *N1* is adjacent to *P1* which has a width of 8 m, narrower than the other segments which have a width of 12 m in the street network.

### 5.2 Case study 2

To demonstrate our proposed representation at the level of street network in a real urban district, we calculated the measures of the street network of an herbal medicine market called “Yakryong-si" in Daegu City, Republic of Korea, which is packed with hundreds of herbal medicine shops.

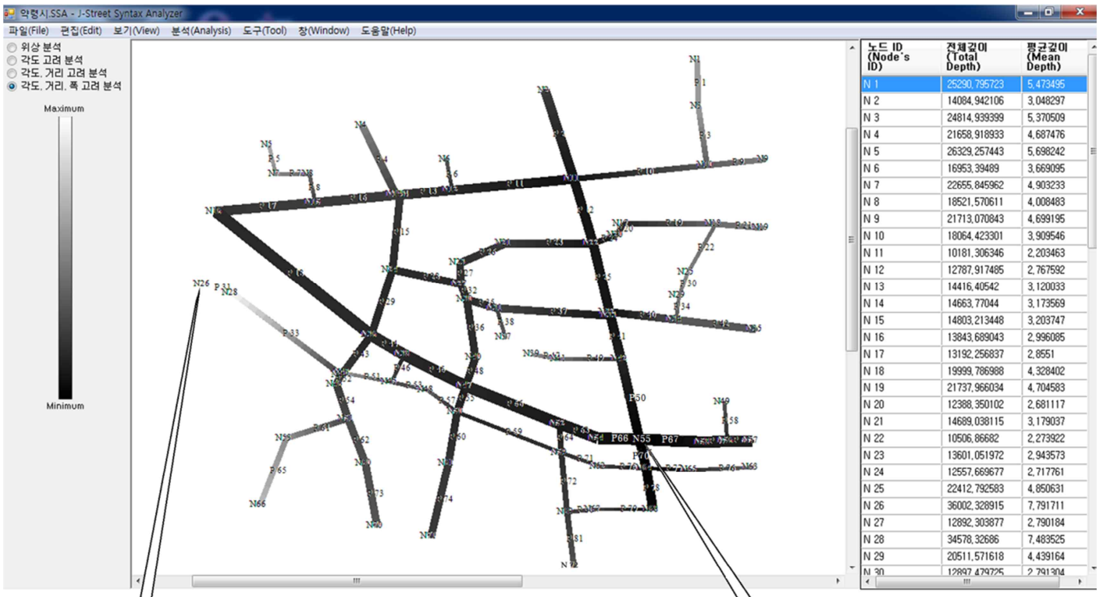
According to the measures obtained by executing J-SSA, *N55* has the shallowest *MD*. This indicates that *N55* is the most integrated space in the network system. This node is adjacent to four path segments, *P66–P67* having a width of 12 m, and *P50–P70* having a width of 10 m. These relatively wide path segments form the axes of two main streets known as the streets of the herbal medicine shop. As shown in Fig. 7, in the spatial network of the actual street, the facades of many shops are placed along these two axes. In addition, the spot corresponding to *N55* (the intersection of the two axes) is located at an effective position that minimizes blind spots and captures a wide angle of view. Hence, public CCTV (Closed Circuit Television) security cameras for crime prevention and parking enforcement are installed there.

On the other hand, *N26* has the deepest *MD.* It is the most isolated space, adjacent to the end of *P31* that has a width of 6 m. In contrast to *N55*, the spot corresponding to *N26* is actually located at an entrance of a secluded back street.



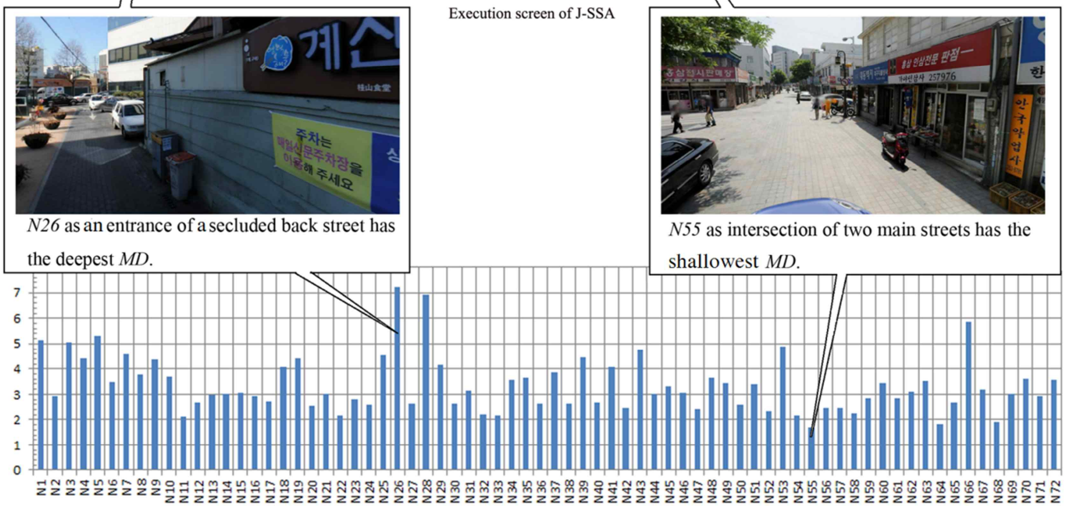
Satellite photo of the surveyed district

The map



○ 위상 분석
○ 각도 고려 분석
○ 각도. 거리 고려 분석
● 각도. 거리. 폭 고려 분석

| 노드 ID (Node's ID) | 전체깊이 (Total Depth) | 평균깊이 (Mean Depth) |
|---|---|---|
| N 1 | 25290,795723 | 5,473495 |
| N 2 | 14084,942106 | 3,048297 |
| N 3 | 24814,939399 | 5,370509 |
| N 4 | 21658,918933 | 4,687476 |
| N 5 | 26329,257443 | 5,698242 |
| N 6 | 16953,39489 | 3,669095 |
| N 7 | 22655,845962 | 4,903233 |
| N 8 | 18521,570611 | 4,008483 |
| N 9 | 21713,070843 | 4,699195 |
| N 10 | 18064,423301 | 3,909546 |
| N 11 | 10181,306346 | 2,203463 |
| N 12 | 12787,917485 | 2,767592 |
| N 13 | 14416,40542 | 3,120033 |
| N 14 | 14663,77044 | 3,173569 |
| N 15 | 14803,213448 | 3,203747 |
| N 16 | 13843,689043 | 2,996085 |
| N 17 | 13192,256837 | 2,8551 |
| N 18 | 19999,786988 | 4,328402 |
| N 19 | 21737,966034 | 4,704583 |
| N 20 | 12388,350102 | 2,681117 |
| N 21 | 14689,038115 | 3,179037 |
| N 22 | 10506,86682 | 2,273922 |
| N 23 | 13601,051972 | 2,943573 |
| N 24 | 12557,669677 | 2,717761 |
| N 25 | 22412,792583 | 4,850631 |
| N 26 | 36002,328915 | 7,791711 |
| N 27 | 12892,303877 | 2,790184 |
| N 28 | 34578,32686 | 7,483525 |
| N 29 | 20511,571618 | 4,439164 |
| N 30 | 12897,479725 | 2,791304 |



Execution screen of J-SSA

*N26* as an entrance of a secluded back street has the deepest *MD*.

*N55* as intersection of two main streets has the shallowest *MD*.

MDs calculated through our method

**Figure 7** Results of space syntax analysis of Yakryong-si, Daegu, using the proposed representation

## 6. Conclusion

To overcome the limitations of the raw space syntax, space syntax models such as ASA were developed by the space syntax community, but there are still some limits caused by not concretely taking into account the metric properties of urban street networks. Therefore, this study proposed another method to effectively manage and represent the metric properties of urban street system in a space syntax focused mainly on the analysis of topological properties.

The algorithms developed here are able to disperse spatial properties on a path segment at regular intervals by regarding *MD*s as the forces acting between two consecutive nodes and considering the effects of not just topological properties but also metric properties such as the length and width of a path segment in a street network.

Furthermore, although the representation proposed here is virtually discontinuous, it is able to visualize continuous spatial properties in an urban street system by finely subdividing a path segment at regular intervals and then applying grayscale or spectrum scale to the subdivided sections. We showed that such effects can helps the understanding of spatial properties of each section of a path segment and the correlations among space units in a street system.

Through these findings, we hope that the methodology developed here will be a useful tool for planning urban streets as a circulation space by analyzing spatial configurations on the basis of spatial and social relationships in an urban street network.

The developed demonstration program, J-SSA can adjust the weights of factors that affect the space syntax of an urban street system. This study added street width as a factor that influences movement in the route structure of an urban street network. Through more case studies in the future, the proper ratio of weights corresponding to newly added influencing factors to other factors should be normalized to conduct a more precise analysis according to the changing environment.

The areas covered by the proposed methodology are limited to streets open to both vehicles and pedestrians inside an urban district, but following studies will explore methods to derive the spatial properties of vehicle-only, multi-lane carriageways outside the district and pedestrian-only zones.

## Acknowledgement

This research has been supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (grant number: 2010-0024189).

## REFERENCES

Batty, M., B. Jiang, and M. Thurstain-Goodwin. 1998. *Local movement: agent-based models of pedestrian flow*, WP 4, Centre for Advanced Spatial Analysis, London: University College London.

Batty, M. 2011. “Exploring isovist fields: space and shape in architectural and urban morphology.” *Environment and Planning B: Planning and Design* 28(1): 123-150.

Dalton, N. 2001. “Fractional configurational analysis and a solution to the Manhattan problem.” In *Proceedings of the 3rd International Symposium on Space Syntax,* Georgia Institute of Technology, Atlanta, GA, pp.26.1 -26.13.

Dalton, N., J. Peponis, and R. Conroy-Dalton. 2003. “To tame a TIGER one has to know its nature: extending weighted angular integration analysis to the description of GIS road-center line data for large scale urban analysis.” In *Proceedings of the 4th International Symposium on Space Syntax*, University College London, London, pp.65.1-65.10.

Daum Communications Corp. 2012. *Map services*, <http://map.daum.net/>. Accessed 01.12.12.

Hillier, B., and J. Hanson. 1984. *The social logic of space*. Cambridge: Cambridge University Press.

Hillier, B. 2007. *Space is the machine*. (electronic ed.). London: Space Syntax Ltd. Available at: http://www.spacesyntax.com.

Hillier, B., J. Hanson, and J. Peponis. 1987. “Syntactic analysis of settlements.” *Architecture et Comportment/Architecture and Behavior* 3: 217-231.

Hillier, B., & S. Iida. 2005. “Network effects and psychological effects: a theory of urban movement.” In *Proceedings of the 5th International Symposium on Space Syntax*, TU Delft, Delft, pp.553-564.

Jiang, B., & C. Claramunt. 2002. “Integration of space syntax into GIS: new perspectives for urban morphology.” *Transaction in GIS* 6(3): 295-309.

Jiang, B., C. Claramunt, and M. Batty. 1999. “Geometric accessibility and geographic information: extending desktop GIS to space syntax.” *Computers, Environment and Urban Systems* 23(2): 127-146.

Krishnamurthy, K. and V. Thamizh Arasan. 2012. “Effect of road width and traffic volume on vehicular interactions in heterogeneous traffic.” *Journal of Advanced Transportation,* doi: 10.1002/atr.196.

Lu, Q., Chen, F., & K. Hancock. 2009. “On path anomaly detection in a large transportation network.” *Computers, Environment and Urban Systems* 33(6): 448-462.

Penn, A., B. Hillier, D. Banister, and J. Xu. 1998. “Configurational modelling of urban movement networks.” *Environment and Planning B: Planning and Design* 25(1): 59-84.

Penn, A., and N. Dalton. 1994. “The architecture of society: stochastic simulations of urban pedestrian movement.” In *Simulating Societies*” In N. Gilbert and J. Doran, pp. 85-126. London: UCL press.

Ratti, C. 2004. “Urban texture and space syntax: some inconsistencies.” *Environment and Planning B: Planning and Design* 31(4): 487-499.

Ratti, C., and P. Richens. 2004. “Raster analysis of urban form.” *Environment and Planning B: Planning and Design* 31(2): 297-309.

Tang, T. Q., X. B. Yang, Y. H. Wu, L. Caccetta, and H. J. Huang. 2012. “A multilane traffic flow model with lane width and the number of lanes.” *Chinese Physics Letters* 29(9): 098903-1-098903-4.

Turner, A. 2001. “Angular analysis.” In *Proceedings of the 3rd International Symposium on Space Syntax*, Georgia Institute of Technology, Atlanta, GA, pp.30.1-30.11.

Turner, A. 2007. “From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis.” *Environment and Planning B: Planning and Design* 34(3): 539-555.