Angular VGA and Cellular VGA

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An exploratory study for spatial analysis methodology based on human movement behavior

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Abstract
In the Space Syntax field, moving distance and turning angle are the two main factors of human movement behavior which have been taken notice of. Several spatial analysis methodologies which apply those issues to existing graph-based methodologies have been published during the recent ten years. One of the most remarkable models is the Angular Segment Analysis (ASA) methodology for successfully reflecting the concepts of moving distance and turning angle. But existing Spatial Analysis methodologies including ASA have problems yet to be solved in terms of moving distance and turning angle. In this study, the conceptual properties and problems of existing Spatial Analysis methodologies in terms of human movement behavior are investigated, and two spatial analysis methodologies based on Visibility Graph Analysis (VGA) or Grid Map methodology, so-called Angular VGA and Cellular VGA, which successfully deal with such problems are newly proposed. The Angular VGA methodology improves behavioral reality by applying the concept of angular depth to the Grid Map, while the Cellular VGA methodology overcomes poor reflection of Euclidean distance in existing spatial analysis methodologies by applying the Neighborhood concept of Cellular Automata model onto the Grid Map. Finally, verification of the capability and usability of the newly proposed methodologies is performed by analyzing an actual museum building with those methodologies. As a result of the verification, it has been revealed that the significances of the Angular VGA and the Cellular VGA can be improved when they are utilized together.

1. Introduction

Since 'Space Syntax' was born in the early 1980's, spatial analysis methodologies have continued its remarkable growth. Spatial analysis methodologies have been utilized to numerous of architectural and urban researches, while various spatial analysis methodologies have been published as well. With the theoretical development of spatial analysis methodologies, concern about human movement behavior which had been taken little notice of eventually surfaced within the Space Syntax field, and several spatial analysis methodologies that positively reflect the aspects of human movement behavior were published continuously.

In the Space Syntax field, moving distance and turning angle are the two main factors of human movement behavior which have been taken notice of. Moving distance refers to the distance of movement path in a built-environment, assuming that one tends to avoid longer movement paths. Turning angle refers to the changing degree of movement direction at a corner or a junction, and is known to be a factor closely related with human movement behavior. (Golledge 1995, Conroy Dalton 2003)

Angular Segment Analysis (ASA) methodology which was recently published in the Space Syntax field is noticeable for reflecting the concept of moving distance and turning angle mentioned above. Recent study has reported that the ASA methodology is an improvement from the Axial Map Analysis methodology as an explanatory method for actual movement patterns. However, existing Spatial Analysis methodologies including ASA have problems yet to be solved in terms of moving distance and turning angle. In this study, the conceptual properties and problems of existing Spatial Analysis methodologies in terms of human movement behavior are investigated, and clues to solve the problems are found from Visibility Graph Analysis (VGA) or Grid Map methodology. Finally, new spatial analysis methodologies which overcome the defeats of the existing methodologies were proposed.

2. Reflecting human movement behavior in Space Syntax field

2.1. Turning angle

In the early 1980's several researchers in the environmental psychology field have already taken notice of the relation between individual orientation perception and angularity, and they have conducted a number of positive researches on the relation between human movement behavior and route angularity.(Sadalla & Montello 1989, Montello 1991, Golledge 1995) Especially, Golledge pointed out that individuals tend to minimize angular deviation from a straight line to destination or direction and conserve linearity while navigating. Furthermore, Conroy Dalton conducted an experiment where participants were instructed to walk to a specific destination in a virtual urban environment made with virtual environment computing technology, and she argued that route choice at a junction is influenced by both direction to final destination and heading direction. (Conroy Dalton 2003)

In the Space Syntax field, there were several researches in which route choice or directional change issue was approached quantitatively and applied to the existing spatial analysis methodology. Turner pointed out that easiness of directional change can be varied as turning angle, and proposed Angular Analysis methodology that applied the shortest angular path based on angular depth to VGA methodology.(Turner 2000, Turner 2001) Dalton pointed out the limitation of analyzing regular grid street structure with axial map methodology, so-called 'Manhattan Problem' and tried to find a solution by proposing Fractional Analysis methodology including different quantification approach of angular depth.(Dalton 2001)

These approaches of Turner and Dalton are based on the concept of fractional/continuous depth which goes against the integerized concept of discrete depth that makes the conventional premise of the Space Syntax. They set the angle of turn from a certain axial line to another adjacent axial line as the explanatory variable of the depth values. Thus, these approaches assume that the depth between adjacent axial lines is the function of the turning angle between the two axial lines. The difference between the two approaches lies in the different functions. Turner assumed that depth between adjacent axial lines is simply the function of turning angle in radian. But Dalton thought that turning angle of 90° corresponds to depth 1 and assumed that depth between adjacent axial lines is the sine function of turning angle. The functional formulae of their studies are as shown below.

$$AD_{Turner}(\theta) = \theta$$
$$AD_{Dalton}(\theta) = \sin\theta \; (0 \leq \theta \leq \pi/2)$$
$$\text{---------------} \; 2-\sin\theta \; (\pi/2 < \theta \leq \pi)$$

Finally, Turner came to propose Angular Segment Analysis methodology that apply the concept of angular depth mentioned above to segmented axial map.(Turner 2005, Turner 2007) In this methodology, the shortest angular path about each pair of origin-destination segments was obtained from segmented axial map representing specific built-environment — usually generated from the load-center line of GIS — and measures of closeness centrality(angular closeness) and betweenness centrality(angular betweenness) are calculated from the shortest angular path information. Recent related research reveals that ASA methodology shows more remarkable predictability for the actual movement pattern than existing traditional Space Syntax methodology.

2.2. Euclidean distance of movement

In the architectural, urban and geographical field, distance has been usually considered as movement cost, that is to say, a deterrent to movement. Accessibility used to be thought of being in inverse proportion to moving distance and this thought was made over to following spatial analysis researchers. Batty proposed measure of Euclidean distance along with that of topological distance on the basis of bipartite matrix proposed before by himself, and compare the distribution patterns of the two measures.(Batty 2004)

But this thought has been challenged continuously by several environmental psychologist who pointed out that human distance perception is influenced by change of visual information and/or relation to moving direction.(Montello 1992, Golledge 1995) Hillier and Iida introduced the concept of least length(Euclidean distance), fewest turns(topological distance), and least angle change(geometric distance) as a basis for identifying the shortest path in disaggregated line-network model, and then they analyzed actual urban street structure using it. As a result, they argued that pedestrian and vehicular movements are shaped far less by the cognitive properties such as metric/Euclidean distance than by the geometrical and topological properties as 'Network effect'.(Hillier & Iida 2005)

In the mean time, Turner applied Euclidean distance to ASA methodology in two different manners in his study. Firstly, he substituted the Euclidean distance between two centroid of a pair of adjacent line segments for the depth between them and calculated angular closeness and angular betweenness upon it. Secondly, he proposed lengths of origin segment and destination segment in a path as weights in calculating angular betweenness measure. This study reveals that the latter has more significance at predictability of actual movement pattern than the former. But the latter is only meaningful as reinforcement of angular betweenness measure, and it is not the case that Euclidean distance is introduced with its original meaning as movement cost.

3. Proposal of Angular/Cellular Visibility Graph Analysis

3.1. Meaning of Depth in Space Syntax field

As it is widely understood, Space Syntax is an analysis model based on graph/network structure. This applies not only to Space Syntax, but also to other models discussed in the previous chapter. That is, these models represent built-environments into graphs, which are then identified by attributes and interpreted following the steps presented by each model. Numerous indices have been developed to measure certain attributes of the graphs, most well known being concerned with centrality. In Space Syntax, indices such as integration (closeness centrality), choice (betweenness centrality) are used to quantify centrality, based on the shortest paths between any two given nodes. In order to measure the 'length' of a path, the concept of 'depth' is used. That is, the shortest path is defined as the path with the least amount of depth.

The understanding of 'depth' is critical in graph-based models. Further developments to the Space Syntax model are mostly based on reinterpretation and redefinition of depth. Directional change as angular depth was applied to Turner's several models and Dalton's Fractional Analysis model, and Euclidean distance as distance depth was applied to Hillier & Iida's model and ASA model. That is, these models are in fact variations of defining depth. This is because depth is the core index in quantifying the length of a path, where different definitions of the concept can lead to different shortest paths, thus different level of centralities of a node. The importance of depth can also be seen in studies where 'weighting' is applied. Weighting can be applied to a graph only via nodes or links. However, since nodes are meant to be extreme simplifications of space in most graph-based models, weighting nodes can be a contradiction to the initial intention. Therefore, weighting should be applied to links, which is what the aforementioned models are. This study also follows this protocol by attempting to introduce the human behavior into the definition of depth.

3.2. Angular Depth

As discussed in the previous chapter, studies dealing with the changes in movement direction were developed into the concept of angular depth. The ASA model applies this concept on a segmented axial map, addressing and overcoming problems that have surfaced in the studies that have lead to the model. However, there is a critical problem that is yet to be solved when applying angular depth on a segmented axial map. That is, the 'turning back' problem, where one, in the middle of his movement, changes direction 180° and retraces his/her steps. This is a very common event in human behavior, but a very difficult problem to be solved in several models based on angular depth.

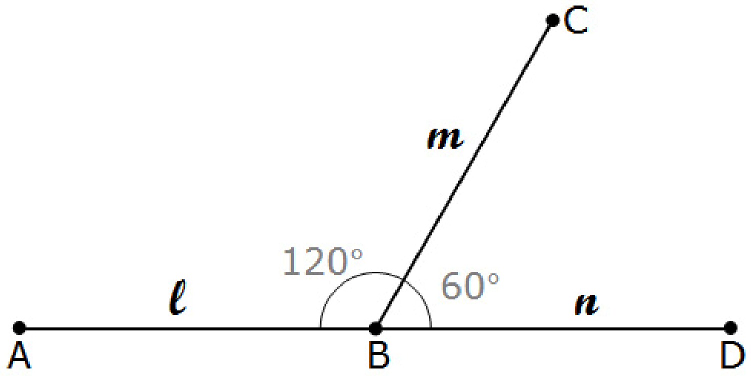


Figure 1

Take figure 1 for example. Shown in the illustration are three segments l, m, n, which have same lengths and intersect at point B. The segments meet at angles ∠ABC = 120°, ∠CBD = 60°, and ∠ABD = 180°. In this case, the shortest path between segment m and segment n, following the original definition in Space Syntax is *m→n*. Applying angular depth onto this path, depth between segment m and segment n is given as a function of the angle in which the movement direction changes, $f_{AD}(120°)$. Using Dalton's function, this is $2-\sin(2\pi/3)$ while Turner's function results in $2\pi/3$. However, when one moves from segment m to segment l, then finally to segment n, the total angular depth of the path is $f_{AD}(60°)+f_{AD}(0°)$, $\sin(\pi/3)+\sin 0=\sin(\pi/3)$ for Dalton's function and $\pi/3+0=\pi/3$ for Turner's. It is clear that these are smaller values compared to those from the path *m→n*, indicating that the shortest angular path is *m→l→n* and not *m→n*. Such contradiction occurs from different definitions of depth and shortest path. This is the 'turning back' problem, which will be abbreviated as the '_/_' problem in this paper, and is a critical problem of the angular depth concept.

To solve this problem, Turner has regulated that movements should be made so that one who entered in a line segment cannot exit to the entrance side of the line segment but to the other side.(Turner 2007) By applying this regulation, the turning back behavior is totally excluded from consideration. However, as mentioned before, this is a very common behavior and should not be disregarded.

It is also true that Turner had no other choice for the axial map and the segmented axial map themselves do not fully regard the human behavior in essence. That is, while there is a certain level of randomness in human behavior, the axial map essentially disregards the diversity in human behavior, such an original limitation that is inherited in the segmented axial map. Turner's solution should be seen as an attempt to keep the human behavior 'within reach' of the axial/segmented axial maps while overcoming the turning back problem.

It is clear that axial/segmented axial maps have limits in considering the human behavior. Therefore, this study will focus on the Grid Map, on which the VGA model is based. The Grid Map is less biased compared to the axial/segmented axial maps for each grid is merely a point on which one can potentially place oneself and visual linkage between two points represent individual movement, so it can reflect human movement behavior well.[1] With such advantages this study will explore a method that can apply angular depth directly onto the Grid Map. Such new method should allow the angular depth concept to fully consider the human behavior.

A study by Choi et al.(2007) has many implications considering angular depth. In their study of the Evacuation Cost Evaluation Model, angles of turns were used to evaluate the evacuation efficiency of a built environment. In this model, Evacuation Cost is quantified as the sum of Distance Cost and Visibility Cost, where Visibility Cost is the visual depth accompanied to the evacuation route. In the case of figure 2, the Visibility Cost of route A→D is $1+f_{AD}(\theta_2)+f_{AD}(\theta_3)$, where Visibility Cost function $f_{AD}(\theta)$ is of turning angle, very similar to and can be substituted by angular depth functions proposed by Turner and Dalton. The visual depth between points A and B is 1, assuming that switching from other activities to evacuation accompanies a Visual Cost equivalent to a right angle.

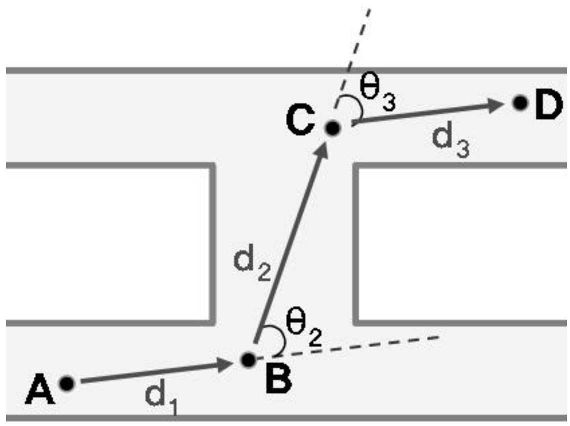


Figure 2

However, Visibility Cost should not be the solution to applying angular depth onto the Grid Map for the concepts of angular depth (from ASA model) and visual depth (from VGA model) are mixed unclearly in the Visibility Cost. That is, visual depth used in the VGA model is based on 'visual linkage' while angular depth used in the ASA model is based on 'directional change'; they are two different concepts. Most noticeable is that directional change is independent from visual linkage and occurs between two pairs of visual linkages. Strictly speaking, Visual Cost reflects directional change well and hardly regards visual linkage.

In the ASA model, which is based on the segmented axial map, this was not a problem for angular depth was a matter of directional change between two segments (nodes). In the Grid Map, however, grid points are nodes, meaning that directional change does not directly relate to the linkage between a pair of grid points(first-order), but to two adjacent linkages(second-order). Therefore, in order to quantify the depth of a path, visual depth (the cost for visual linkage) and angular depth (the cost for directional change) should be reflected clearly independent from each other. A method on how to distinguish the two concepts and quantify the total depth of a path will be presented through a new concept called 'sense of depth'.

In this study, sense of depth is the perceived depth when one moves from one node to another. In the ASA model, sense of depth occurs during a directional change between two linking segments and surely at a 'corner' or 'junction'. Before making the turn, one cannot sense the 'actual sense of depth' which will be sensed upon making the turn and can only sense the existence of a forthcoming turn. But there is still a certain amount of expectance before making the turn, which will be designated as 'expectative sense of depth'. Expectative sense of depth can be understood as potential depth which accompanies the speculation process that one will soon have to make a turn. Since movement is a sequential process, one cannot foresee the exact level of directional change but only expect 'an average turn'. Assuming that mankind is so accustomed to the rectangular coordinate system, 'an average turn' should in fact be a 90° turn. This also agrees to Dalton's angular depth function where a 90° turn is equivalent to one unit depth.

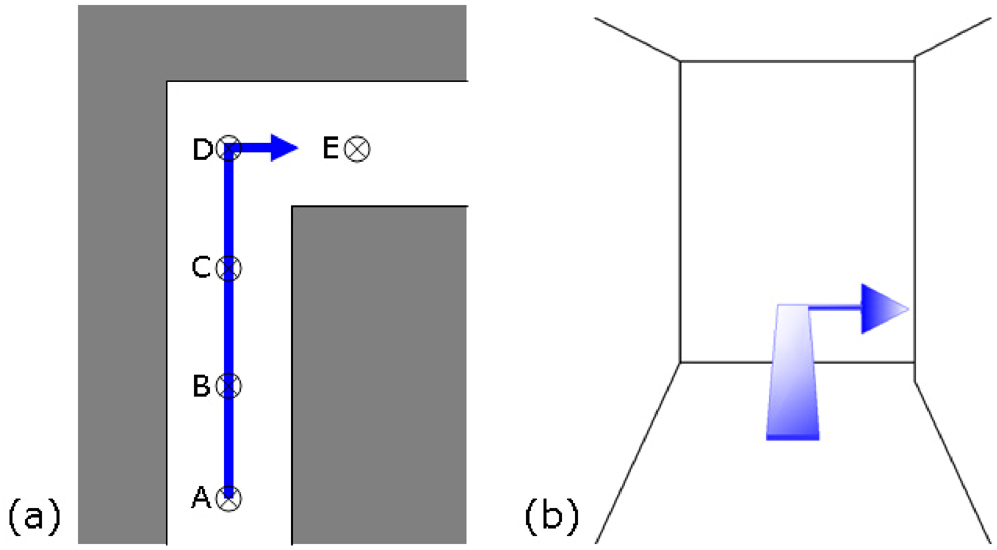


Figure 3

Let us now move on to the Grid Map, and discuss actual sense of depth and expectative sense of depth when applied to the Grid Map. In figure 3(a), point D is the 'corner' for the path A→B→C→D→E, meaning that actual sense of depth occurs when one changes directions there. This actual sense of depth is defined by the angular depth function of the turning angle at ∠ADE. Before making the turn, however, the actual sense of depth cannot be sensed; only the existence of a 90° (assumed) turn is sensed, resulting in an expectative sense of depth value of one. (Refer to figure 3(b).) Therefore, the actual sense of depth and expectative sense of depth for point D can be described as below.

$SD_A(D) = f(\angle ADE)$
$SD_E(D) = f(\pi/2)$
- SD_A : Actual Sense of Depth
- SD_E : Expectative Sense of Depth

The next point of discussion is how the cost of visual linkage, namely visual depth used in the VGA model can be interpreted for the sense of depth concept. Going back to figure 2, the visual depth between points B and C is affected by the directional change already made at point B for one must make a turn at point B that brings point C into his/her visual field in order to move from point B to point C, thus it should vary as the amount of directional change made at point B. The visual depth between the two points is also affected by the expected directional change at point C for one will have to prepare for the turn while moving between points B and C. Comprehensively, the visual depth between the two points consists of two elements, the actual sense of depth for corner B and the expectative sense of depth for corner C. This can be described as shown below.

$VD(B \rightarrow C) = f_{VD}(SD_A(B), SD_E(C))$
- VD : Visual Depth

In sum, angular depth (from ASA model) is equivalent to actual sense of depth while visual depth (from VGA model) is equivalent to a combination of actual and expectative sense of depth. The key point now is to numerically define the visual depth function. For the path A→B→C→D→E illustrated in figure 3(a), points B and C are disregarded in the VGA model for points A and D are directly linked. (Visual depth value for A→D is one unit depth.) The ASA model does regard points B and C, although their angular depths are naught for no directional change occurs. In other words, visual depth for A→B→C→D is one unit depth as well. This discussion can be described as shown below to reach a meaningful conclusion.

$$VD(B \rightarrow C) = VD(C \rightarrow D) = 0$$

According to the definition of visual depth in the VGA model,

$$VD(A \rightarrow D) = 1$$

Therefore,

$$VD(A \rightarrow D) = VD(A \rightarrow B) + VD(B \rightarrow C) + VD(C \rightarrow D) = 1$$
$$VD(A \rightarrow B) = 1$$

That is,

$$VD(A \rightarrow B) = f_{VD}(SD_A(A), SD_E(B)) = 1$$
$$VD(B \rightarrow C) = f_{VD}(SD_A(B), SD_E(C)) = 0$$
$$VD(C \rightarrow D) = f_{VD}(SD_A(C), SD_E(D)) = 0$$

Since $SD_E(□P) = 1,\ SD_A(B) = SD_A(C) = 0$, we will define the visual depth function by multiplying the two independent variables. By assuming that the actual sense of depth at point A, the starting point is one, the formulae retain consistency. This can be described as shown below.

$$VD(A \rightarrow B) = f_{VD}(SD_A(A), SD_E(B)) = SD_A(A) \times SD_E(B) = 1 \times 1 = 1$$
$$VD(B \rightarrow C) = f_{VD}(SD_A(B), SD_E(C)) = SD_A(B) \times SD_E(C) = 0 \times 1 = 0$$
$$VD(C \rightarrow D) = f_{VD}(SD_A(C), SD_E(D)) = SD_A(C) \times SD_E(D) = 0 \times 1 = 0$$

For the actual sense of depth at the starting point, the assumption used in the Evacuation Cost Evaluation Model was brought in. That is the behavioral cost to switch from other activities to the initial movement is equivalent to a 90° angle of turn. Therefore, visual depth weighted by angular depth on the Grid Map can be described as shown below. In this study, to avoid confusion with visual depth (from the VGA model), this will be designated as 'angular depth on the Grid Map'.

$$AD(P \rightarrow Q) = SD_A(P) \times SD_E(Q)\ (□P, □Q)$$
$$SD_A(P) = f(\theta_P)$$
$$SD_E(Q) = f(\pi/2) = 1$$

- AD : Angular Depth
- θ_P : turning angle at corner P

In the above formula, either Turner's or Dalton's function can be used for $f(\theta_P)$. Angular depth on the Grid Map remains valid for the VGA model by locking the actual sense of depth to one (no angular depth weighting). That is, since expectative sense of depth is, by definition, one, the product of the two variables will always be one, as is the case in the VGA model. Furthermore, according to angular depth on the Grid Map, the number of points along the movement path without turns (such as points B and C in figure 3(a)) do not affect the depth of the path, thus fully inheriting the angular depth concept of the ASA model. Like the word 'splitting any line in the system makes no difference to the angular mean depth of any line in the system'(Turner 2001), putting any more point between two points makes no difference to the angular mean depth of any point in the system.

Most important is that angular depth on the Grid Map solves the _/_ problem mentioned already. For example, take the shortest path between points C and D in figure 1. Dalton's angular depth function will be used for $f(\theta_P)$.

Angular depth for path C→B→D is:

$$AD(C \rightarrow D) = SD_A(C) \times SD_E(B) + SD_A(B) \times SD_E(D)$$
$$= f(\pi/2) \times 1 + f(2\pi/3) \times 1 = 1 \times 1 + (2 - \sin(2\pi/3)) \times 1 = 3 - \sin(2\pi/3)$$

Angular depth for path C→B→A→B→D is:

$$AD(C \rightarrow D) = SD_A(C) \times SD_E(B) + SD_A(B) \times SD_E(A) + SD_A(A) \times SD_E(B) + SD_A(B) \times SD_E(D)$$
$$= f(\pi/2)\times 1 + f(\pi/3)\times 1 + f(\pi)\times 1 + f(0)\times 1 = 1\times 1 + \sin(\pi/3)\times 1 + 2\times 1 + 0\times 1 = 3+\sin(\pi/3)$$

Therefore, C→B→D is indeed the shortest path, solving the _/_ problem with reasonable result. While previous models such as the ASA model failed to quantify the cost of turning back because of the lack of theoretical instrument covering it, newly proposed method does reflect the cost of turning back successfully with angular depth on the Grid Map.

In this paper, graph-based spatial analysis methodology introducing angular depth onto the Grid Map will be designated as 'Angular VGA'. It can be expected that the Angular VGA model solves the problems of the previous models while reflecting the human behavior to a better level.

3.3. Unit Distance

As discussed in the previous chapter, many attempts have been made to introduce Euclidean distance into graph-based spatial analysis models, though their effectiveness is questioned. Euclidean distance is rather seen as inappropriate compared to topological depth when interpreting behavioral characteristics within a built environment. However, since Euclidean distance is not completely independent from human behavior, it should not be disregarded.

This dilemma rises from the inappropriate approaches taken in the previous studies. That is, previous studies were mainly focused on the depth of a path, considering Euclidean distance by simply taking in the distance variables without any reproduction. Considering the graph theory has its roots in the seven bridges of the town of Königsberg, it is reasonable that Euclidean distance is used as a scale for quantifying depth. However, as Batty(2004) has pointed out, in the dual problem where axial lines become nodes, Euclidean distance can hardly be considered. The most critical error is, however, that such attempts handle Euclidean distance and topological depth in the same dimension. In the primal problem, it is reasonable that Euclidean distance becomes the depth of link. However, as spatial analysis developed based on the dual problem, the concept of depth of link has moved on from Euclidean distance to topological depth. So, it doesn't make sense to consider Euclidean distance as depth of link in the dual problem, where Euclidean distance is rather embedded in the nodes (axial lines) while the uniform treatment of axial lines sterilizes the effects of Euclidean distance.

Therefore, Euclidean distance should be approached from a different direction. If the idea of Euclidean distance is embedded in an axial line, two kinds of approaches seem possible. First is to see Euclidean distance as a critical independent variable and apply either its length or distance between two points where the axial line intersects with neighboring axial lines into the graph system. However, the uniform treatment of axial lines does not allow such an approach. The second is to see Euclidean distance as a bias and remove this bias by leveling off the Euclidean distance variable of axial lines. Similar to the segmented axial map limiting the number of intersecting points of an axial line to less than two, all axial lines have the same length. However, in reality, this is impossible unless the space follows a strict grid pattern.

For the Grid Map, however, the latter is possible. Since the Grid Map itself is an array of grid points at regular intervals, distances between two neighboring grid points are always the same. By limiting visual linkage to neighboring grids, Euclidean distance is leveled off and the bias can be successfully dealt with. This reminds us of the Neighborhood concept used in the Cellular Automata model (CA model). In this study, a new grid layout method is established to completely standardize the Euclidean distance between two neighboring grid points. The Von Neumann Neighborhood and the Moore Neighborhood, shown in figure 4, are the most commonly used Neighborhood types in the CA model.

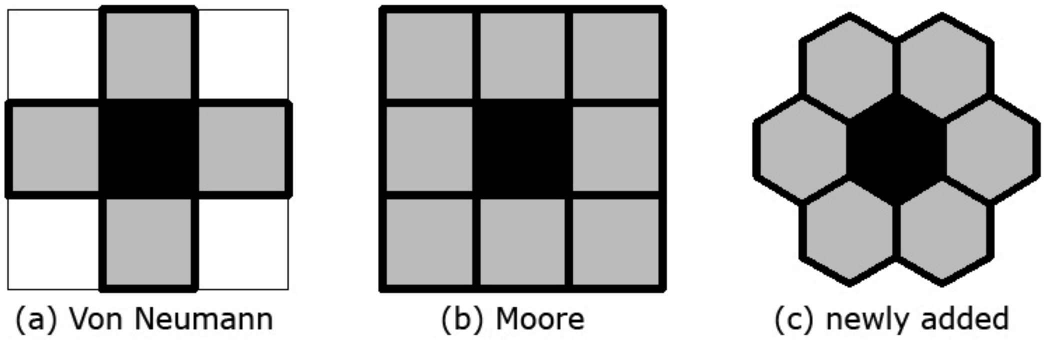


Figure 4
((a),(b) from Batty(2005), reproduced)

The Von Neumann Neighborhood only regards the four cells that linearly border the core cell as neighboring cells while the Moore Neighborhood also considers the four cells that border the core cell only at one point. In the Moore Neighborhood, there is a difference in the distances between the core cell and the linearly bordering cells against the core cell and the cells that are diagonal to the core cell. The Von Neumann Neighborhood and the Moore Neighborhood differ in diffusion patterns reflecting the form of the underlying grid (Batty 2005, p.78). In this study, a new 'Beehive Neighborhood' where all neighboring cells have the same distance and has a near-circular diffusion pattern is suggested. By applying this 'Beehive Neighborhood' onto the Grid Map, it is possible to generate Visibility Graphs where Euclidean distance is completely controlled.

In this paper, graph-based spatial analysis methodology introducing Neighborhood onto the Grid Map will be designated as 'Cellular VGA'. It can be expected that the Cellular VGA model overcomes the primitive treatment of Euclidean distance and reflects the already-embedded Euclidean distance in the model into spatial analysis.

4. Verification

The two spatial analysis methodologies were proposed in the previous section, Angular VGA applying the concept of angular depth to Grid Map and Cellular VGA applying the Neighborhood concept of Cellular Automata model to Grid Map. In this section, verification of the capability and usability of newly proposed methodologies is performed by analyzing an actual museum building with those methodologies. For this work of analysis, analysis software was newly developed[2] and The National Folk Museum located at Samcheong-dong, Seoul was selected as the subject for the analysis. The museum has a common open plan layout, and the major exhibition halls are all situated on the ground level so that most of the visitors' activities occur on the single ground floor. figure 5 shows the first floor plan of the museum. The lobby connects to the rectangle shaped central passage circumscribing the Special theme exhibition hall, which successively connects to the other three exhibition halls.

The following three methodologies were applied to the subject museum and the analysis results were compared for the verification of Angular VGA: the original VGA not applying the concept of angular depth, and Angular VGAs each adopting Turner's and Dalton's functions for applying angular depth. Also, for the verification of Cellular VGA, the following four methodologies were applied to the subject museum and the analysis results were compared: the original VGA not applying the Neighborhood concept, and Cellular VGAs each applying Von Neumann Neighborhood, Moore Neighborhood, and Beehive Neighborhood.

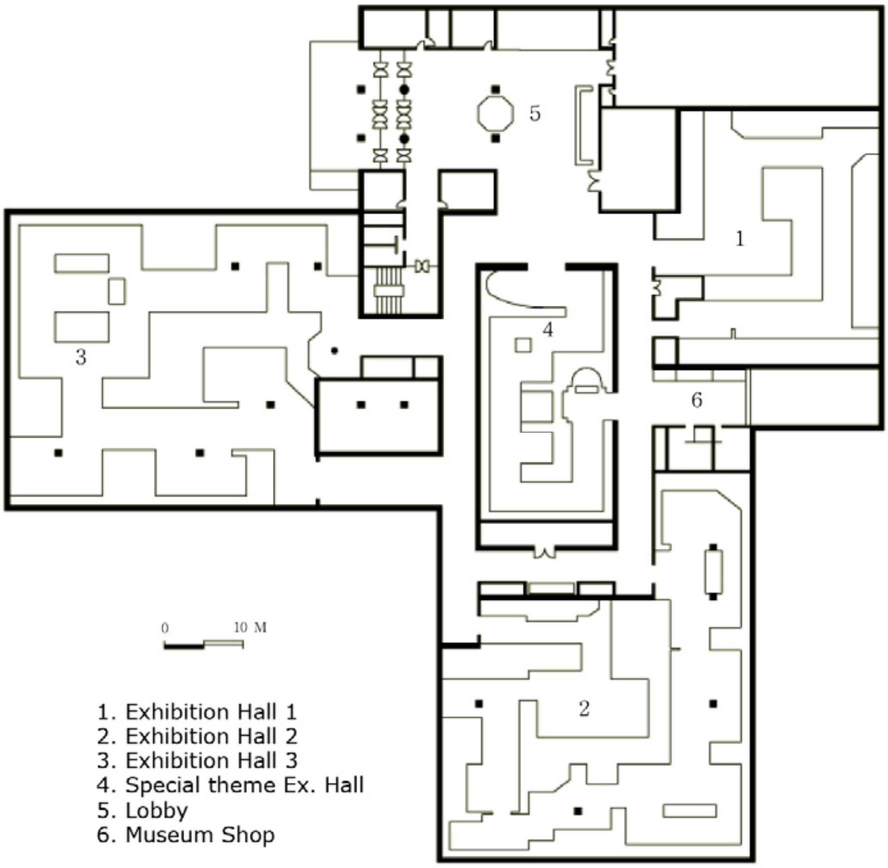


Figure 5
Plan of The National Folk Museum of Korea

(a) Not Cellular	R^2 of Closeness Centrality	R^2 of Betweenness Centrality
Original vs. Angular (Turner)	0.7520	0.0968
Original vs. Angular (Dalton)	0.8322	0.1913
Angular (Turner) vs. Angular (Dalton)	0.9786	0.6966

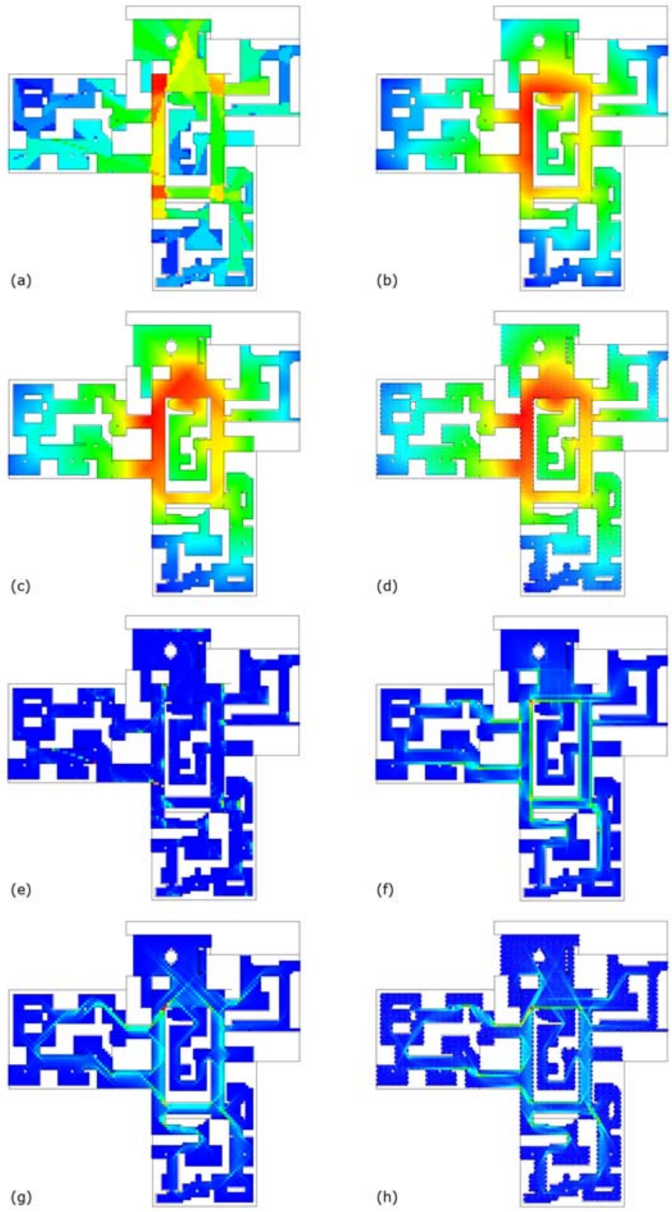
(b) Honeycomb Neighborhood	R^2 of Closeness Centrality	R^2 of Betweenness Centrality
Original vs. Angular (Turner)	0.5745	0.5390
Original vs. Angular (Dalton)	0.5765	0.5332
Angular (Turner) vs. Angular (Dalton)	0.9754	0.9971

Table 1
Correlation results for Angular VGA

Table 1 shows the correlation results of the Closeness Centrality and Betweenness Centrality indexes for the three tested Angular VGA methodologies.

Table 1(a) shows the cases not applying Neighborhood, Table 1(b) the cases applying Beehive Neighborhood. As for the cases not applying Neighborhood, strong correlations are found in the Closeness index distributions among the three methodologies, while the correlations in the Betweenness index distributions among the three methodologies can hardly be found as the differences in distribution were very large. Considering these results, the validity of the Angular VGA methodologies can be doubted in terms of Betweenness. However, this cannot be judged too early as we consider that there are almost no studies examining the significances of the Betweenness index or applications of it for the existing VGA methodologies. On the other hand, in the cases applying Beehive

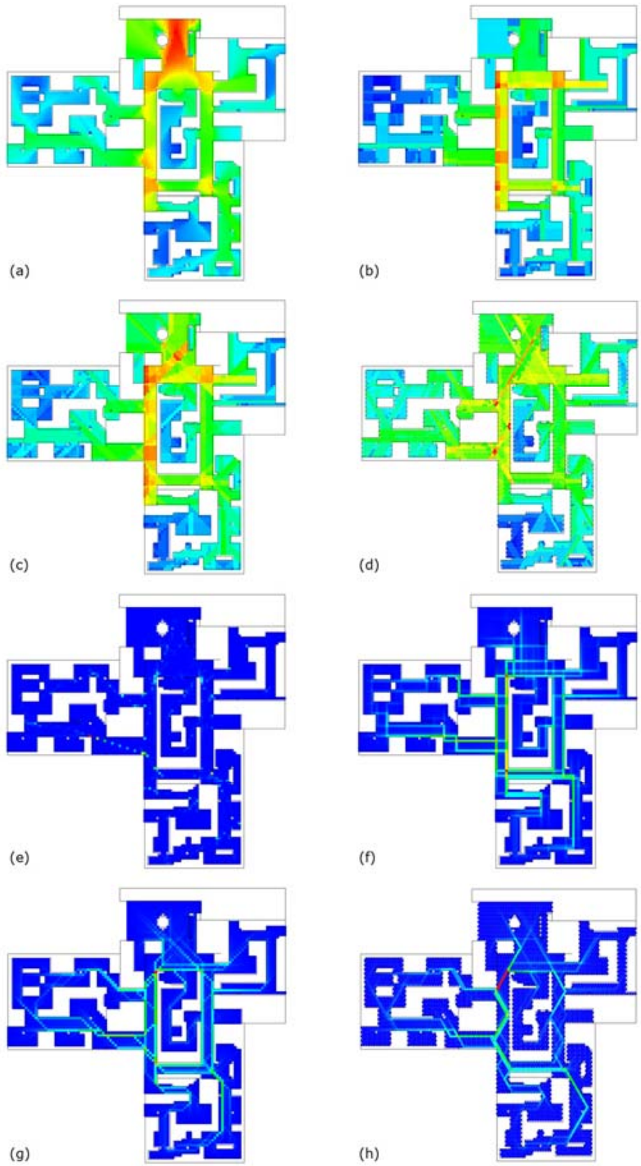
Neighborhood, quite significant correlations are found in the Closeness index distributions among the three methodologies although they are rather weak compared to those in the cases not applying Neighborhood, and stronger correlations are found in the Betweenness index distributions among the three methodologies than in the cases not applying Neighborhood. The similar results are observed when applying Von Neumann Neighborhood and Moore Neighborhood. Putting these results together, it can be concluded that the significance of the Betweenness index in Angular VGA can be improved when the Neighborhood concept is applied together with it. Also, as the analysis results for applying Turner's and Dalton's functions have no significant difference from each other, the results for Angular VGA applying Dalton's function will be solely discussed from now on.



Result of Cellular VGA
(a)(b)(c)(d): Closeness distribution,
(e)(f)(g)(h): Betweenness distribution,
(a)(e): Not Cellular
(b)(f): Von Neumann Neighborhood
(c)(g): Moore Neighborhood
(d)(h): Beehive Neighborhood

Figure 6

Figure 6 shows the analyzed patterns of the Closeness Centrality and Betweenness Centrality indexes for the four tested Cellular methodologies (Correlation analysis is not applicable here as the grid system of Beehive Neighborhood differs from those of others). As for the Closeness index, the analyzed patterns for the three Cellular methodologies except for the cases not applying Neighborhood all showed similar results. This leads to the conclusion that each Neighborhood method has almost the same effect on deciding the pattern of the Closeness Centrality index. However, the patterns of Betweenness for the four methodologies all emerged different from one another. The interesting part is that the Von Neumann Neighborhood cases show clear patterns in horizontal/vertical directions, the Moore Neighborhood cases in diagonal directions, and the Beehive Neighborhood cases in 60° directions. These result from the properties of each Neighborhood concept that decides the diffusion pattern of it.



Result of Cellular & Angular VGA
(a)(b)(c)(d): Closeness distribution,
(e)(f)(g)(h): Betweenness distribution,
(a)(e): Not Cellular
(b)(f): Von Neumann Neighborhood
(c)(g): Moore Neighborhood
(d)(h): Beehive Neighborhood

Figure 7

Figure 7 shows the analyzed patterns of the Closeness Centrality and Betweenness Centrality indexes for the four tested Cellular methodologies applied also with Angular VGA (Dalton's function). The four results for the Closeness index show different patterns from one another, unlike in figure 6. As mentioned above, these result from the properties of each Neighborhood concept deciding the diffusion pattern. Similar results are observed in the Betweenness index cases.
Now let's compare the analysis results for the Closeness index patterns in figure 6 and figure 7. In figure 6, all the results except for the cases not applying Neighborhood show similar figures, the diffusion patterns starting from the central rectangular main passage of the museum and spreading out to each exhibition hall. In other words, the Neighborhood diffusion pattern is overwhelmed by the diffusion effect of Euclidean distance. However, in figure 7, the four results clearly display the different diffusion patterns of each Neighborhood, which evidently differs from the simple diffusion pattern spreading out from the main passage. The diffusion pattern of each Neighborhood is now revealed with its own properties. In this respect, it can be concluded that the

significance of Cellular VGA is improved when it is applied with Angular VGA, that is, the concept of angular depth. This fact also corresponds to the interpretation results of table 1. In other words, the concept of angular depth helps overcoming the problem of the Neighborhood concept that it can possibly be overwhelmed by the diffusion effect of Euclidean distance, and the Neighborhood concept offsets the unrealistic assumption of angular depth, the 'distance-free' approach.

5. Conclusion

It comes through in this study that the conceptual properties and problems of existing Spatial Analysis methodologies were examined in terms of human movement behavior, and Angular VGA and Cellular VGA based on Grid Map of the VGA methodology are proposed in order to overcome the problems of the existing methodologies. The newly proposed methodologies were applied to the actual built environment to find out that the significances of Angular VGA and Cellular VGA are improved when they are applied together. This relationship between the two is similar to that of angular depth and segment line in the ASA methodology. As the concept of angular depth came to be integrated with the concept of segmented axial map through angular analysis and fractional analysis and eventually set up as the ASA methodology, the proposed angular depth applied in Grid Map in this study needs to be integrated with the Cellular/Neighborhood concept in order to be set up as a significant spatial analysis methodology.

The newly proposed Angular VGA and Cellular VGA were verified only in terms of capability and usability in this study, and the validity study of them through the comparison with the actual movement pattern or the examination of the significance of them through the comparison with the existing spatial analysis methodologies were not done. These verifications need to be conducted in further studies. Also, the methodologies need to be applied to more various built environments in order to widen the capabilities of them and to further develop them.

Notes

1 Angular Analysis methodology is originally proposed with applying the concept of angular depth onto VGA methodology. However, Angular Analysis methodology is based on segmented axial map which is generated through second-order representation from original grid map. Therefore, Angular Analysis methodology is identical to Axial Segment Analysis methodology in terms of the form of ultimate representation.

2 This software was developed as AutoCAD 3rd-Party Application using ARX technology. Application file and manual are available at the following location. http://ladonara.blogspot.com/2009/03/savisibility-v20.html

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