# USING SPACE SYNTAX TO UNDERSTAND KNOWLEDGE ACQUISITION AND WAYFINDING IN INDOOR ENVIRONMENTS

Rui Li

*GeoVISTA Center, Department of Geography*
*The Pennsylvania State University*
rui.li@psu.edu

Alexander Klippel

*GeoVISTA Center, Department of Geography*
*The Pennsylvania State University*
klippel@psu.edu

## Abstract

*It is critical to understand how characteristics of environment influence human acquisition of spatial knowledge and wayfinding behaviors. The understanding provides insights for designing cognitively ergonomic wayfinding aids. Space syntax has been increasingly used in applications such as formal descriptions of environments and predicating wayfinding behaviors. From the perspective of cognitive geography, we review two popularly used methods of space syntax and relate them to the legibility of the environment. That is, how the elements of the environment aid the acquisition of spatial knowledge. The five elements of built environments in cognitive maps and the legibility of the environment are used as the theoretical frame to review each method. An exploratory behavioral experiment is designed to validate the formal descriptions produced by space syntax. Results indicate that different methods of space syntax have specific strengths on understanding knowledge acquisition and wayfinding behaviors in environment. Further directions of improving space syntax are also discussed.*

***Keywords:*** *Space syntax, legibility, knowledge acquisition, wayfinding*

## 1. INTRODUCTION

Wayfinding behaviors are the interactions between human and the environment. Designing cognitively ergonomic wayfinding aids has the promising benefits to facilitate acquisition of environmental knowledge and wayfinding performances. Therefore the two interactive parts involved in wayfinding are the focus of current wayfinding research. Individual differences characterized by human's familiarity, age, sex, or spatial abilities are factors from human on one hand. On the other hand, environmental characteristics play an important role on influencing wayfinding behaviors as well. Efforts from perspectives such as architecture, urban design, behavioral geography, environmental psychology, and computer science have contributed to advancing the understanding of wayfinding.

How environmental characteristics influence knowledge acquisition and wayfinding behaviors is among the top research questions. Legibility of built environments indicates how characteristics of an environment differently contribute to the development of knowledge acquisition [1]. O'Neill suggested legibility as "the degree to which the designed features of the environment aid people in creating an effective […] cognitive map of the spatial relationships within a building, and the subsequent ease of wayfinding within the environment" [2, p. 259]. Weisman [3] suggested a model of legibility: differentiation of environment, layout complexity, visual access, and signs. Later Gärling *et al.* [4] refined this model by considering signage as an independent influential factor [4]. The acquired elements of environments —paths, edges, districts, nodes, and landmarks [1]— reflects the legibility of the environment. Characteristics of environment are suggested to relate to wayfinding behaviors in many studies [5-9]. In this study, we review two popularly used methods of space syntax based on environmental characteristics they represent and their role in understanding human knowledge acquisition and wayfinding behaviors. The legibility and elements of environment are used as the theoretical frame to compare between methods. We carried out a small behavioral experiment to validate the outcomes of space syntax.

## 2. LEGIBILITY OF ENVIRONEMNT

The environment itself is a major factor that leads to different wayfinding behaviors. Different aspects of the physical environment are found to be related to the legibility of an environment. A brief introduction of each aspect is given below.

First, the *degree of differentiation* affects human's ability to recognize environments. For example, the degrees to which different parts of an environment look different or which objects in an environment make the environment more or less recognizable. The differentiation of environments can be the result of varying size and shape of environment or architectural style [10], or using salient landmarks to specify an environment.

Second, *visual access* refers to which different parts of the environment can be seen from a vantage point. If parts of the environment are visible from different vantage points, the

learning of the parts is easier. Maintenance of orientation during the execution of a travel plan can be facilitated if visual access is greater between origin and destination. Empirical evidence indicating that visual access facilitates spatial orientation and wayfinding (i.e. [11]).

Third, *complexity of the spatial layout* is one important aspect to understand wayfinding behavior [12]. Although complexity of layout is difficult to define concisely, it is determined by the environmental size, the number of possible choices of routes in environment, and whether the routes intersect at right angles or not. A simple layout can facilitate both the formation and execution of travel plans by making it easier to choose destinations and routes, maintain orientation, and understand the environment [10]. The complexity of spatial layouts seems to be associated with the visual access. It is also likely that an environment of lower layout complexity is associated with higher visual access. Overall, understanding the influences of different aspects of environments is crucial to reveal how they influence the legibility of environment and the subsequent wayfinding behaviors.

## 3. SPACE SYNTAX

Space syntax is used to provide formal descriptions of built environments. These descriptions can be used to understand wayfinding behaviors. Originally this method was used in urban planning and social theory to relate urban morphology with social movement. The use of space syntax in research of wayfinding behaviors can be characterized as "one of representing and quantifying aspects of the built environment and then using these as the independent variables in a statistical analysis of observed behavior pattern"[14, p. 34]. Different methods of space syntax have been introduced to meet specific needs. The most popularly used space syntax methods include isovists [15], Visibility Graph Analysis (VGA) [16] and Inter Connection Density (ICD). Isovists address the visual access a person has at one location in the environment. VGA, which uses the similar concept, represents the visual access of the whole environment at a time. ICD addresses the density of connectivity characterized by the number of nodes and the connections all nodes posses. Detailed reviews of these methods will be given in the third section.

Space syntax has demonstrated its roles on interpreting wayfinding behaviors. One of its roles is correlating environmental characteristics with wayfinders' spatial preferences. For example, using isovists, Wiener and Franz [17] suggested the efficiency of using isovists on predicting the best overview or hiding place in an environment as the preference is directly related to visibility in the environment. Another role space syntax plays is to understand wayfinding strategies in an unfamiliar environment. Hölscher et al. [18] derived the values of connectivity and integrity from space syntax and found that wayfinders were inclined to walk in areas whose connectivity of routes and visibility are higher.

In general, space syntax provides formal descriptions through quantitative methods and indicates spatial intelligibility of a space which is "the property of the space that allows a situated or immersed observer to understand it

in such a way as to be able to find his or her way around it" [19, p. 26]. In the following sections, the formal descriptions of two popular methods of space syntax will be introduced first. And a behavioral experiment will follow to validate the merits of each method.

## 4. FORMAL DESCRIPTIONS OF ENVIRONMENT

Different methods are widely used in space syntax [19]. Elements of built environments represented in cognitive maps—nodes, paths, edges, districts and landmarks [1]—are the most used characteristics of environment in formal descriptions. In this section, two popular methods of space syntax are reviewed regarding their contributions to the understanding of wayfinding behaviors in environments. At first, a short introduction of each method will be given. In the review of each method, the elements of environments and their strengths of understanding wayfinding behaviors will be used as the main frame. Output of using each method to formally describe one of our experimental sites will be given in each review.

### 4.1 Inter connection density (ICD)

Nodes and the connectivity between them on a floor are considered to be important factors that influence the development of spatial knowledge and wayfinding strategies. Nodes are considered points in the environment where wayfinding decisions such as turns are made. ICD represents the mean number of connectivity of all nodes in an environment [2]. Particularly, intersections in an environment which have more than two options of directional changes are considered as nodes. The number of connections to other nodes from each node is considered as the connectivity. Finally, the value calculated in ICD shows the mean connectivity of all nodes in an environment by dividing the total number of connectivity on total number of nodes.

ICD is a measure of the layout complexity of an environment. The original purpose of developing the measure of ICD was to understand the influence of complexity of topological configuration on the legibility of an environment. In O'Neil's study (1991), it was suggested that the legibility of an environment mediated the development of cognitive maps, which influenced wayfinding behaviors. According to the elements of environments represented in cognitive maps (Lynch, 1960); nodes are the elements considered in ICD.

The method of ICD is an effective description of complexity of a floor plan resulting from topology. It has been suggested that topological complexity of an environment plays an important role on the ease of developing cognitive maps. The reason assumed is that topological relationships are the knowledge acquired by

wayfinders before they perceive other information such as distance or direction [2]. Hence it could be considered as an important evaluation for estimating wayfinding behaviors of novices in an environment. However, ICD is not as effective to address complexity resulting from geometry. It has been pointed out that the development of cognitive maps is not only affected by the topological complexities but also geometric complexity. Studies suggest that floors can have the same topological complexity but different geometric complexity leading to differences in acquiring spatial knowledge [20] and wayfinding performances [21]. In short, the effectiveness of using ICD should be carefully justified because an environment with extremely irregular floor plans can result in dramatic differences in geometric complexity, which is not reflected in ICD.

It is of importance to point out that one aspect of the floor plan was neglected in the ICD method. In its original concept, library floors were chosen as the experimental sites to testify this measure. The rationale of choosing nodes for ICD was the decision points in the environment that only main hall ways were considered. However, in a library setting the aisle shaped by two nearby stacks forms a path for wayfinders. The end of aisles is an important decision point to wayfinders when they have to locate a certain library item. Hence we suggest nodes and connectivity formed by the book stacks should be considered in calculating the ICD for libraries. In the example of assessing a library area (Central Stacks) at the Penn State campus, all possible paths that would be walked by a user of the library are considered in calculating ICD (Figure 1).
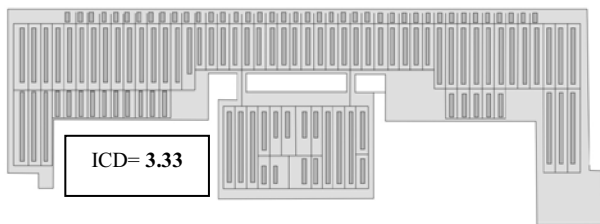


**Fig. 1.** Connectivity of nodes and ICD of a library floor.

In sum, ICD indicates the mean connectivity formed by the number of nodes and the connectivity between these nodes. Its original purpose is to correlate the topological complexity of a built environment with ease of developing cognitive maps. It has also been used to assess the design of built environment for evacuation [22]. Overall, the topological complexity represented in ICD is a key component of the layout complexity that influences the legibility of the built environment. It has been pointed out, though, that the geometrical complexity has a role on the influence of legibility [23]. That is to say, when using ICD to evaluate a built environment, the geometry of the environment should be taken into consideration first, especially if multiple environments are being assessed. ICD can be used effectively to convey the topological complexity

underlying the built environments possessing similar geometrical complexities. Furthermore, even though ICD uses nodes and the connectivity to perform assessment of the layout complexity, other aspects of legibility such as differentiation of environment and visual access are overlooked in this measure. If a research purpose is to evaluate the legibility of a built environment comprehensively, supplemental methods should be used to address the other two aspects.

## 4.2 Visibility graph analysis (VGA)

Visual access is identified as a critical factor of affecting the legibility of environments. Isovists were introduced first to indicate human's visual access restrained by the boundaries of the environment. An isovist is the shape of space that a person can perceive in his/her vision at a location in the environment considered [15]. Isovists are an intuitive way to represent the environment with regards to wayfinding. Isovists are implemented to represent only one location at a time using the visual convex constrained by the boundaries and vision that a person can reach. Consequently, VGA [16] extended the representation of isovists to mutually all visible locations of the environment. In the output of VGA in Figure 2 (contact the author for color image), locations of different degrees of visual access are shown [14].
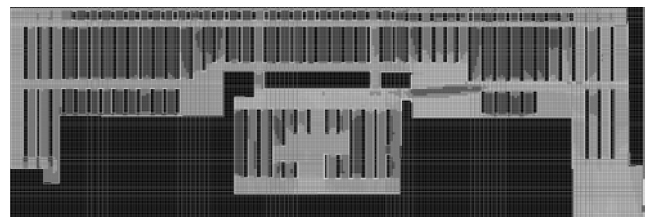


**Fig. 2.** Visibility Graph Analysis of a library floor. Areas in red and orange represent good visibility and areas in blue and purple represent poor visibility.

The strength of VGA is to correlate the visual access of an environment with human preferences of spatial experiences. As visual access is identified as a critical factor of affecting the legibility of environments, the difficulty of acquiring spatial knowledge at locations of low visibility will likely be greater. However, if the spatial task is related to wayfinding, isovists will be questionable because cognitive processes underlying wayfinding do not only relate to the visual access but also relate to locations where wayfinding decisions are made [24].

VGA represents a couple elements of environment represented in cognitive maps that are essential to the development of the spatial knowledge. First, the areas where vision reaches represent the areas that this person can access. Second, the restrictions provided by the walls which influence the visibility can be considered as boundaries.

VGA has been used in studies to verify the relationship between visual access of environments and wayfinding behaviors [7].

VGA is demonstrated to be efficient correlating visibility and general spatial experiences in the environment. However studies showed also challenges of using VGA to correlate visibility and locations in environment where orientation is performed. Orientation is an important step of using cognitive maps for route planning and executing in wayfinding behaviors [25]. Davies *et al.* [24] tested using VGA and behavioral experiments to evaluate wayfinders' estimations of orientation. The results showed the shortcomings of using visibility to predict accuracy of orientation. In the experiment, signs were more favored to be selected to indicate locations for orientation. Additionally, the study was done in a desktop environment, which has limitation of explaining human behavior in real world. A following study is necessary to investigate the effectiveness and challenges of using visibility and people's real-world wayfinding behaviors.

In sum, VGA offers effective assessments of visual access in a built environment. However, while the visual access is represented by VGA, the topological relationship is overlooked in this method compared to the previous method. It seems that VGA is primarily effective at providing overall visibility of decision points and at predicting general preferences of locations. Using VGA to investigate wayfinding behaviors should be complemented by measures that address other characteristics of environment that have influences on wayfinding, too.

## 5. BEHAVIORAL EXPERIMENT

In order to validate the relationship that space syntax can establish between environment and wayfinding behaviors. Space syntax provides formal descriptions based on different characteristics of environments. In previous section, two different methods of space syntax were introduced to characterize their strengths and challenges. The exploratory behavioral experiment was carried out to compare the differences between what these methods reveal and to relate them to wayfinding behaviors. In this pilot study, eight participants were recruited to perform a series of wayfinding tasks. The university libraries at the authors' campus have three different areas and are complained by users that they were very easy to get lost inside. With the consideration of individual difference in mind, two groups of the participants were formed based on their familiarity. Four of them had limited experiences with the library areas and the other 4 had never been to the library before the experiments were carried out. Each participant was asked to locate 2 books in each of the three library areas (Paterno Library, Central Stacks, and West Pattee). At the end of finding books in each area, the participant was asked to give a horizontal estimation of direction to the main reference desk. The whole procedure of locating books were videotaped and later digitized to obtain the distance and time each participant took in each task.

VGA and ICD used in this study show distinct characteristics of the environment: VGA mainly addresses on the visual access of the environment, and the ICD emphasized the layout complexity which is represented by the number of connectivity and the number of nodes in the environment. A summary of two formal descriptions is summarized in Table 1. Generally, the Central Stacks show the lowest visibility and the highest ICD. The Paterno Library has the second highest ICD and high visibility. West Pattee has the lowest ICD but also very high visibility.

**Table 1.** ICD and VGA summaries of three libraray areas

| Formal Descriptions | Paterno Library | Central Stacks | West Pattee |
|---|---|---|---|
| **ICD** (density) | **3.21** | **3.33** | **2.84** |
| **VGA**(visibility) | **High(319)** | **Low (80)** | **High (293)** |

Several measures of participants are considered to represent their wayfinding performances in this experiment. These measures include the time participants spend on locating books in each area, additional distances walked by participants compared to the shortest route, and errors in directional estimations. The wayfinding performances of participants were categorized into two groups depending on their familiarity with the environments. These results are shown in Table 2.

**Table 2.** Wayfinding performances in each area by groups

| | Familiarity | Paterno Library | Central Stacks | West Pattee |
|---|---|---|---|---|
| **Time** | Limited | **9.80** | **14.08** | **7.96** |
| (min) | No | **16.66** | **14.30** | **13.38** |
| **Distance** | Limited | **132.24** | **179.95** | **144.11** |
| (m) | No | **179.45** | **217.60** | **142.07** |
| **Estimation** | Limited | **45.00** | **70.00** | **23.75** |
| **Errors** ($^{o}$) | No | **78.75** | **75.00** | **95.00** |

The formal descripts produced by both space syntax mehtods address different aspects of participant' performances. First of all, the values ICD produced seem to corrleate positively with the time participants spent in each area. Specifically, regardless of familiarity, participants spent least time in the area whose ICD is the lowest. One noticable finding is that the familiarity and high ICD have an intervened impact on wayfinding time. Second, the results VGA produced seem to be related positively with the distances that participants additional walked in each library area. For example, the longest additional distances were walked by participants in Central Stacks (lowest visibility) regardless their familiarity. Third, the directinal estimations do not represent a simple relatioship with outcomes of both methods. The directional estimations made by group who

had limited familiarity are related to the results VGA produced. However, to the group who has no familarity to the library, the area with lowest VGA is related to the lowest errors of estimation while the lowest ICD is related to the highest error of estimation.

It is important to point out that the degrees of influences on wayfinding from individual familiarity and layout complexity are not constant. The time and the distances took by participants were longer in the Central Stacks compared to the other two library areas. The pointing errors also imply that the Central Stacks did have more difficulty to participants at estimating their spatial orientation. The layout complexity of the Central Stacks played a much more important role than participants' familiarities. However, in the Paterno Library and West Pattee where the layout complexity was comparatively low, the familiarity of the environment plays a more important role than the layout complexity. This finding contradicts earlier findings in which familiarity was suggested to play a more important role on wayfinding performance than layout complexity [26]. Further assessments are necessary to clarify the intervened influences of layout complexity and familiarity of wayfinders on wayfinding behaviors.

In sum, it is important to acknowledge that individual differences (i.e. familiarity) have an influence on wayfinding behavior. Additionally, the role that environments play on impacting wayfinding should not be overlooked either. Through the observations of the selected formal descriptions of environments and designed wayfinding experiments, the differences between methods are clearly presented. The purpose of using both methods is to testify their strengths of relating environments to cognitive behaviors while pointing out the directions that following studies can address to improve these methods.

# 6. CONCLUSION

This articles reviewed two popularly used methods of space syntax and their roles on understanding human cognitve behaviors in environemnts. Elements of built environments represented in cognitive maps were those used in reviews of space syntax methods in order to indicate the characteristics of environments being represented in space syntax. A behavioral experiment was carried out to shed light on the strengths and challenges each method has. The specific aspect of legibility represented in each method and its role on cognitive behaviors was then clarified from both perspectives, the assessments of the environment and human behavior.

In order to improve the assessment of the differentiation of environments of legibility, landmark saliency is a possible way to address this aspect neglected in formal descriptions. Landmarks are prominent in indicating an environment accurately. As the effectiveness of using landmarks in human wayfinding has been favorably suggested [29], the consideration of landmarks cannot be eliminated for the full account of legibility. Therefore assessing characteristics of landmarks can not only benefit the more comprehensive understanding of legibility of environments but also contribute to the design of navigational systems.

Visual, structural and semantic properties of landmarks [30] have been used to carry out saliency measure of landmarks [29, 31]. Another approach was suggested to address the saliency of landmarks from a different perspective [32]. Cognitive saliency, perceptual saliency, and contextual saliency were introduced as the three aspects of landmark saliency. This framework provided a new lens of looking at landmark saliency to assess environments. However, as this framework is still on a conceptual level, practical justification is necessary to verify its feasibility in interpreting landmark saliency through the new lens. The achievement of these methods on landmark saliency will significantly contribute to the assessment of legibility regarding differentiation of environment.

It is important to acknowledge that although the reviewed methods of space syntax do not cover all aspects of legibility, they serve important roles of understanding the environment in a particular context. In the context of wayfinding, characteristics of environments used by wayfinders such as landmarks cannot be neglected in formal descriptions of environment due to their prominent role in knowledge acquisition and wayfinding. Supplementing current methods of space syntax is likely to be a feasible way to provide formal descriptions of the environment and relate them to benefit wayfinding research. The improvement of measuring landmark saliency serves an important role of providing insights on how environments can be differentiated by salient landmarks and providing fuller account of legibility. The inclusion of assessment of landmark saliency in future space syntax methods is likely a potential way to improve current methods of space syntax to provide more insights on formal descriptions of environment, wayfinding behaviors and application of these findings on the design of cognitively ergonomic wayfinding aids.

## Acknowledgements

# References

[1] K. Lynch, *The Image of the City*, Cambridge, MA: MIT Press, 1960.

[2] M. J. O'Neill, "Evaluation of a conceptual model of architectual legibility," *Environment and Behavior,* vol. 23, no. 3, pp. 259-284, 1991.

[3] J. Weisman, "Evaluating architectural legibility: Way-finding in the built environment," *Environment and Behavior,* vol. 13, no. 2, pp. 189-204, 1981.

[4] T. Gärling, A. Böök, and E. Lindberg, "Spatial orientation and wayfinding in the designed environment: A conceptual analysis and some suggestions for postoccupancy evaluation," *Journal of Architectural and Planning Research,* vol. 3, no. 1, pp. 55-64, 1986.

[5] G. Franz, and J. M. Wiener, "Exploring isovist-based correlates of spatial behavior and experience." pp. 503-518.

[6] S. Haq, and S. Girotto, "Ability and intelligibility: Wayfinding and environmental cognition in the designed."

[7] C. Hölscher, and M. Brösamle, "Capturing indoor wayfinding strategies and differerences in spatial knowledge with space syntax."

[8] D. R. Montello, "The contribution of space syntax to a comprehensive theory of environmental psychology," *Proceedings, 6th International Space Syntax Symposium*, pp. iv01-iv12, Istanbul, 2007.

[9] E. Tuncer, "Perception and intelligibility in the context of spatial syntax and spatial cognition."

[10] G. W. Evans, M. A. Skorpanich, T. Gärling *et al.*, "The effects of pathway configuration, landmarks and stress on environmental cognition," *Journal of Environmental Psychology,* vol. 4, no. 4, pp. 323-335, 1984.

[11] T. Gärling, E. Lindberg, and T. Mäntylä, "Orientation in buildings: effects of familiarity, visual access, and orientation aids," *Journal of Applied Psychology,* vol. 68, no. 1, pp. 177-86, 1983.

[12] R. Conroy-Dalton, and C. Hölscher, "Understanding Space: the nascent synthesis of cognition and the syntax of spatial morphologies," *Space Syntax and Spatial Cogntion-Proceedings of the Workshop held in Bremen, 24th September 2006*, C. Hölscher, R. Conroy-Dalton and A. turner, eds., Bremen: SFB/TR8, 2007.

[13] J. Peponis, C. Zimring, and Y. K. Choi, "Finding the building in wayfinding," *Environment and Behavior,* vol. 22, no. 5, pp. 555-590, 1990.

[14] A. Penn, "Space syntax and spatial cognition: Or why the axial line?," *Environment and Behavior,* vol. 35, no. 1, pp. 30-65, 2003.

[15] M. L. Benedikt, "To take hold of space: isovists and isovist fields," *Environment and Planning B: Planning and Design,* vol. 6, no. 1, pp. 47-65, 1979.

[16] A. Turner, M. Doxa, D. O'Sullivan *et al.*, "From isovists to visibility graph: A methodology for the analysis of architecture space," *Environment and Planning B: Planning and Design,* vol. 28, no. 1, pp. 103-121, 2001.

[17] J. M. Wiener, and G. Franz, "Isovists as a means to predict spatial experience and behavior," *Spatial Cognition IV: Reasoning, Action, and Interaction, Lecture Notes of Artificial Intelligence* C. Freksa, M. Knauff, B. Krieg-Brückner *et al.*, eds., pp. 42-57, Berlin Heidelberg: Springer, 2005.

[18] C. Hölscher, M. Brösamle, and G. Vrachliotis, "Challenges in multi-level wayfinding: A case-study with space syntax technique."

[19] S. Bafna, "Space syntax: A brief Introduction to its logic and analytical techniques," *Environment and Behavior,* vol. 35, no. 1, pp. 17-28, 2003.

[20] S. Haq, and C. Zimring, "Just down the aoad a piece: The development of topological knowledge of building layouts," *Environment and Behavior,* vol. 35, no. 1, pp. 132-160, 2003.

[21] S. Werner, and L. E. Schindler, "The role of spatial reference frames in architecture: Misalignment impairs way-finding performance," *Environment and Behavior,* vol. 36, no. 4, pp. 461-482, 2004.

[22] A. Ünlü, G. Ülken, and E. Edgü, "A Space Syntax Based Model in Evacuation of Hospitals."

[23] S. Werner, and P. Long, "Cognition meets le corbusier:Cognitive principles of architectural design," *Spatial Cognition III*, C. Freksa, W. Brauer, C. Habel *et al.*, eds., pp. 112-126, Berlin Heidelberg: Springer, 2003.

[24] C. Davies, R. Mora, and D. Peebles, "Isovists for orientation: Can space syntax help us predict directional confusion."

[25] L. Liben, and R. Downs, "Understanding person-space-map relations: Cartographic and developmental perspectives," *Developmental Psychology,* vol. 29, no. 4, pp. 739-52, 1993.

[26] M. J. O'Neill, "Effects of familiarity and plan complexity on wayfinding in simulated buildings," *Journal of Environmental Psychology,* vol. 12, no. 4, pp. 319-327, 1992.

[27] B. Jiang, and C. Claramunt, "Integration of space syntax into GIS: New perspectives for urban morphology," *Transactions in GIS,* vol. 6, no. 3, pp. 295-309, 2002.

[28] S. Haq, "Investigating the syntax line: configurational properties and cognitive correlates," *Environment and Planning B,* vol. 30, no. 6, pp. 841-864, 2003.

[29] M. Raubal, and S. Winter, "Enriching wayfinding instructions with local landmarks," *Geographic Information Science: Second International Conference, GIScience 2002 Boulder, CO, USA, September 25-28,2002 Proceedings*, M. J. Egenhofer and D. M. Mark, eds., pp. 243-259, Berlin Heidelberg: Springer, 2002.

[30] M. E. Sorrows, and S. C. Hirtle, "The nature of landmarks for real and electronic spaces," *Spatial Information Theory. Cognitive and Computational Foundations of Geographic Information Science. International Conference COSIT'99 State Germany, August 25-29, 1999 Proceedings* C. Freksa and D. M. Mark, eds., pp. 37-50, Berlin Heidelberg: Springer, 1999.

[31] A. Klippel, and S. Winter, "Structural salience of landmarks for route directions," *Spatial Informaiton Theory, International Conference, COSIT 2005, Ellicottville, NY, USA September 14-18, 2005 Proceedings*, A. Cohn and D. M. Mark, eds., pp. 347-262, Berlin Heidelberg: Springer, 2005.

[32] D. Caduff, and S. Timpf, "On the assessment of landmark salience for human navigation," *Cognitive Processing,* vol. 9, no. 4, pp. 249-267, 2008.