

# A review of variables of urban street connectivity for spatial connection

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**Abstract.** Several studies on street connectivity in cities and towns have been modeled on topology, morphology, technology and psychology of people living in the urban environment. Street connectivity means the connection of streets that offers people alternative routes. However, there emerge difficulties to determine the suitable variables and analysis to be chosen in defining the accurate result for studies street connectivity. The aim of this paper is to identify variables of street connectivity by applying GIS and Space Syntax. This paper reviews the variables of street connectivity from 15 past articles done in 1990s to early 2000s from journals of nine disciplines on Environment and Behavior, Planning and Design, Computers, Environment and Urban Systems, Applied Earth Observation and Geo-information, Environment and Planning, Physica A: Statistical Mechanics and its Applications, Environmental Psychology, Social Science and Medicine and Building and Environment. From the review, there are four variables found for street connectivity: link (streets-streets, street-nodes or node-streets, nodes-nodes), accessibility, least-angle, and centrality. Space syntax and GIS are suitable tools to analyze the four variables relating to systematic street systems for pedestrians. This review implies that planners of the street systems, in the aspect of street connectivity in cities and towns, should consider these four variables.

## 1. Introduction

People use street as a space that involves action and reaction; space for a movement to find a place; space for a meeting to interact with others; space for a recreation activity; space for people to appreciate and remembers their historic. Thus, street is an important public space for human lifestyle in cities and towns. A street connects people from one point to a destination in any activities [1]. It is also identified as a space between blocks [2] and as the edge of block [3] in cities and towns. Studies related to space syntax represent streets as straight-lines connecting nodes such as junction to form a street network [3-10]. Thus, reflection of people movement through the street network for their wayfinding to the destination is influenced by its connectivity.

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Good street-network design formed from the consideration of connectivity of streets. Connectivity exists when a subject linked to others in any form, for example, when people move from point A to point B, they need to pass through street A, street B and street C. The situation shows how street name of street A, street B and street C are connected. In the study done by Jiang and Claramunt [7], street connectivity is defined as the number of streets directly linked by a node. This means that connectivity can be formed by street function or character of the environment linked. For example, street connectivity form in intersection such as junction [9]. There are varies studies utilize street connectivity as their parameter, for example, researchers in planning and transportation used street connectivity as a key aspects for creating walkability indices. A study by Leslie et al.[11] reveals that connectivity of street determines the mean value for the high- and low- walkable neighbourhoods in Australia and North American regions [11]. Other study done by Tomko, Winter and Claramunt [3] found that street connectivity promotes the movement flow that capable to educate people to experience the streets and generate cognitive of spatial knowledge. In the view of spatial study, recent developments of the spatial information science have introduced the identification of street connectivity. Spatial layout of street is generated based on the psychological reaction of people mind to an object either in their interest or not to a feature in streets. Thus, the identification capable to determine the factors that might increase or decrease the probability of people being physically active according to selected spatial units of interest in connected street [10]. This shows a sign that spatial may connected in streets.

Nowadays, studies on street connectivity have achieved another level where the computer is used analyze the street connectivity of a city or town. Geographic Information System (GIS) and Space Syntax are applied to analyze street network. These applications have improved the studies on streets in terms of to standardize the analysis and the validity of the result based on the variables of street connectivity. However, there emerge difficulties to determine the suitable variables to be chosen in defining the most accurate result for a study on spatial connection in street connectivity [10]. The analytical review is required to reveal the appropriate variables for a study using GIS and Space Syntax analysis. Thus, the aim of this paper is to identify variables of street connectivity in cities and towns using GIS and Space Syntax. Hence, this paper offers a review to the variables of street connectivity that can assists researcher to determine suitable variables in studying street network in urban setting.

## **2. Methodology**

Based on nine disciplines, the review refined the variables of street connectivity. The disciplines were Environment and Behavior, Planning and Design, Computers, Environment and Urban Systems, Applied Earth Observation and Geo-information, Environment and Planning, Physica A: Statistical Mechanics and its Applications, Environmental Psychology, Social Science and Medicine and Building and Environment. Fifteen collective articles were selected from years 1990s until 2000s which were conducted using online database from Science Direct, Scopus, Web of Science and Conference Proceedings. The review addressed the relationship between street connectivity variables and spatial connection served as the aspects that applicable to be used in GIS and Space Syntax software. The aspects taken into consideration were based on the most approaches benefits the street network planning and design.

## **3. Result**

The study of street connectivity covers the aspects of street environment, users and structures. It includes understanding from the various perspectives in exploring the space.

**Table 1.** Overview of articles reviewed to identify variables used in past studies.

Author(s)	Disciplines	Study	Variables	Dimensions
Montello [12]	Environment and Behavior	Spatial orientation and the angularity of urban routes: A field study	<ul style="list-style-type: none"> <li>• Level of Familiarity</li> <li>• Pointing Performance</li> </ul>	<ul style="list-style-type: none"> <li>• Target of Place</li> <li>• Location of Place</li> <li>• Pointing Accuracy</li> <li>• Pointing Error</li> <li>• Response Time</li> </ul>
Peponis, Wineman, Rashid, Kim, and Bafna [13]	Planning and Design	On the generation of linear representations of spatial configuration	<ul style="list-style-type: none"> <li>• Set of Maps</li> </ul>	<ul style="list-style-type: none"> <li>• Set of lines</li> <li>• Visibility Polygon or Isovist</li> <li>• Convex Space or e-partition</li> </ul>
Jiang, Claramunt, and Batty [14]	Computers, Environment and Urban Systems	Geometric accessibility and geographic information: extending desktop GIS to space syntax	<ul style="list-style-type: none"> <li>• Accessibility</li> <li>• One step connectivity</li> <li>• One step distance</li> </ul>	<ul style="list-style-type: none"> <li>• Distance travel</li> <li>• Weighted travel</li> <li>• Number of vertices/nodes</li> <li>• Depth (overall steps)</li> </ul>
Jiang, Claramunt, and Klarqvist [7]	Applied Earth Observation and Geo-information	Integration of space syntax into GIS for modelling urban spaces	<ul style="list-style-type: none"> <li>• Link (streets and nodes)</li> <li>• Control value</li> <li>• Mean depth</li> <li>• Integration (global and local)</li> </ul>	<ul style="list-style-type: none"> <li>• Number of nodes</li> <li>• Linked nodes</li> <li>• Distance travel</li> <li>• Number of steps</li> <li>• Distance between steps</li> </ul>
Jiang and Claramunt [1]	Environment and Planning	Topological analysis of urban street networks	<ul style="list-style-type: none"> <li>• Clustering Coefficient</li> </ul>	<ul style="list-style-type: none"> <li>• Street Named</li> <li>• Street Length</li> <li>• Number of Intersection</li> </ul>
Hochmair [15]	Environment and Planning	Investigating the effectiveness of the Least-Angle Strategy (LAS) for wayfinding in unknown street networks	<ul style="list-style-type: none"> <li>• Least-Angle</li> <li>• Route Strategy</li> <li>• Memorized Strategy</li> </ul>	<ul style="list-style-type: none"> <li>• Alternatives Street (Streets)</li> <li>• Route (Origin Point and Destination Point)</li> <li>• Target Line</li> <li>• Angle of decision</li> </ul>
Porta, Crucitti, and Latora [16]	Physica A: Statistical Mechanics and its Applications	The network analysis of urban streets: A dual approach	<ul style="list-style-type: none"> <li>• Topological Analysis</li> </ul>	<ul style="list-style-type: none"> <li>• Path Length</li> <li>• Number of Nodes</li> <li>• Number of Edges</li> <li>• Average Number of Edges per Node</li> <li>• Largest Degree</li> </ul>
Porta, Crucitti, and Latora [6]	Environment and Planning	The network analysis of urban streets: A primal approach	<ul style="list-style-type: none"> <li>• Degree Centrality</li> <li>• Closeness Centrality</li> <li>• Betweenness Centrality</li> <li>• Straightness Centrality</li> <li>• Information Centrality</li> </ul>	<ul style="list-style-type: none"> <li>• Number of Edges</li> <li>• Number of Nodes</li> <li>• Minimum Distance or Geodesic</li> <li>• Average Distance</li> <li>• Number of Geodesic</li> <li>• Edges Incident</li> </ul>
Jiang [5]	Physica A: Statistical Mechanics and its Applications	A topological pattern of urban street networks: Universality and peculiarity	<ul style="list-style-type: none"> <li>• Average Degree of Nodes</li> <li>• Range of Path Length</li> <li>• Average of clustering coefficient vertices</li> </ul>	<ul style="list-style-type: none"> <li>• Number of streets</li> <li>• Distance between i and j</li> <li>• Actual Edges</li> <li>• Possible Edges</li> <li>• Average Degree of Streets</li> </ul>
Guo and Ferreira Jr [17]	Environment and Planning	Pedestrian environments, transit path choice, and transfer penalties: Understanding land-use impacts on transit travel	<ul style="list-style-type: none"> <li>• Transfer Attributes</li> <li>• Pedestrian Environments</li> <li>• Trip and Personal Information</li> </ul>	<ul style="list-style-type: none"> <li>• Transfer Walking Time</li> <li>• Transfer Waiting Time</li> <li>• Extra In-Vehicle Time</li> <li>• Escalator Presence</li> <li>• Pedestrian Friendly Parcels</li> <li>• Sidewalk</li> <li>• Intersections</li> <li>• Open Space</li> </ul>

			<ul style="list-style-type: none"> <li>• Topography</li> <li>• Trip Characteristics</li> <li>• Demographic Characteristics</li> </ul>	
Peponis, Bafna, and Zhang [2]	Environment and Planning	The connectivity of streets: reach and directional distance	<ul style="list-style-type: none"> <li>• Metric Reach</li> <li>• Directional Distance</li> <li>• Directional Reach</li> </ul>	<ul style="list-style-type: none"> <li>• Block</li> <li>• Linear Street Length</li> <li>• Intersection Density</li> <li>• Syntactic Distance (Step)</li> <li>• Angular Distance (Degree)</li> </ul>
Borst et al. [8]	Environmental Psychology	Influence of environmental street characteristics on walking route choice of elderly people	<ul style="list-style-type: none"> <li>• Route choice value</li> </ul>	<ul style="list-style-type: none"> <li>• Perceived positive utility route</li> <li>• Perceived negative utility route</li> <li>• Walking route</li> <li>• Sum of utility of the links</li> <li>• Links characteristic</li> <li>• Links factors</li> </ul>
Cutts, Darby, Boone, and Brewis [18]	Social Science and Medicine	City structure, obesity, and environmental justice: an integrated analysis of physical and social barriers to walkable streets and park access	<ul style="list-style-type: none"> <li>• Walkability Index</li> <li>• Residential accessibility</li> </ul>	<ul style="list-style-type: none"> <li>• Dwelling density</li> <li>• Connectivity</li> <li>• Land use attributes</li> <li>• Net retail area</li> <li>• Buffer distance (0.4km)</li> </ul>
Hang, Sandberg, Li, and Claesson [19]	Building and Environment	Flow mechanisms and flow capacity in idealized long-street city models	<ul style="list-style-type: none"> <li>• Flow Rate</li> <li>• Energy Density</li> <li>• Velocity Scale</li> </ul>	<ul style="list-style-type: none"> <li>• Wind Velocity</li> <li>• Street Length</li> <li>• Street Width</li> <li>• Stream-Wise</li> <li>• Span-Wise</li> <li>• Vertical Velocity Fluctuations</li> </ul>
Lwin and Murayama [10]	Computers, Environment and Urban Systems	Modeling of urban green space walkability: Eco-friendly walk score calculator	<ul style="list-style-type: none"> <li>• Greenery by Coordinates</li> <li>• Greenery by Block</li> <li>• Greenery by Walking Route</li> </ul>	<ul style="list-style-type: none"> <li>• Total Green Area</li> <li>• Total Area</li> <li>• Percentage Greenery</li> </ul>

Table 1.0 suggests that there is a pattern of regularity on street studies. The variables of street connectivity are related with (1) human and street, (2) form of human behavior, and (3) aspects of walkability, health, and psychology. In the aspect of human and street, Montello[12] found that connectivity means people identifying the location of a place. He tried to create a connection of human with the urban space that influenced the decision making to a target. In other words, direction and positioning of oneself on the street are the key factor of street connectivity.

Focusing on street connectivity in street network, Hillier[20] reveals the idea of human behavior in space reflects to the revolution in analyzing street network through theory of space syntax. Studies on human behavior in quality of street connectivity are Peponis, Wineman, Rashid, Kim, and Bafna[13], Jiang, Claramunt, and Batty[14], Jiang, Claramunt, and Klarqvist[4], Jiang and Claramunt[1], Hochmair[15], Porta, Crucitti, and Latora[16], Porta, Crucitti, and Latora[6], Jiang[7] and Peponis, Bafna, and Zhang[2]. These articles used Hillier's theory of space syntax. Peponis, Wineman, Rashid, Kim, and Bafna[13] presented the human behavior in urban street in the form of maps. Furthermore, Jiang, Claramunt, and Batty[14] and Jiang, Claramunt, and Klarqvist[4] expanded the variables and them formalized in GIS and Space Syntax software. They have stepped up the variables to a different level where the result can be defined in computer set of analysis. Continuously, Jiang and Claramunt[1] develops a model for topological analysis of street network that refined the variables of street connectivity in form of topological network of a city or town. In other perspective, Hochmair[15] have developed novel variables by discovered Least-Angle Strategy in wayfinding approaches for unknown places. Then, new variables have been exposed by Porta, Crucitti, and

Latora[6, 16,] by revealed the concept of centrality in street analysis study. These are the positive development of knowledge to the street connectivity study which potentially assist researcher to define the accuracy of street connectivity analysis in street network.

Studies by Guo and Ferreira Jr[17], Borst et al.[8], Cutts, Darby, Boone, and Brewis[18], Hang, Sandberg, Li, and Claesson[19] and Lwin and Murayama [10] suggest that the street connectivity is related walkability, health and psychology of movement. For example, Borst et al.[8] defined the relation of street characteristics influence the route choice for elderly. They explain that the street connectivity is closely link with attractive features for walking that increase ‘place value’ and ‘functional value’ which project the decision making of elderly for route choice. Cutts, Darby, Boone, and Brewis[18] relate street connectivity in medication and health study where walking reduces obesity. Thus, the studies have opened the view that variables of street connectivity are related to wayfinding, place identity, urban morphology and even the economic sector. Integrating the variables is important in study of walkability. In summary, the appropriate variables for street connectivity study are presented in Table 2.

**Table 2.** Summary of variables capable in street connectivity study applicable for GIS and Space Syntax.

Item	Variables	Sub-Variables	Dimensions	Author(s)
1	Link (streets-streets, streets-nodes, nodes-nodes)	<ul style="list-style-type: none"> <li>• Control Value</li> <li>• Depth</li> <li>• Integration (Local and Global)</li> <li>• Clustering Coefficient</li> </ul>	<ul style="list-style-type: none"> <li>• Number of nodes</li> <li>• Linked nodes</li> <li>• Distance travel</li> <li>• Street Named</li> <li>• Street Length</li> <li>• Number of Intersection</li> <li>• Number of steps</li> <li>• Distance between steps</li> </ul>	Peponis, Wineman, Rashid, Kim, and Bafna [13], Jiang, Claramunt, and Klarqvist[7], Jiang and Claramunt[1], Guo and Ferreira Jr[17], Peponis, Bafna, and Zhang[2], Lwin and Murayama[10]
2	Accessibility	<ul style="list-style-type: none"> <li>• Steps</li> <li>• Depth</li> </ul>	<ul style="list-style-type: none"> <li>• Distance travel</li> <li>• Weighted travel</li> <li>• Unit edge</li> <li>• Number of vertices/nodes</li> <li>• Depth (overall steps)</li> </ul>	Peponis, Wineman, Rashid, Kim, and Bafna[13], Jiang, Claramunt, and Batty[14], Borst et al.[8], Cutts, Darby, Boone, and Brewis[18]
3	Least-Angle	<ul style="list-style-type: none"> <li>• Route Strategy</li> <li>• Memorized Strategy</li> </ul>	<ul style="list-style-type: none"> <li>• Alternatives Street (Streets)</li> <li>• Route (Origin Point and Destination Point)</li> <li>• Target Line</li> <li>• Angle of decision</li> </ul>	Montello[12], Hochmair[15]
4	Centrality	<ul style="list-style-type: none"> <li>• Degree</li> <li>• Closeness</li> <li>• Betweenness</li> <li>• Straightness</li> <li>• Information</li> </ul>	<ul style="list-style-type: none"> <li>• Number of Edges</li> <li>• Number of Nodes</li> <li>• Minimum Distance or Geodesic</li> <li>• Average Distance</li> <li>• Number of Geodesic</li> <li>• Edges Incident</li> </ul>	Peponis, Wineman, Rashid, Kim, and Bafna[13], Porta, Crucitti, and Latora[6]

#### 4. Discussion

According to Table 2.0, four variables influence the study of street connectivity: link, accessibility, least-angle and centrality.

Street connectivity variable as link define as level of connection between street to streets, street to nodes or node to streets, and node to nodes which affect other aspects such walkability, wayfinding and spatial connection in streets environment. This implies that spatial connection can be measured through link as a variable of street connectivity. This is because connectivity existed in a street environment when a space is collaborated with street features in term of position, formation, and symbolism. Additionally, the level of connection produce by link may influence degree of spatial connection between streets. Besides, accessibility means the measurement and analysis spatial connection. It is the relation of a place to another place in terms of nearness and propinquity. This variable suggested because attraction in a street environment have influence on distance travel of the origin point to the destination and this widely used in other studies such as spatial analytic measure. Therefore, accessibility is a variable for study of street connectivity.

Another variable of street connectivity is the least-angle that influences people perception walking along a route. The least-angle is the acute angle between a destination direction and street to be selected in traveling to the destination. The angle to decide a route involved with percentage of perceived spatial quality in streets. This shows that least-angle is a fresh idea in measure and analyzes street connectivity for spatial connection.

The last street connectivity variable is centrality which derived from two concepts; central as being near others and central of being between or intermediary of others. Centrality looks to explain the relation between human and street elements such junctions or streets. This variable can be an analysis to determine suitable junctions' location in street base on human capability and limitation. Thus, centrality is suggested is a factor analyzing street network in a city or town. Therefore, all of the suggested variables are appropriate to measure or analyze street connectivity for spatial connection in streets environment.

#### 5. Conclusion

The exposure of street connectivity variables, which are link, accessibility, least-angle and centrality, can assist researcher for the measurement and analysis of the research related with street connectivity. However, immensity and apprehension in deciding the selected variables for a research in street connectivity study is required to make sure the variables selected are appropriate to reveal the inquiry in a research. The variables are fit to be used for in wayfinding, urban appreciation, and historical investigation with street network. The analysis tools are space syntax and GIS can be used to analyze the four variables resulting to systematic street system for pedestrian.

#### References

- [1] Jiang B and Claramunt C 2004 *Environment and Planning B* **31** 151-62
- [2] Peponis J, Bafna S and Zhang Z 2008 *Environment and Planning B* **35** 881-901
- [3] Tomko M, Winter S and Claramunt C 2008 *Computers, Environment and Urban Systems* **32** 41-52
- [4] Batty M 2004 *A new theory of space syntax* (University College London) 34
- [5] Jiang B 2007 *Physica A: Statistical Mechanics and its Applications* **384** 647-55
- [6] Porta S, Crucitti P and Latora V 2006 *Physica A: Statistical Mechanics and its Applications* **369** 853-66
- [7] Jiang B, Claramunt C and Klarqvist B 2000 *Journal of Applied Earth Observation and Geoinformation* **2** 161-71
- [8] Borst H C et al. 2009 *Journal of Environmental Psychology* **29** 477-84

- [9] Marshall W E and Garrick N W 2010 *The Effect of Street Network Design on Walking and Biking* (T.R. Board) 1-24
- [10] Lwin K K and Murayama Y 2011 *Computers, Environment and Urban Systems* **35** 408-20
- [11] Leslie E et al. 2005 *Health Place* **11** 227-36
- [12] Montello D R 1991 *Environment and Behavior* **23** 47-69
- [13] Peponis J et al. 1998 *Planning and Design* **25** 559-76
- [14] Jiang B, Claramunt C and Batty M 1999 *Computers, Environment and Urban Systems* **23** 127-46
- [15] Hochmair H H 2005 *Environment and Planning* **32** 673-91
- [16] Porta S, Crucitti P and Latora V 2006 *Environment and Planning B* **33** 705-25
- [17] Guo Z and Ferreira J Jr 2008 *Environment and Planning B* **35** 461-79
- [18] Cutts B B et al. 2009 *Soc Sci Med* **69** 1314-22
- [19] Hang J et al. 2010 *Building and Environment* **45** 1042-53
- [20] Hillier B and Hanson J 1984 *The Social Logic of Space* (Cambridge: Press syndicate of the University of Cambridge)