Space Syntax Analysis:

Concept, Method, and Hands-on Tools for R and Python

Zicheng Fan | 20230724

Agenda

1. Introduction
2. Concepts
3. Tools
4. Summary

The slides are created and developed by Zicheng Fan,
with reference to the space syntax training materials created by
Genevieve Shaun Lin,
Po Nien Chen,
Sepehr Zhand,
from Space Syntax Laboratory

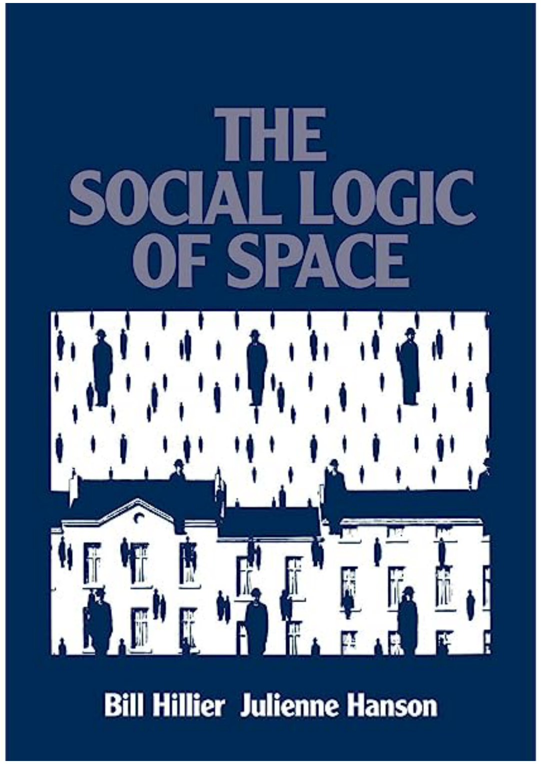
A general Introduction of Space Syntax

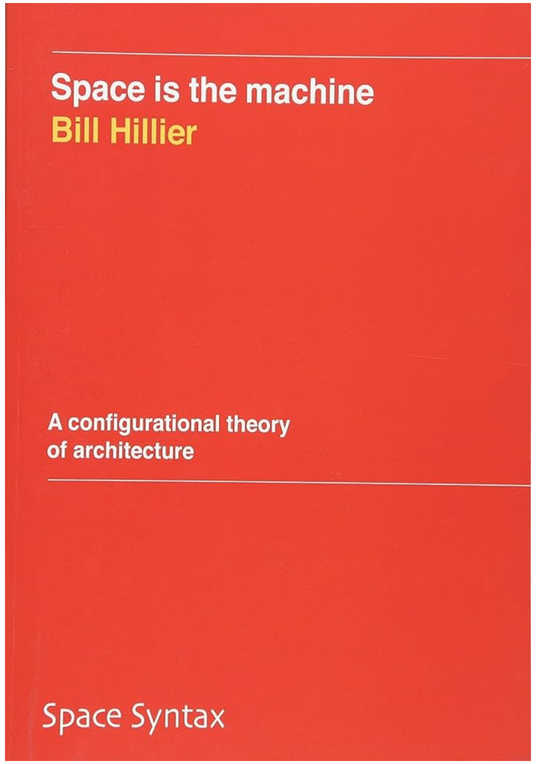
Bill Hillier (1937-2019)

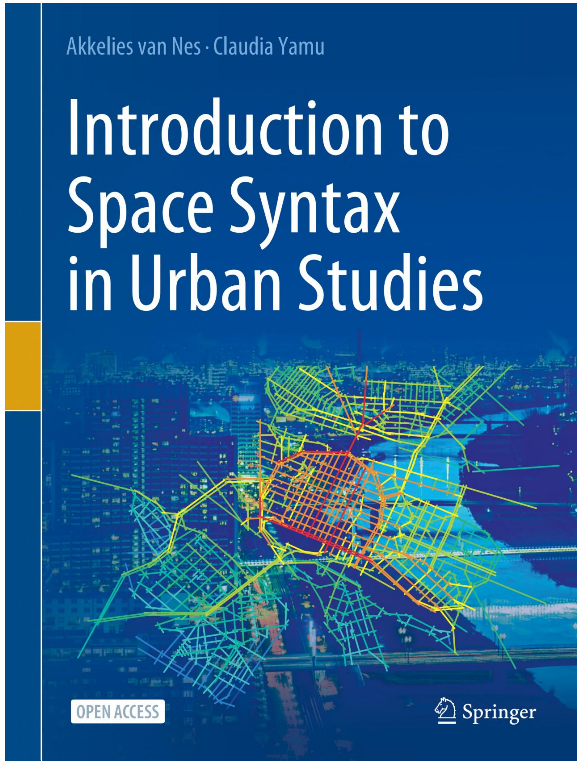
“Space syntax is a theory of space and a set of analytical, quantitative and descriptive tools for analysing the layout of space in buildings and cities. By learning to control the spatial variable at the level of the complex patterns of space that make up the city, it is possible to gain insights into both the social antecedents and consequences of spatial form in the physical city or in buildings ranging from houses to any complex building.”

Hillier, B. & Hanson, J. (1984), The Social Logic of Space, Cambridge University Press: Cambridge. pp.1-5.

Derived from the graph theory and the complex system theory, space syntax develops the quantitative understanding of the hidden logic and spatial relations behind the real spatial system.







Some reference readings to get familiar with space syntax

Space Definition in Space Syntax

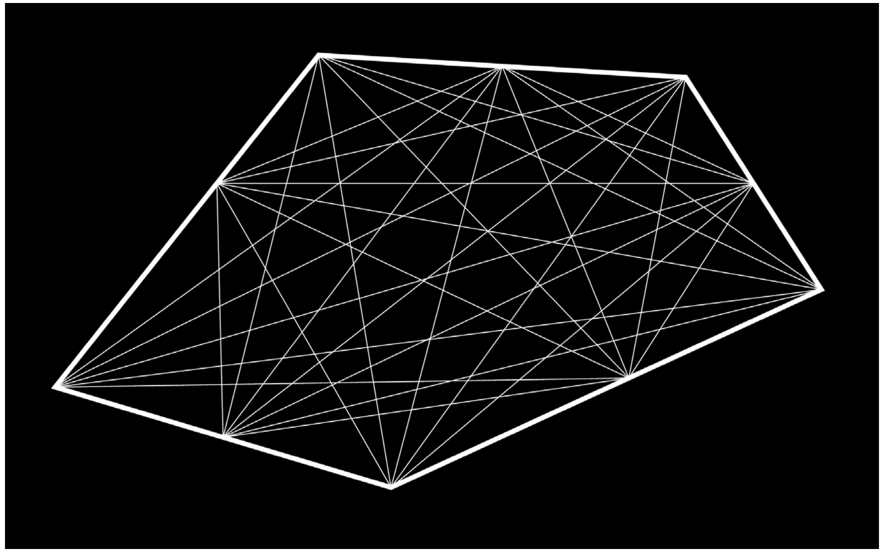
The definition of **space** :

“Space, in the space syntax approach, is defined as relatedness, and as it is, and might be, created by buildings and cities, and as it is experienced by the people who use them.

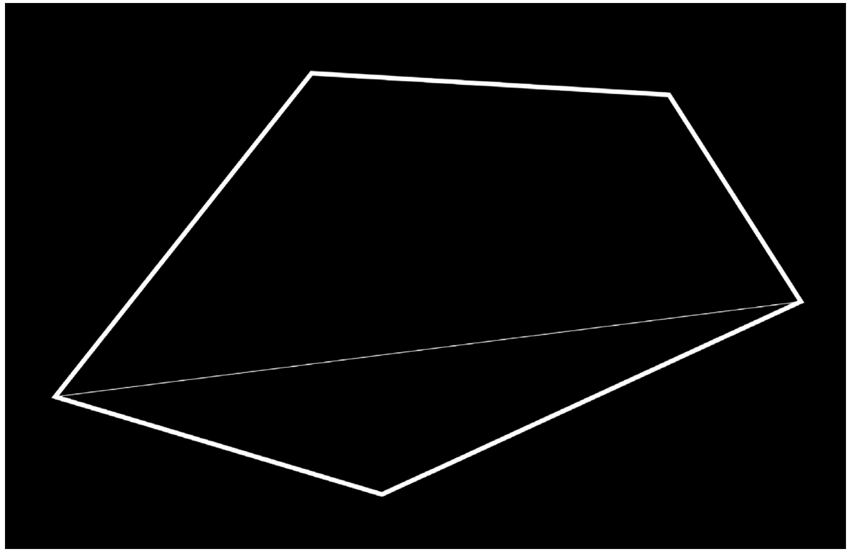
Thus, space is thought of as an intrinsic aspect of everything human beings do in the sense that moving through space, interacting with other people in space, or even just seeing ambient space from a point in it, rather than the background to objects.“

Hillier, B. & Hanson, J. (1984), The Social Logic of Space, Cambridge University Press: Cambridge. pp.1-5.

Space is constructed as a mixed concept, with consideration of spatial configuration, people’s perception, movement, social activities and daily behaviors.



Convex spaces are spaces in which all points can see all others

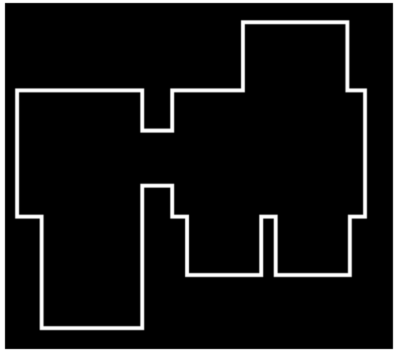


Axial lines are longest lines of sight in a spatial configuration, which can be regarded as simplified representation of space.

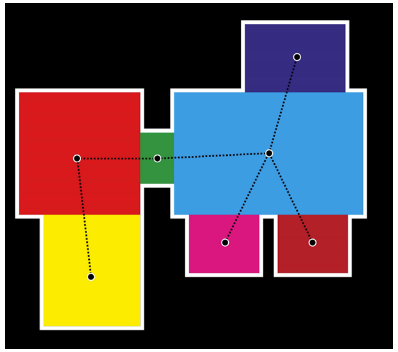
In 2D convex space, what you can see almost equal to where you can reach:

Visibility ~ Accessibility

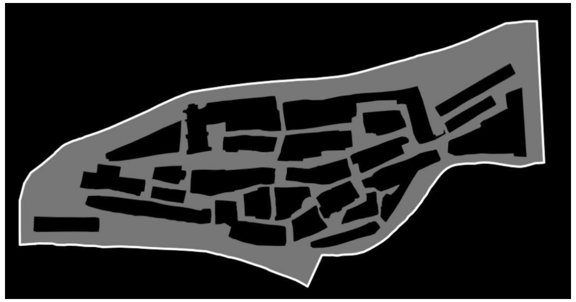
Space Definition in Space Syntax



(a)

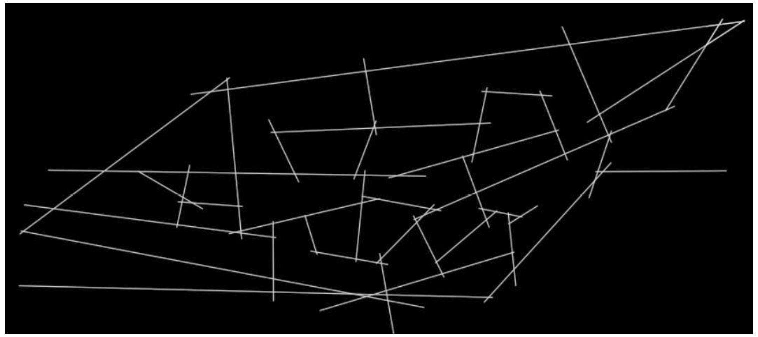


(b)



(a)

(b)



(c)

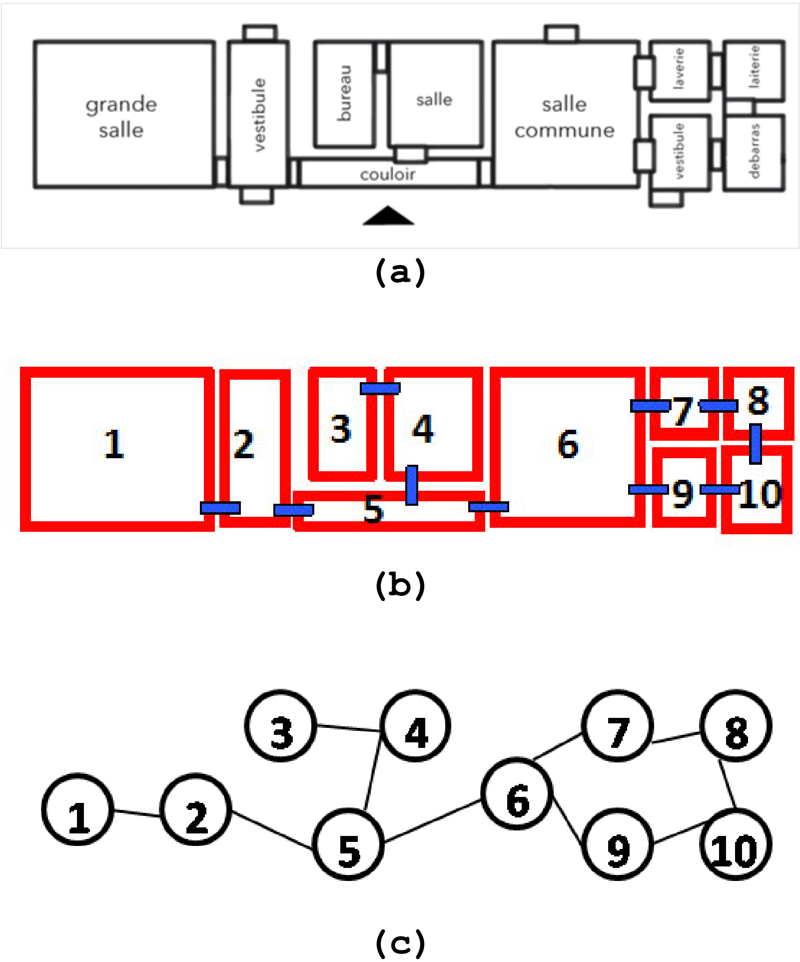
Convex maps depict the least number of convex space that fully cover a layout and the connections between them.

Axial maps depict the least number of axial lines covering all convex spaces of a layout and their connections.

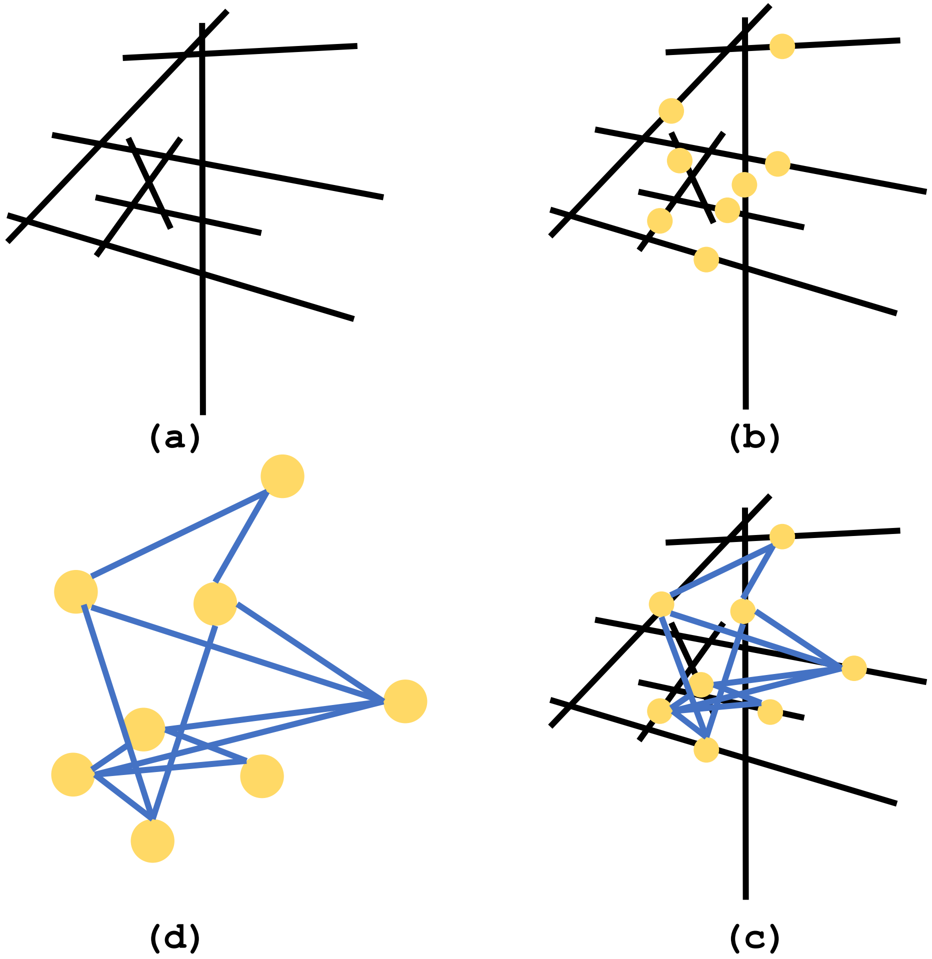
Dual Graph in Space Syntax

Graph in Network Analysis	Graph in Space Syntax
Dual Graph A dual graph is a graph that represents the edges of a given (primal) planar graph as nodes, and the adjacency between shared edges as edges. Essentially, it flips the roles of nodes and edges in the primal graph.	**Convex Adjacency Graph** Convex spaces(rooms/squares)are represented as nodes, and permeable adjacencies (doors/corridors) are represented by edges.
	Axial Graph /Segment Graph The street space are represented as nodes, and the intersections of street as connections between the nodes.
	Visibility Graph Each node in the graph represents a viewpoint within the space. A edge is drawn between two nodes if there is a direct line of sight (inter-visibility) between the two corresponding viewpoints.

Dual Graph in Space Syntax

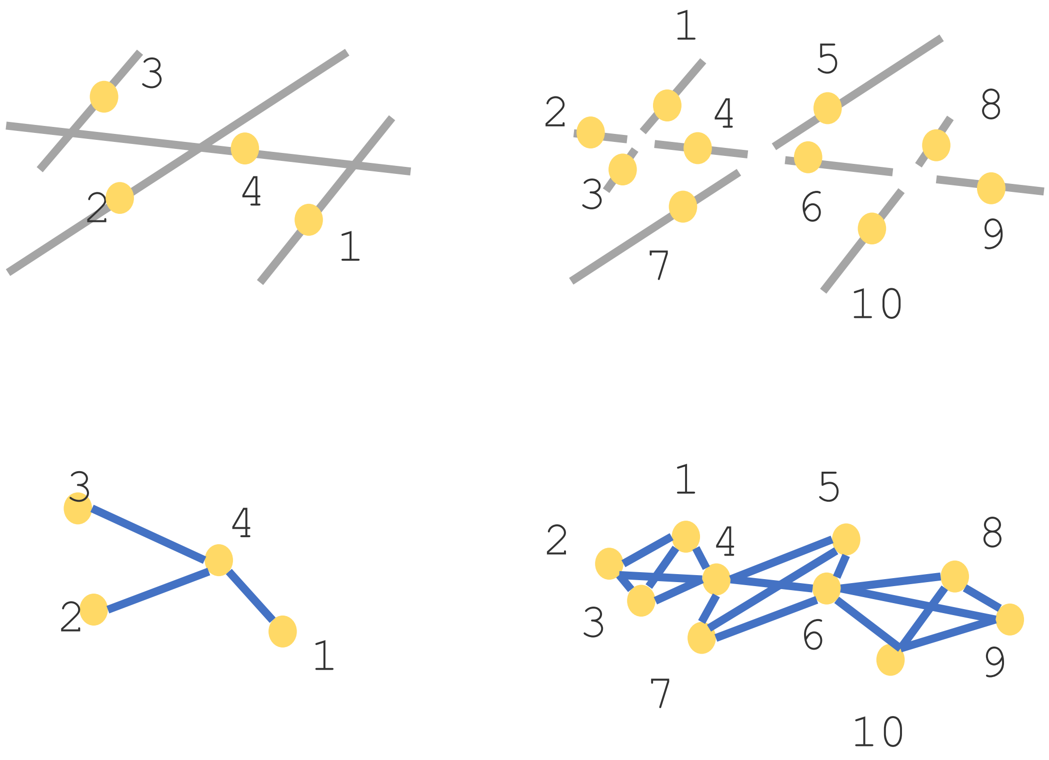


Convex Adjacency Graph



Axial Graph

Dual Graph in Space Syntax



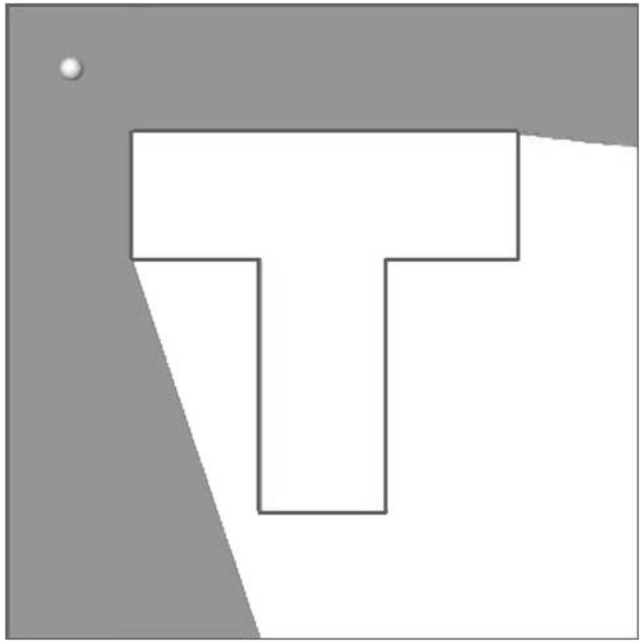
Axial Graph vs **Segment Graph**

The segment graph is normally constructed from an axial map. **Axial lines are broken at their intersections.**

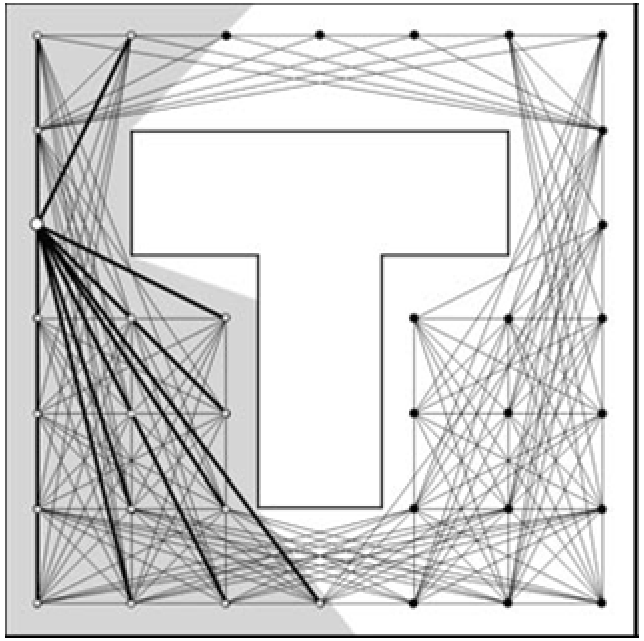
An alternative method takes the **road centrelines** from a pre-drawn transport network, and simplifies and cleans it up to reduce over-articulated curves and to remove extraneous road traffic features.

With segment graph, the **geometry features** of node and edges can be better integrated to analysis. The development of segment graph analysis extend the application of space syntax in general road networks.

Dual Graph in Space Syntax



Isovist
from single view point



Visibility graph
Based on isovist analysis from all the potential view points

Network Measures In Space Syntax

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General Network Analysis	Space Syntax
Closeness Centrality The reciprocal of the sum of the length of the shortest paths between the node and all other nodes in the graph (reciprocal of mean depth), by Sabidussi (1966).	**Integration (HH)** Integration can be regarded as a variation of closeness centrality, normalised using the node count of graph. The calculation is first proposed by Hillier and Hanson (1984), to deal with **symmetry** and **scale difference problems**, when analysing and compare centrality measures in dual graphs built from different real world spatial systems.

$$C_i = \frac{1}{TD_i} = \frac{1}{\sum_j d_{ij}}$$

C_i represents the closeness centrality of any node i in the graph, TD_i represents the total depth of node i, d_{ij} represents the depth of the shortest path between any node i and j in the graph, and n represents the total number of nodes in the graph. (Calculation of closeness centrality may also apply node counts to normalize the value, like in network below. C_i is reciprocal of mean depth of node i in the graph.)

$$C_i = \frac{n}{TD_i} = \frac{n-1}{\sum_j d_{ij}}$$

$$RA_i = \frac{\frac{TD_i}{n-1} - 1}{\frac{n}{2} - 1} \qquad D = \frac{n\left(log_2\left(\frac{n}{3} - 1\right)\right) + 1}{\frac{(n-1)(n-2)}{2}} \qquad I_i = \frac{D}{RA_i}$$

RA_i represents the Relative Asymmetry value of any node i in the graph. D represents the Relativized Asymmetry value of a whole diamond graph corresponding to the total number of graph nodes. I_i represent the integration value for any node i in the graph.

Network Measures In Space Syntax

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General Network Analysis	Space Syntax
Betweenness Centrality	**Choice**
The betweenness centrality for each node is the number of these shortest paths that pass through the node (Freeman, 1977).	In space syntax, choice same as betweenness Centrality, is a measure for quantifying the probability that an axial/street segment falls on a randomly selected shortest path linking any pair of axials/segments.

$$C_B(i) = \sum_{j \neq k} g_{jk}(i)/g_{jk}$$

where $C_B(i)$ is the betweenness centrality of node i, $g_{jk}(i)$is the number of shortest paths connecting node j and k and passing through I; g_{jk} is the total number of shortest paths.

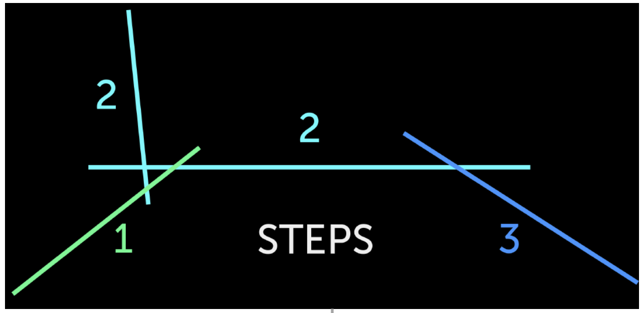
Distance, Shortest Path, and Radius

Searching shortest paths is commonly applied in centrality measures,
but how do we define distance in shortest paths ?

Convex Adjacency Graph
Axial Graph
Visibility Graph

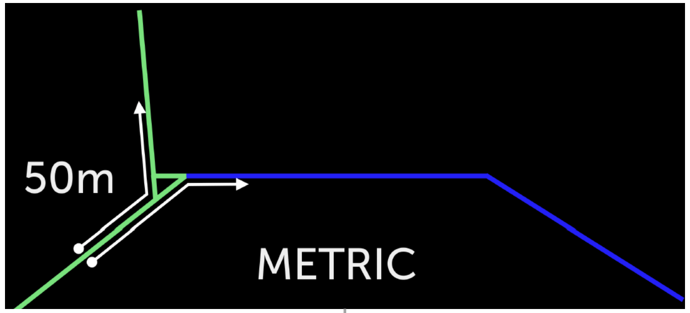
Segment Graph

Topological Steps
(space that people passed by)

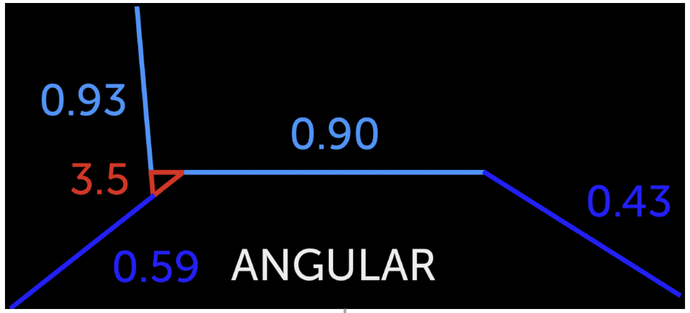


Better for conceiving space

Metric
(geometric distance between two segments)



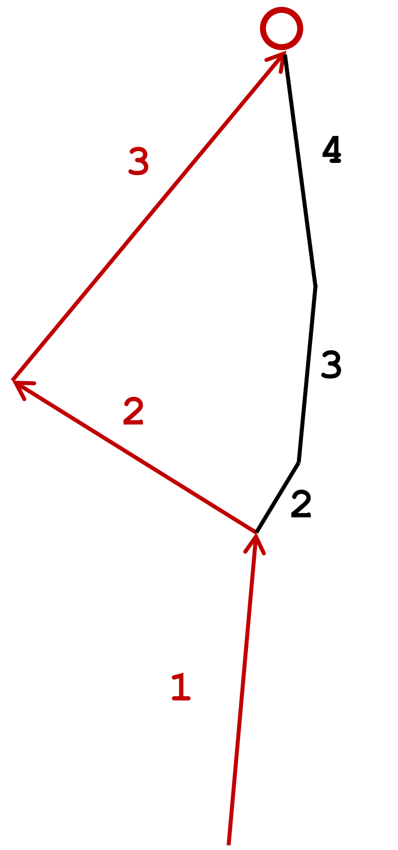
Angular
(degree change between two segments)



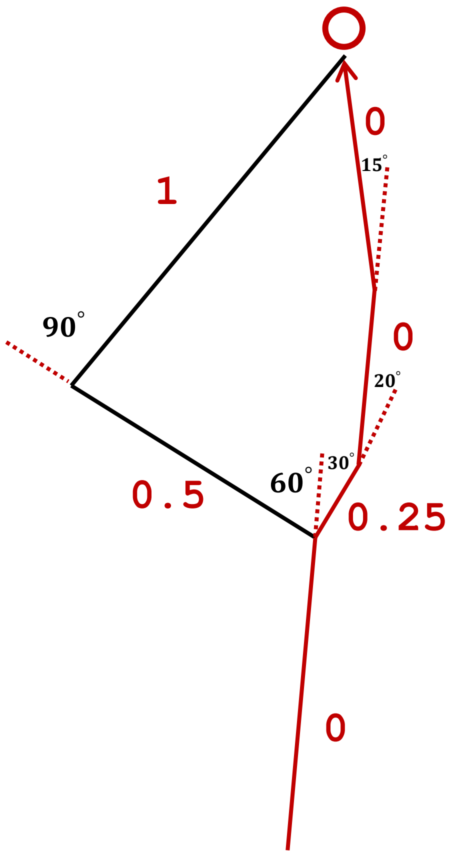
Better for movement analysis

Distance, Shortest Path, and Radius

How do we search shortest paths?



Shortest Path in
Axial Analysis

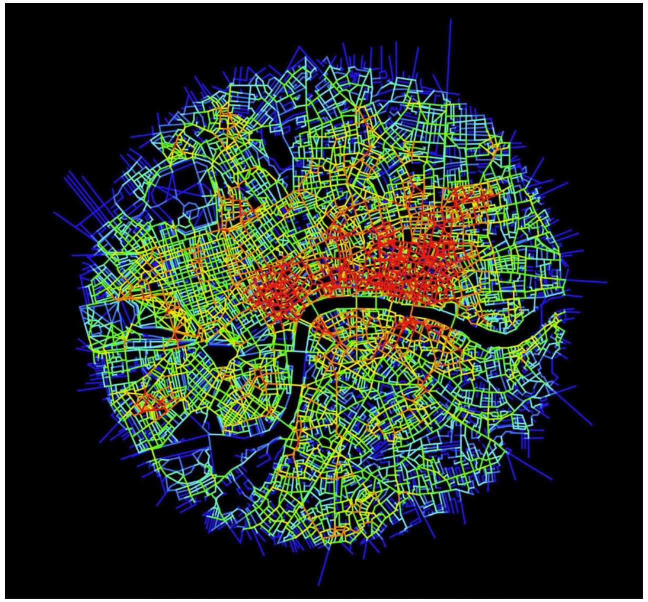


Shortest Path in
Angular Segment Analysis

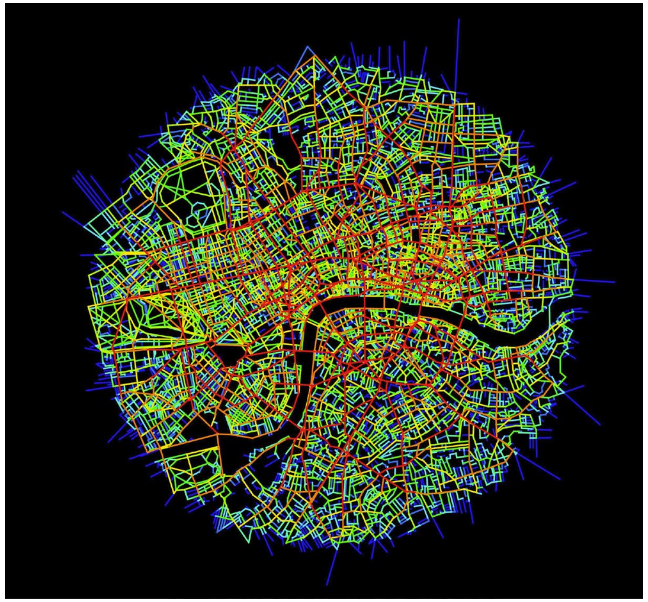
$0 - 22.5^{\circ}$	weighted by 0.25
$22.5 - 45^{\circ}$	weighted by 0.5
$45 - 67.5^{\circ}$	weighted by 0.75
$67.5 - 90^{\circ}$	weighted by 1
	...
$157.5 - 180^{\circ}$	weighted by 1

Dijkstra algorithm has been widely used in searching shortest path in network analysis, and it is the same in space syntax. However, depending on the distance type/weight we assign to the node, the searching result for shortest path can vary greatly.

By introducing a radius concept, we decide how many nodes are included in graph analysis, thus limiting the background environment to be considered in the analysis



Choice, radius = 500m



Choice, radius = 5000m

Three different distance measures, **step, metric and angular**, also apply to the radius selection for segment analysis, while only step distance apply to the axial analysis. **Most space syntax studies make use of angular segment analysis** with **metric distance as radius**.

Normalized Measures from Angular Segment Analysis for Multi-scale Research

NAIN (Normalized Angular Integration)

Normalised integration, total depth weighted by the total nodes of graph. The idea is similar to integration(HH), but the method has been simplified and can be applied to the metric/angular based analysis.

NACH (Normalized Angular Choice)

Normalised choice aims to solve the paradox that segregated designs add more total (and average) choice to the system than integrated ones. It divides total choice by total depth for each segment in the system. This adjusts choice values according to the depth of each segment in the system, since the more segregated is, the more its choice value with be reduced by being divided by a higher total depth number.

$$NAIN(i) = \frac{n^{1.2}}{\sum_j d_{ij} + 2}$$

n represents the total node count in the graph, d_{ij} represents the depth of the shortest path between any node i and j in the graph

$$NACH(i) = \frac{\log(C_B(i) + 1)}{\log(\sum_j d_{ij} + 3)}$$

$C_B(i)$ represents the betwness centrality of any node i in the graph, d_{ij} represents the depth of the shortest path between any node i and j in the graph, n represents the total node count in the graph

An Overview of Space Syntax Tools

General Tools

DepthmapX

- Isovist/ Visibility Graph Analysis
- Agent Analysis
- Axial/ Segment Network Analysis

https://www.spacesyntax.online/software-and-manuals/depthmap/

Software | Qgis | R Studio | Grasshopper | Github

sDNA

- 2D/ 3D Network Analysis
- Pedestrian/ Cyclist Network

https://sdna.cardiff.ac.uk/sdna/

Software | Qgis | Arcgis | AutoCAD | Grasshopper | Github

Isovist/ Visibility Tools

Isovist

- Local Isovist Measures
- Global Space Syntax Measures
- Semi-local Visibility Measures

Software https://isovists.org/

Decoding Space

- Building/ Road Form Generation
- Street Network Analysis
- Visibility Analysis

Grasshopper https://toolbox.decodingspaces.net/#aboutToolbox

Network Analysis Tools Related

NetworkX

Python

https://networkx.org/

momepy

Python

http://docs.momepy.org/en/stable/

Urbanity

Python

https://github.com/winstonyym/urbanity

t4gpd

Python

https://t4gpd-docs.readthedocs.io/

An Overview of Space Syntax Tools

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- Local Isovist Measures
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Software https://isovists.org/

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- Building/ Road Form Generation
- Street Network Analysis
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Grasshopper https://toolbox.decodingspaces.net/#aboutToolbox

Network Analysis Tools Related

NetworkX

Python

https://networkx.org/

momepy

Python

http://docs.momepy.org/en/stable/

Urbanity

Python

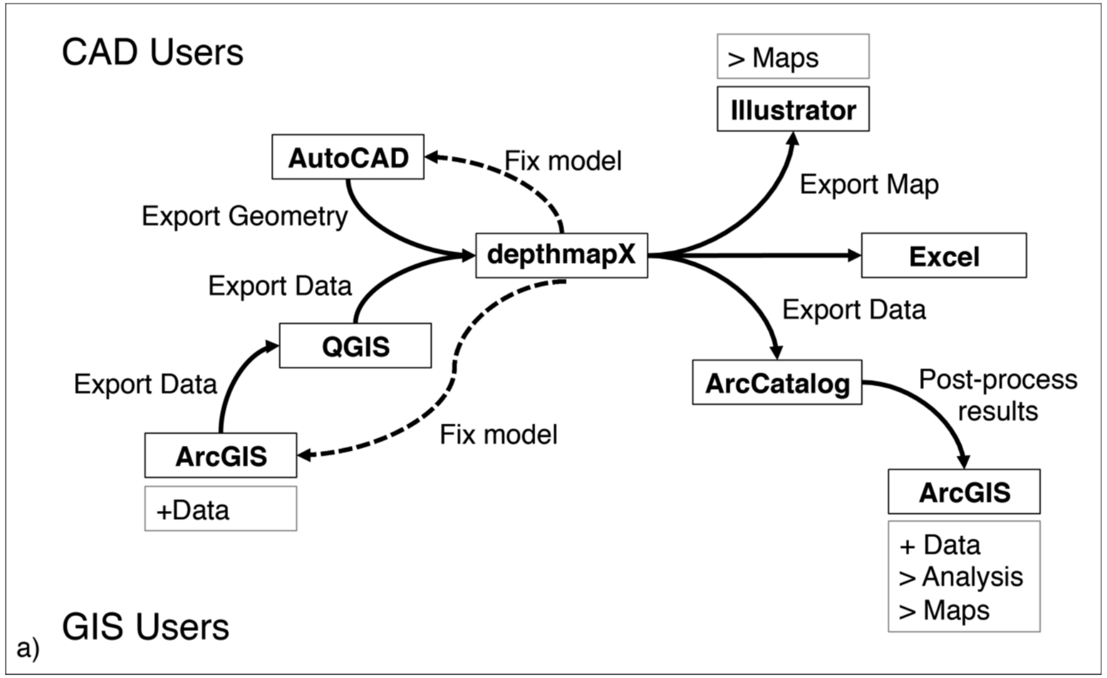
https://github.com/winstonyym/urbanity

t4gpd

Python

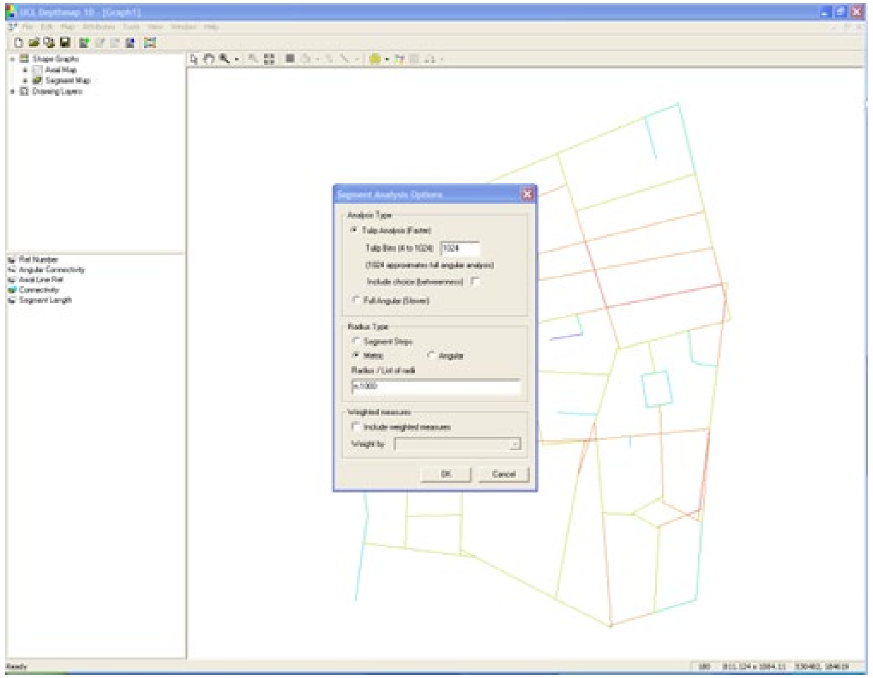
https://t4gpd-docs.readthedocs.io/

DepthmapX



Traditional workflow for using depthmapX in Space syntax analysis

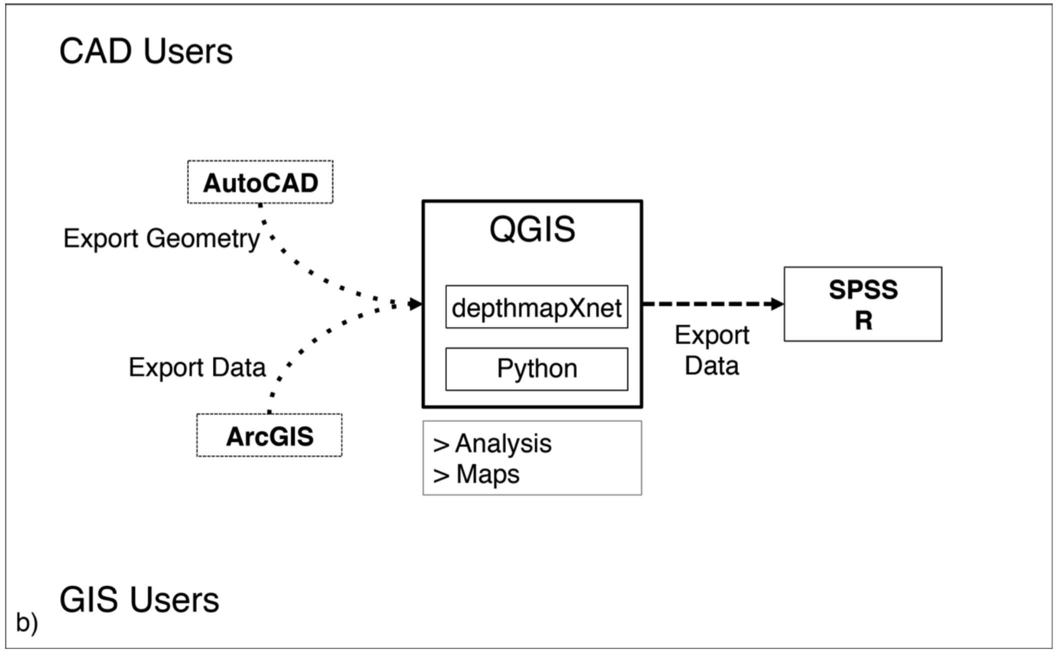
https://github.com/SpaceGroupUCL/qgisSpaceSyntaxToolkit/blob/master/documents/SST_demonstration_workshop.pdf



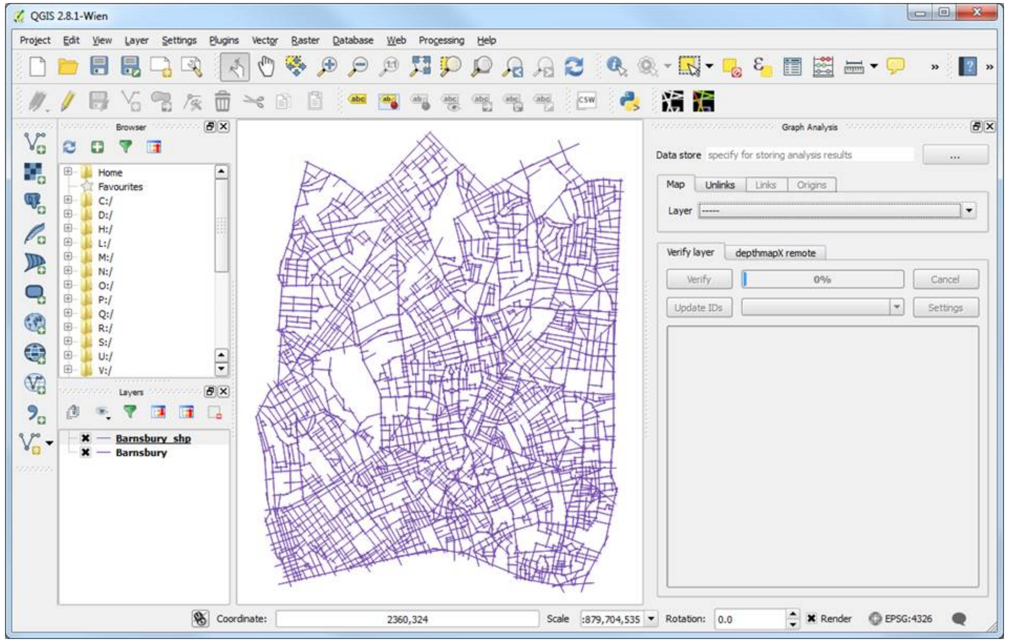
DepthmapX software interface

https://www.spacesyntax.online/software-and-manuals/depthmap/urban-spatial-model/

Qgis Toolkit



Simplified workflow with Qgis toolkit



Qgis toolkit interface

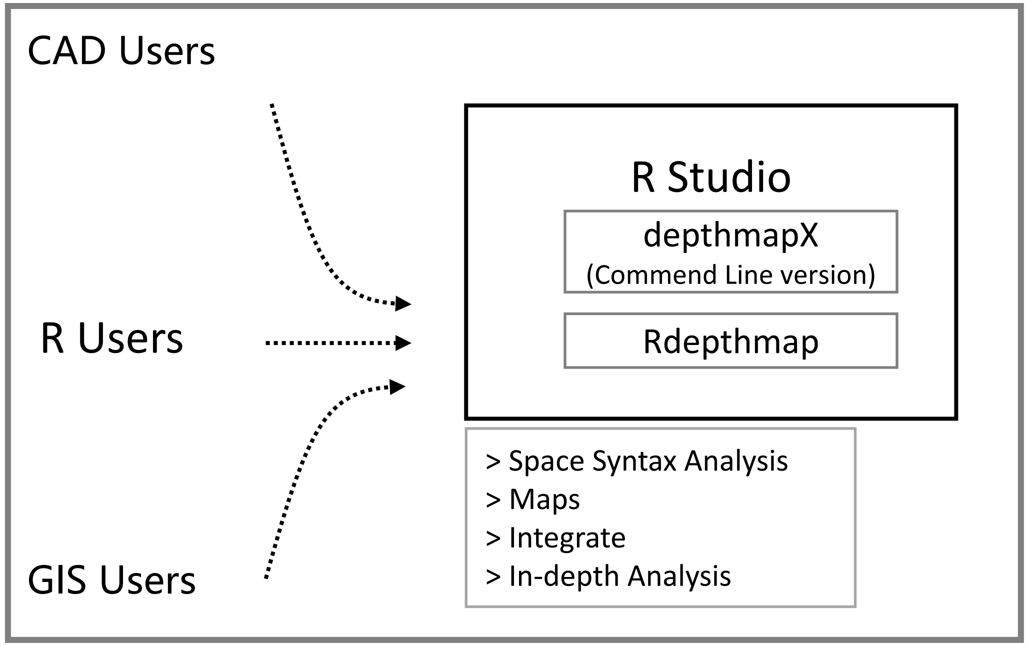
https://github.com/SpaceGroupUCL/qgisSpaceSyntaxToolkit/blob/master/documents/SST_demonstration_workshop.pdf

https://www.spacesyntax.online/software-and-manuals/space-syntax-toolkit-2/getting-started-on-qgis-space-syntax-toolkit/

(For beginners with raw road network data, I would recommend the Qgis toolkit, which includes the raw network processing function and can make multi-platform tasks easier)

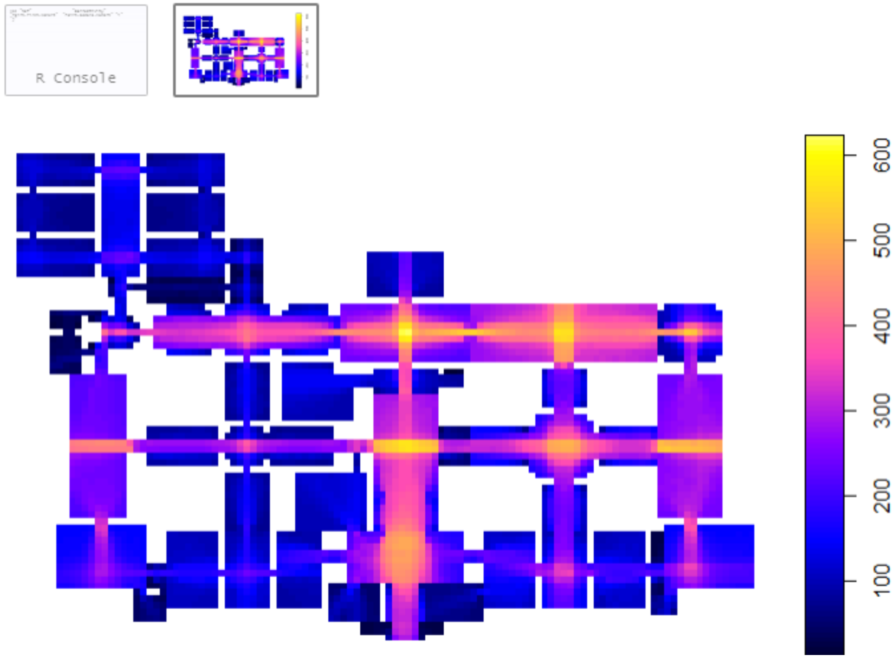
Space Syntax in DepthmapX & Qgis Toolkit & R

Rdepthmap



Further simplified workflow with Rdepthmap

```{r}
rdepthmap::importLines(galleryLines, "data/gallery/gallery.graph")
rdepthmap::createGrid("data/gallery/gallery.graph", gridSize = 0.04)
rdepthmap::fillGrid("data/gallery/gallery.graph", fillX = 2.86, fillY = 6.68)
rdepthmap::makeVGAGraph("data/gallery/gallery.graph")
galleryVGA = rdepthmap::getPointmapData("data/gallery/gallery.graph")$map
names(galleryVGA)
plot(galleryVGA[, "Connectivity"])
```



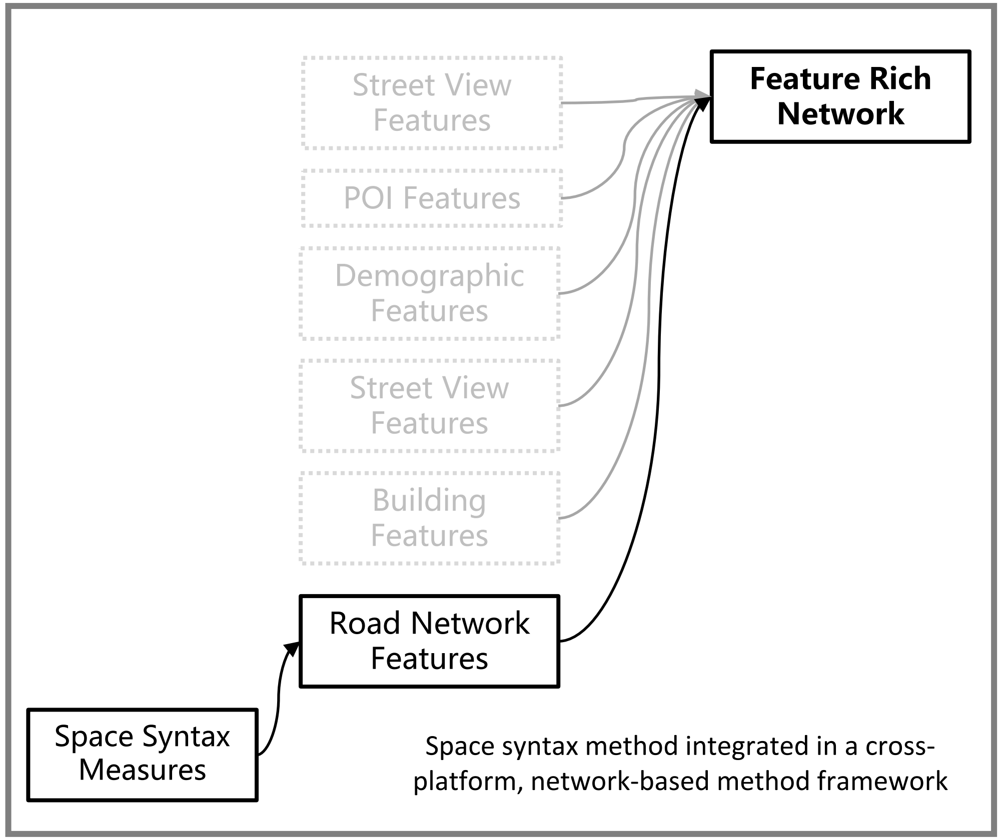
VGA Analysis in Rstudio

https://github.com/pklampros/rdepthmap/tree/master

https://github.com/pklampros/12_sss_workshop/tree/master

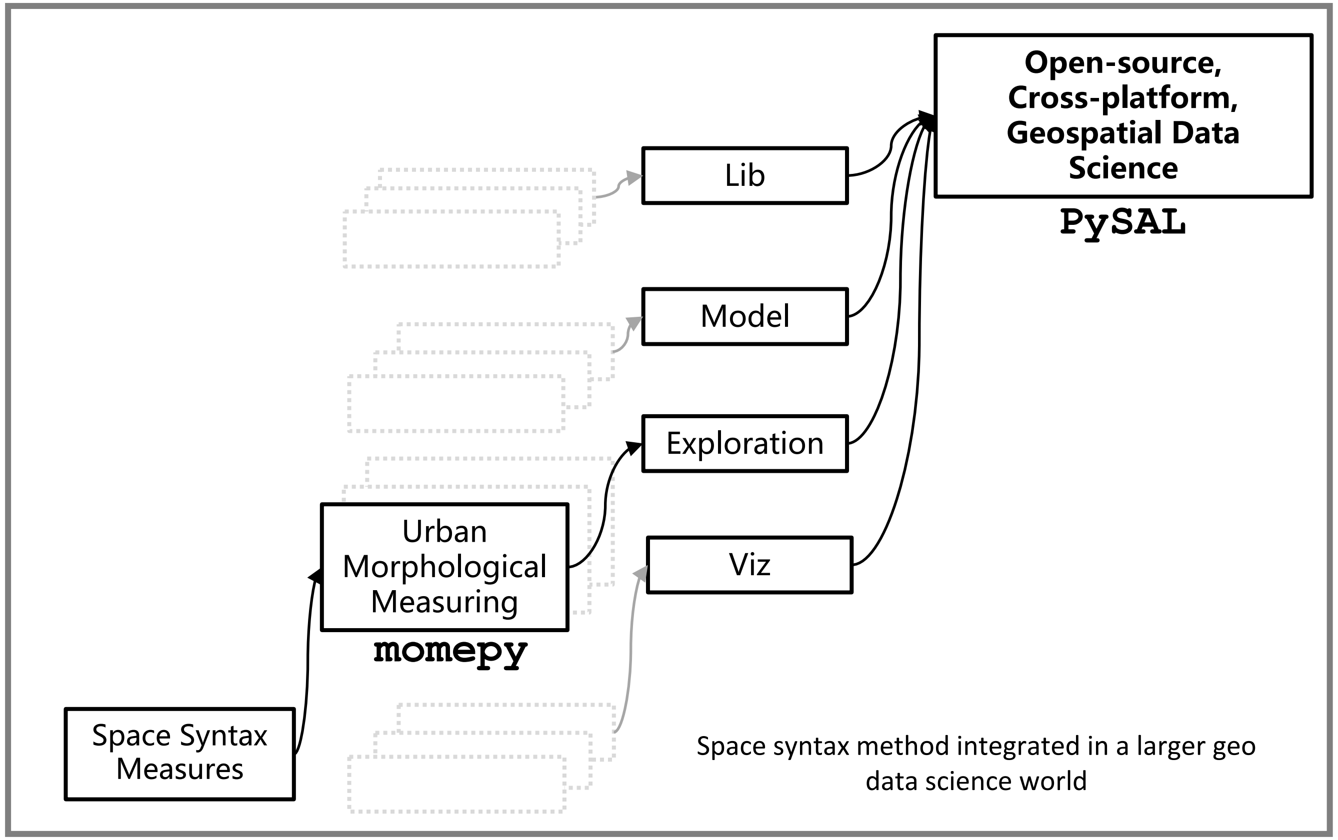
Space Syntax in Python – momepy & Urbanity & More

Urbanity



https://urbanity.readthedocs.io/en/latest/index.html

momepy



http://docs.momepy.org/en/stable/#

http://pysal.org/packages/

Points covered:

- How space syntax define space, spatial relationship, and organize them into a spatial analytics framework
- The most important and frequently used space syntax measures
- Tools applied to space syntax analysis and some latest development
- Hands-on code to begin space syntax analysis in r and python

Possible future Workshop:

Space Syntax in 3D space

Bibliography

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Thanks for listening!