Reuse: On Evaluating the Fitness of Spatial Configurations Before & After Retrofitting for Reuse of Architectural Heritage

Nourian, Pirouz; Bai, N.

Publication date
2021
Document Version
Final published version
Published in
Mastermind Crash

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

MASTERMIND
CRASH

A method to reveal the impact of architectural redesign

edited by Ana Pereira Roders

Contents

Reuse

by Pirouz Nourian & Nan Bai

3.1 Introduction

Focusing on the quality of reuse of buildings with respect to the efficiency of human movement patterns and the effectiveness of allocation of functional spaces with respect to their needs for social encounter and avoidance reveals the configurative nature and the human impact of architectural design. By comparing such functionality assessments before and after a redesign process for retrofitting, a clearer grasp of the effect of the spatial configuration on the efficiency and the effectiveness of a design can be explicated. In configurational analysis the focal point of attention is the structure of the walkable space in the building, detached and abstracted from the shape of the building. In configurational functionality assessment, the focus is to synthesize multiple analyses, aggregate the results, and derive indicators of quality with respect to either quantitative objectives or qualitative ideals.

Does the structure of the space and the allocation of functional spaces to various locations in the spatial network of a building have an effect on its overall functionality/ utility? How can we study these effects? Are the functional spaces placed in their best-fitting locations? Do the design operations like adding an external staircase or tearing down an interior wall make a difference in the accessibility of functional spaces? By digging into this topic, you will gain a methodology with which you can describe and analyse a spatial configuration in a reproducible way.

Learning Objectives
After finishing this course, and having worked on the topic of reuse, you are expected to be able:

- [Knowledge] to describe the functionality of a building using the terminology of network [centrality] analysis.

- [Comprehension] to match their knowledge of network [centrality] analysis to actual situations/examples in indoor spatial configurations, and produce fact sheets on the functionality of a building.

- [Application] to prepare spatial network models for network [centrality] analysis for comparing and judging the change of the configuration of a building before and after a renovation.

Expected Prior Knowledge

All students are welcome to choose the topic of reuse, regardless of their technical knowledge level. However, from a pragmatic point of view, it is recommendable to choose this topic if you have prior affinity with [or enthusiasm for learning] mathematics, programming, and/or computational design. Having some practical knowledge of grasshopper is recommended.

Technical Preparations

Title	Software Installations
Objective	To get all the necessary tools up and running and familiarize yourself with the UIs
Notes	If you need a Windows OS on your Mac; for further info and support on how to do this please go to @hoc: http://adhok.bk.tudelft.nl/site/info/windows-on-mac/
Description	Required Installations for the first Practicum (at home) Needed software packages: Rhino 5, Grasshopper 1 (0.9.0076) **Rhinoceros 5.0**: Can be downloaded from software.tudelft.nl, Go on Installation tab and follow the instructions. **Grasshopper**: from http://www.grasshopper3d.com/ **Gephi**: https://gephi.org/ NOTE: DO NOT TRY TO USE GRASSHOPPER FOR MAC (because it is still a work-in-progress!). Instead, use a Windows OS on your Mac; for further info and support on how to do this please go to @hoc: http://adhok.bk.tudelft.nl/site/info/windows-on-mac/

Platform	Getting started with **Rhino and Grasshopper**:
	Rhino tutorials: (A-Z-Reference)
	      (must watch & practice, about 5 minutes)
	      (must watch & practice, about 1 hour)
	      (must watch & practice, about 2 hours)
	Getting started with Gephi:
	(must watch & practice, about 30 minutes)

Plugins	Centrality Analysis: Rectangle-to-Rectangle graph, using SYNTACTIC and Gephi Accessibility Analysis (optional): CONFIGURBANIST Optional/Extra: The following tools 'might be useful' for your project: SpiderWeb, Mesh+, Weaverbird & Rasterworks.dll: Voxel and Iso-surface Tools: 1, 2, 3, 4, 5

Literature

In this course, we teach the basics of spatial network analysis. These references are for further methodological reading. Technological know-how (related to software) can be strengthened by self-study, practice and active participation in workshops*.

*__Methodology:__ Mathematical Formalisms, Computational Methods (Algorithms represented as pseudo-code) and Data Models

Technology: Programming Languages, Standards, File Types, Software Applications, IDEs, Robotics, Power Tools, etc.

Computational Design Literature:

If you are interested in understanding the fundamental concepts of configurational analysis, then you are advised to remedy your math knowledge by reading extra books e.g. [1] pp.137-181 [2] pp.29-51, [3], [4] pp. 9-26 & pp. 225-236. Most of the topics about computer geometry are covered in [5] pp. 1-5, 7-13, 21-24, 29-33 and [6] pp. 62-63. Highlighted pages are the least you are recommended to read from the following books. For getting started with programming, check [7] (please do the exercises on pages 17, 22, 23, 27, 69, 70, 72), [8], [9], and [10]. For getting started with spatial maths see [11], [12].

[1]   R. Fenn, *Geometry*. Springer London, 2001.

[2]   C. Tremblay, "Mathematics for game developers," 2004.

[3]   M. Batty, *Essential Engineering Mathematics*. 2011.

[4]   D. Cherney, T. Denton, R. Thomas, and A. Waldron, *Linear Algebra*. 2013.

[5]   M. Botsch, L. Kobbelt, M. Pauly, P. Alliez, and B. Lévy, *Polygon mesh processing*. 2010.

[6]   H. Edelsbrunner and J. Harer, *Computational Topology, an Introduction*. 2010.

[7]   R. Issa, *Essential Mathematics for computational design*, 4th Editio. Mc Neel, 2019.

[8]   A. B. Downey, B. • Cambridge, • Farnham, • Köln, • Sebastopol, and • Tokyo, "Think Complexity."

[9]   A. Downey, "Think Python How to Think Like a Computer Scientist 2nd Edition, Version 2.2.23,"   2015.

[10]   E. Matthes, *Python Cash Course*. 2016.

[11]   P. Nourian, "Rudiments of Linear Algebra & Computer Graphics," 2019.

[12]   P. Nourian, "Rudiments of Geometry and Topology for Computational Design," in *Fundamentals of Spatial Computing & Generative Design*, Preprint., no. September, Delft, 2020.

Disclaimer

This is not a contract. This document is only made for informative purposes. No rights, complaints, or excuses can be derived from this document. This course is research-oriented and as such it is inherently experimental. We might deviate from the path described here if/when deemed necessary, observing the class dynamics. Please keep in mind that the content of the 'tasks of the week' and lectures might change during the course. For every major update we shall put an announcement on Brightspace. Considering that this document is going to change a few times, please do not print it.

License and Intellectual Property Rights:

The contents of the lectures, the codes/software applications/add-ons, the approach, the setup, the agenda, and the method of scheduling are the intellectual properties of the instruction team, unless specified and/or licensed otherwise, which are shared with the students and the staff involved in CRASH under a **Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0) License**: https://creativecommons.org/licenses/by-nc-sa/4.0/.

🎩 3.2 Define

Terminologies

Functionality. According to the Merriam-Webster Learner's dictionary, functionality can be 1. [uncountable] the quality of having a practical use, as the quality of being functional (e.g. a design that is admired both for its beauty and for its functionality); 2. [either countable or uncountable] the particular use or set of uses for which something is designed (e.g. The cameras are comparable in price and functionality. It is equipped with new functionalities).

Spatial Functionality. Concerning to the field of architecture/urban design, we define the term spatial functionality as the "efficiency, effectiveness, diversity, and lucidity of a spatial configuration, respectively in terms of its accessibility, centrality, diversity, and visibility distributions", for the sake of our research purpose, where **Spatial Configuration** can be defined as an indoor/outdoor **walkable** network environment.

It is important to bear in mind that the closeness in the sense of **geodesics** (optimal paths through networks) is different from the distance in Euclidean space since you have to walk on a "walkable network" (see the example below in Figure 1)
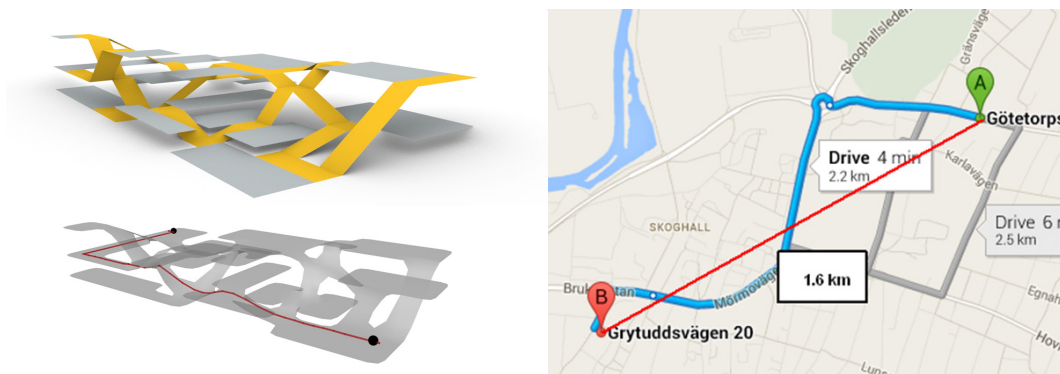

Figure 3.1 : Difference between the geodesic distance and the Euclidean distance. The Euclidean distance for a pedestrian is typically irrelevant in built environments, because the straight path is almost always obstructed and one has to walk through a network to get from A to B; for a bird, however, the distance is typically the length of the straight-line between A & B.

Challenges

Why is research on spatial functionality important? A good design should contribute to both the users in the building and the context where the building fits. From a societal point of view, the following problems can easily occur in an irrational functional design:

- inefficient **accessibility** within large building leads to fatigue and economic loss at work

- ineffective distribution of spatial potentials and spatial needs for **centrality** reduces work efficiency, causes stress, unrest, segregation, fragmentation

- deficient **diversity** makes places socially boring, economically unattractive, and eventually abandoned, thus leaving significant environmental and economical burdens

Through the entire exercise, we would like you to have gained some sense of the following scientific challenges through your readings (self-study):

- How to aggregate accessibility from/to different Point of Interests (POI)?

- How to compute universally comparable indicators of accessibility?

- How to compute universally comparable indicators of centrality?

- How to evaluate centrality levels?

- How to benchmark minimum diversity levels?

Deconstruction

Spatial Configuration is the particular way in which spaces are linked to each other in a building or a built environment. Technically speaking, using the concepts from Graph Theory and Social Network Analysis (which will be covered later in this reader), the way things are related to each other can be modelled as a graph of nodes/vertices and links/edges. Therefore, space can also be seen as a set of labelled objects (nodes/vertices) connected to each other with links/edges. Such an abstraction of space to graph/network is shown below in Figure 2. You may be quite familiar with the form, as it highly resembles bubble diagrams that you may have encountered in your early years in architecture. Interestingly, the nature of bubble diagrams and networks such as metro networks can be described in matrices (watch the full story here).
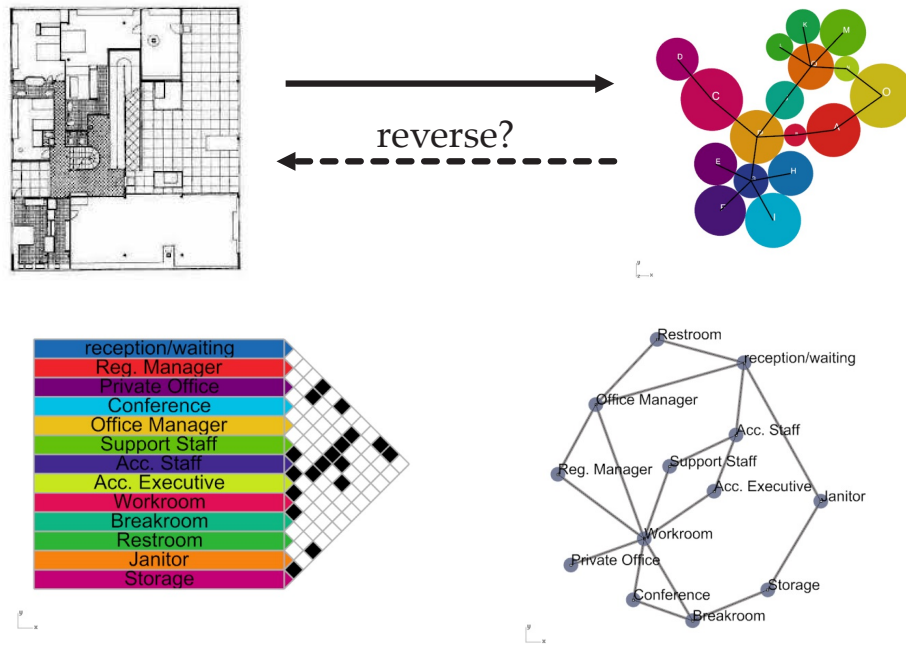
Figure 3.2 : The abstraction of space in architecture plan into a graph/network. Each room is represented with a node (a coloured circle), and two nodes are connected if the rooms are directly connected (e.g. with a door). (Nourian, 2016)

As a supplementary information, Space Syntax methods are also based on Social Network Analysis and/or Graph Theory. You will find certain degree of similarities within the methods if you are familiar with Space Syntax. Feel free to make comparison if you like.

Indicators

Three main indicators will be covered in this topic: efficiency represented as **Accessibility**, effectiveness represented as **Centrality**, and vitality represented as **Diversity**. Here we will give a mathematical definition for each of the indicators, respectively. Don't be afraid of the mathematical formulas at this moment, we will come of their meanings later.

Efficiency w.r.t. Accessibility is the fitness of spatial locations and flows. It can be measured with the temporal efficiency (e.g. logistic efficiency) comparing the spatial distance and the real flowrate within the places:

$$C_i(\rho) = \frac{N}{\sum_{j \in \Omega(i,\rho)} D_{i,j}}, \text{ where } \Omega(i, \rho) = \left\{ j \in V \middle| i \sim j \wedge D_{i,j} < \rho \right\} \text{ is a neighborhood of } i.$$

Effective w.r.t. Centrality is the match of spatial potential and activities happening in the space, and reflects a spectrum of socio-spatial configurations. The spatial effectiveness can be measured with a set of centrality metrics (e.g. closeness centrality):

$$\text{Diversity} = -\sum_{i=1}^{n} p_i \ln p_i, \text{ where } p_i = \frac{N_i}{\sum_{i=1}^{n} N_i}, N_i \text{ denotes the number of POI of } i_{th} \text{ function}$$

Vitality w.r.t. Diversity is the degree of mixed-use in a building/residential block/district. It can be measured with an entropy-based function showing the degree of mix-use:

$$\eta = \sum_i \sum_j T_{i,j} D_{i,j}, \text{ where } T_{i,j}, D_{i,j} := \text{flow rate and distance between } i \text{ and } j.$$

All three indicators will be reached throughout the semester. Possibly more than one methods will be provided to each indicator. It is up to you to decide which method to use for your group project.

Key References

[1] P. Nourian, "Configraphics: Graph Theoretical Methods for Design and Analysis of Spatial Configurations," Doi.Org, vol. 6, no. 14. pp. 1–348, 2016.
https://books.bk.tudelft.nl/index.php/press/catalog/book/546
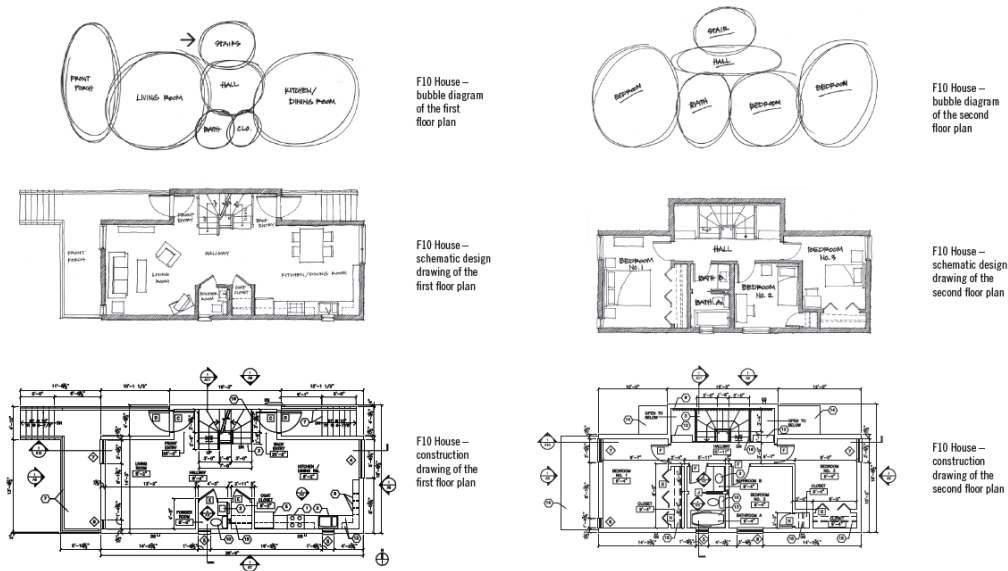
🏃 3.3 Collect

Bubble Diagram and Graph

Figure 3.3 : Bubble diagrams for architecture design (Massengarb et al., 2008).

For many architecture students, bubble diagrams (Figure 3) are the beginning step for the architecture design projects in early years. They provide a structural understanding of the functional requirements of a building: an entrance needs to be connected with a corridor before entering the living room, the canteen needs to be close to the kitchen, etc. This was important for us as novice architecture students to know if our design fulfils the basic needs and provided us ideas on how to arrange architectural floor plans rationally (see this video for the full story).
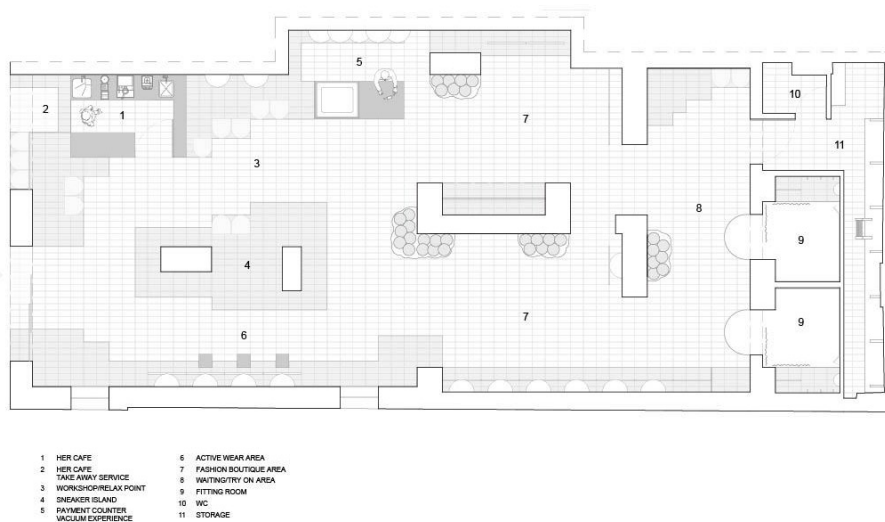

Figure 3.4 : an architecture plan with functional spaces labelled on the graph (https://www.archdaily. com/919104/her-shop-clap-studio/5d01c066284dd152050000e2-her-shop-clap-studio-floor-plan)

As also shown in Figure 2, the bubble diagram is in itself a graph: rooms of different functions are represented as nodes, and the direct connections (for example a door) are represented as links (or edges). All our analyses depend on those graphs. Then the problem is: how to collect the data we need to draw such graph?

The answer is quite simple: we will start from the architecture plan.

As many plans also provide labels of the spatial functions for architects to read and for users to navigate, as is shown in an example in Figure 4 from archdaily.com, the main efforts then go to how do we extract the spatial information systematically as our data.

Walking Spaces, Standing Spaces, and Sitting Spaces

Besides the practical functions, the walkable spaces inside a building can also be annotated with one of the following semantic subdivision:

- Walking spaces are corridors, stairs, ramps, escalators, and all such spaces that should be kept free of obstacles as bridges between pairs of spaces. These spaces mark the routes that are wide enough for people to walk through.

- Standing spaces are platforms on both sides of doors, landings of stairs, or corridor junctions which must be kept horizontal and free of obstacles. These spaces are for humans to stand on for a short while, find their way, and possibly change their paths. Thus, the intersections of walking spaces with other walking spaces or sitting spaces are labelled as standing spaces.

- Sitting spaces are horizontal spaces for stationary objects and moveable furniture. At a medium level of detail, these spaces are rooms to which one can attribute a name/function, at a high level of detail these are the tiles of space where stationary (moveable) objects are placed. Stationary immoveable objects which permanently block pedestrian movement are ignored in this classification because they do not exist in the walkable space network.

The semantic relations between these elements are such that the sitting spaces are connected to each other through walking spaces and standing spaces. The three sorts of spaces can be interpreted as a higher-level meta-function of the walkable space. Such differentiation is not only useful for analysing the space, but also applicable in generative design. An example of using the walking/standing/sitting spaces for such purpose can be found in the following lecture on configurative design:

https://www.researchgate.net/publication/336799509_Configurative_Design_A_Generative_Approach_to_Digitization_Digitalization_and_Digital_Transformation_in_Architectural_and_Urban_Design (video)

This being said, our target data format is going to be a spatial network (or graph) representing the walking space in your building project. The nodes of the graph are going to be the quadrangular tiles (will be introduced next week) separating the rooms; the links of the graph are going to be the direct connections between the tiles (meaning you could literally walk from one tile to the other).

Each node will need to be annotated with two levels of "functions". For a higher level, each tile needs to be labelled as walking, standing, or sitting spaces (**function type**); for a lower level, each sitting space need to be labelled with its practical **function name** (e.g., office, kitchen, storage, shop, etc.).

Data Collection Methods

Generally speaking, the following methods are all helpful to analyse the spatial functionality (i.e., efficiency, effectiveness, and diversity) for different research purposes and complexities. However, for our exercise, we mainly suggest the first- "reading and transforming from building plans" (and second – "experiencing and observing the space occupation", if covid-19 allows us) approach to derive the graph/ network data. However, we do encourage you to explore alternative possibilities of collecting both primary and secondary spatial functionality data (a concept that you should encounter from the very first chapters of this booklet) if you really feel confident, interested and motivated by the examples.

• Reading and Transforming the Building Plans

Trained as architects, it is very intuitive to first read the building plans carefully to understand how the space and the functions are organized. Most of the connectivity information for generating the nodes and edges on the spatial graph/network is clearly shown on the plan. And usually it is already obvious where the walking spaces and sitting places are, as the former mostly correspond with commute space and circulation space, and the latter are probably either given a name/label on the plan or filled with furniture to imply the usage.

A simple (probably too simple for our purpose) but powerful pioneer of such approach is the Convex Map in space syntax, where each room is abstracted as a node and the doors become the edges connection the nodes (see Figure 5).
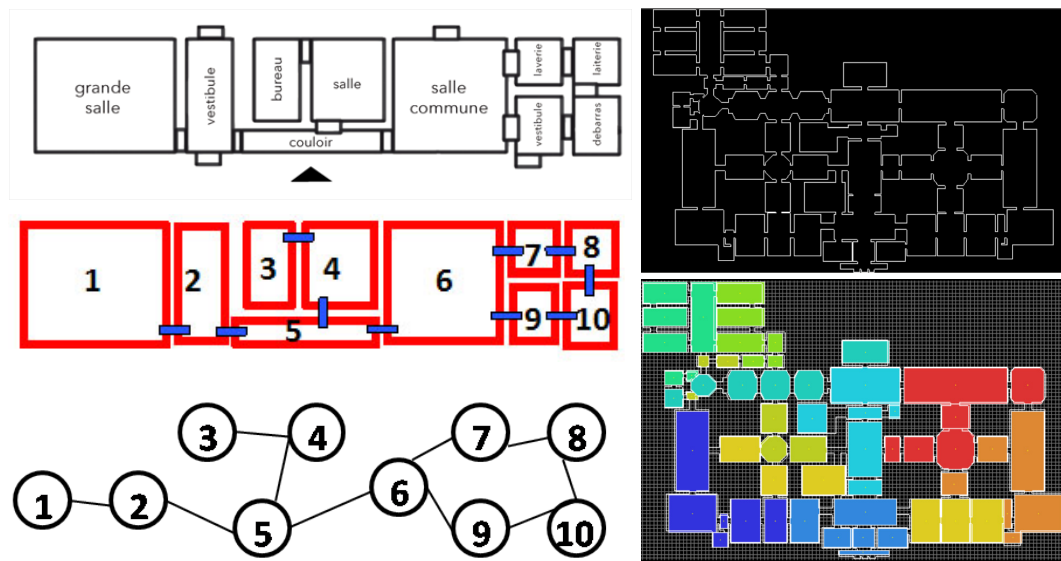

Figure 3.5 : From plan to convex map to show the configuration of the space. ([http://otp.spacesyntax.](http://otp.spacesyntax.net/applying-space-syntax/building-methods/representations-of-space/) [net/applying-space-syntax/building-methods/representations-of-space/](http://otp.spacesyntax.net/applying-space-syntax/building-methods/representations-of-space/))([http://archtech.gr/](http://archtech.gr/varoudis/depthmapX/LearningMaterial/depthmap7convex.pdf) [varoudis/depthmapX/LearningMaterial/depthmap7convex.pdf](http://archtech.gr/varoudis/depthmapX/LearningMaterial/depthmap7convex.pdf))

- Experiencing and Observing the Space Occupation

Sometimes the actual usages of certain spaces are not directly reflected on the maps, especially after some self-organization of the users. Sometimes the spaces are not occupied in the same manner that they are designed for. Sometimes the spaces are not even divided in the same way as the original plan. In all those circumstances, it is important to experience the building yourself to observe and record the actual usage of the space. The methodology Public Spaces Public Life (PSPL) proposed by Jan Gehl has been a systematic way to observe, record, and analyse the place (see Figure 6).
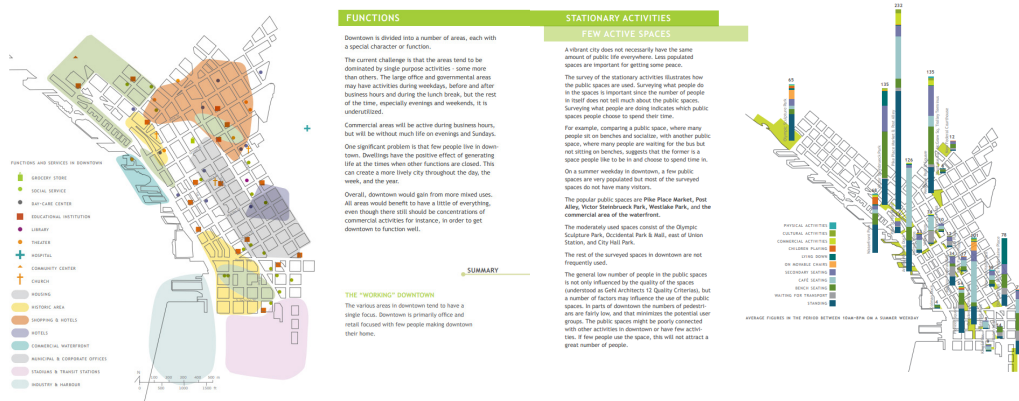
Figure 3.6 : An example of using PSPL to observe and record the usage of public space by people (http://greenfutures.washington.edu/images/publications/Public-Spaces-Public-Life-Downtown-Seattle-Gehl.pdf)

- Monitoring and Recording the Real Behaviour

Though implemented systematically, the human observation may still be biased. We as observers can only be at a spot for a limited time and we have to assume that the samples occurred during the experiment are representative enough. Furthermore, it may be really difficult for human to precisely record the counts, flows, and paths of people. Technological developments in in- and out-door positioning devices and wearable sensors (such as Wi-Fi, GPS, Bluetooth, Ultra-wide Band, etc.) provide us a possibility to monitor and record the exact real-time occupation situation in space (see an example in Figure 7). Privacy, on the other hand, always needs to be a central issue to concern with.
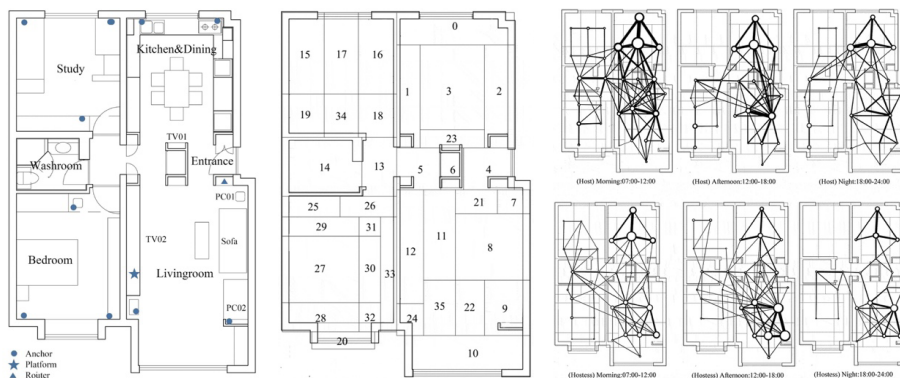

Figure 3.7 : An example of using Indoor positioning devices to track real-time occupation in building (Yang & Huang, 2019).

- Searching and Mining the Archived Documents

For redesign projects, we also care about their status before retrofitting/renovation/ redesign. Plans of the pre-redesign phase are still likely to be available, but sometimes the functions were not written on the plan. What could this space be for at that time? How could this space be occupied and used? In such case it would be impossible to directly observe or monitor the usage of space. You may need to be acting like a detective and dive into the archived documents to find the detailed traces indicated in the description (see an example in Figure 8). Be creative at finding source. It is likely that you will find something in the library and the city archive, but don't miss possible information in old postcards, novels, online blogs, and even social media posts!
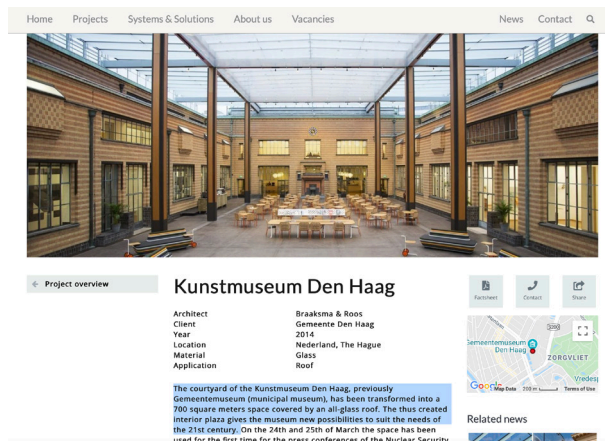
The courtyard of the Kunstmuseum Den Haag, previously Gemeentemuseum (municipal museum), has been transformed into a 700 square meters space covered by an all-glass roof.

The thus created interior plaza gives the museum new possibilities to suit the needs of the 21st century.

Figure 3.8 : An example of how you can dig into the existing documents to search for useful information about functionality in the Kunstmuseum Den Haag (https://www.octatube.nl/en_GB/ project-item/projectitem/142-gemeentemuseum.html).

- Simulating and Analysing the Walking Flow

Finally, sometimes you cannot enter a building for several annoying reasons. Maybe because it's temporally or permanently closed for public (such as an office building). Maybe it is during the restoration phase and not yet open. In such case it is still possible to rationally "guess" (or estimate) how the place will be occupied using simulations. By setting some reasonable rules for the virtual people (we sometimes call them "agents") and let them move in the space, we can also obtain enough theoretical walking flows for research and design purposes (see an example in Figure 9).
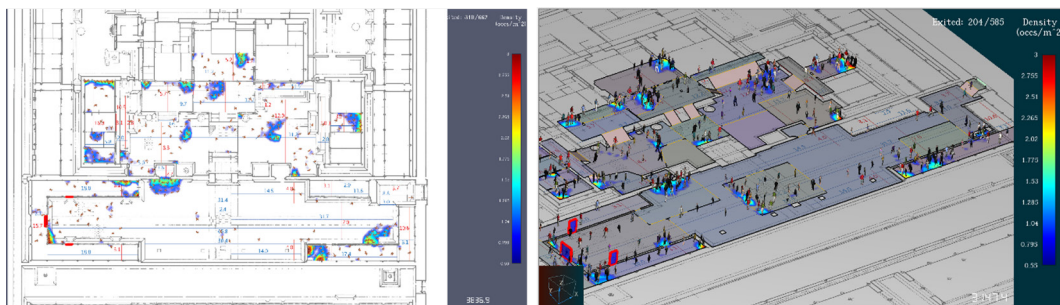

Figure 3.9 : An example of using Agent-based simulation for getting pedestrian's walking flows in Palace Museum, Beijing, China. (Bai et al., 2020)

As a conclusion, there are multiple possible ways to collect the spatial functionality data. Use your creativity and imagination to adapt the fittest method and find the most suitable data for your research interest. As we will mainly deal with the spatial configuration of different function types and practical functions, it is essential to collect plans and information related to function and usage. It is not required for you to collect data of actual/virtual usage (using observation, monitoring, or simulation), but you are welcome to discover those tools.

Exercise Tutorial

Along the topic of reuse, we provide you with an additional excel file to help you record, organize and structure the data that you will collect (and generate). Every week you will need to fill in some columns in the first sheet ("_weekly progress_", as shown in Figure 10) of the table to record your progress. An example from last year is given. Start checking the file and filling the information of first two weeks.

Basic Information (Week1)			Function List (Week 2)		
Content	Answer		ID	Function Type	Function Name
Student Name				Walking/Standing/Sitting	eg. Kitchen, Office, Reading Space
Student ID			0	Sitting Space	Exhibition
Architect Name	O-office Architects		1	Sitting Space	Head Office
Case Name	Stone Art Gallery		2	Sitting Space	Meeting
Case Place	Guangzhou, China		3	Sitting Space	Office
Case Size	1270 m2		4	Sitting Space	Outside Platform
Original Construction Date	1960s		5	Sitting Space	Reception
Renovation Date	2013		6	Sitting Space	Relaxation
Original Main Function	YJQ Factory		7	Sitting Space	Storage
Main Function Now	Art Gallery		8	Sitting Space	Technical
			9	Sitting Space	Toilet
			10	Standing Space	Buffer Zone
Reason for Function Change			11	Standing Space	Crossing
			12	Standing Space	Ending Zone
Attitude After Renovation			13	Standing Space	Out
Attitude Before Renovation			14	Standing Space	Platform

Figure 3.10 : Example of the Sheet "weekly progress" that we provide you for organizing your data

At this stage, you are required to make a list of at least 15 different types of functional spaces that existed and are existing in your case before and after the redesign. Among the functional spaces, at least one should be standing space and one should be walking. You can always add to the list some new functional spaces after you start building your model and labelling the nodes, but it is crucial to have a broader idea of what might come.

We will show you next week how to generate a spatial network from the plans that you have collected, after which you will be filling the second sheet ("_Detailed Node List_", as shown in Figure 11) and annotate each node with its function.

ID	Function Type	Function Name	Area	Depth from the Outside World	Degree Centrality	Closeness Centrality	Betweenness Centrality	Eigenvector Centrality
	Assigned by Hand with help of Syntactic		Known with Rhino Model			Computed with Gephi		
0	Standing	Ending Zone	19,897432		6	0.159091		112.916.667	0.372095
1	Sitting	Relaxation	41,42423		6	0.158192		1.333.333	0.4079
2	Sitting	Relaxation	41,731049		6	0.140234		41.983.333	0.198763
3	Sitting	Meeting	4,498588		4	0.124077	0.333333		0.112605
4	Walking	Passway	2,831295		6	0.125749	6.7		0.169207
5	Walking	Passway	2,679318		8	0.14094		81.033.333	0.259511
6	Standing	Buffer Zone	6,915867		6	0.160612	275.95		0.381233
7	Sitting	Exhibition	41,42423		6	0.157598	0.5		0.413745
8	Sitting	Meeting	24,865231		10	0.141892	81.85		0.342082
9	Standing	Buffer Zone	6,877326		4	0.159091		59.866.667	0.321745
10	Sitting	Exhibition	41,42423		6	0.157598	0.5		0.410921
11	Sitting	Meeting	33,899603		10	0.141892	70.9		0.386479
12	Sitting	Outside Platform	117,263369		4	0.125561		0	0.179809
13	Walking	Hall	195,56637		22	0.185841	1328.1		1
14	Sitting	Exhibition	41,42423		6	0.157598	0.5		0.39331
15	Standing	Buffer Zone	13,978969		8	0.16	101.95		0.499506
16	Walking	Passway	10,097707		6	0.140234		4.416.667	0.271262
17	Sitting	Exhibition	18,903782		6	0.138843	0.333333		0.28972
18	Standing	Ending Zone	17,04686		4	0.112		5	0.044234

Figure 3.11 : An example of the Sheet "Detailed Node List" that we provide you to annotate the nodes in your graph

Key References

[1] Masengarb, J., Rehbein, K., & Norris, B. (2008). *The architecture handbook: a student guide to understanding buildings*. Chicago Architecture Foundation. pp. 230-239.
https://discoverdesign.org/sites/default/files/2018-08/CAC_Bubble_Diagrams.pdf

[2] Nourian, P. (2019). Configurative Design A Generative Approach to Digitization, Digitalization, and Digital Transformation in Architectural and Urban Design, lecture note. pp. 115-123.
https://www.researchgate.net/publication/336799509_Configurative_Design_A_Generative_Approach_to_Digitization_Digitalization_and_Digital_Transformation_in_Architectural_and_Urban_Design

[3] UCL Space Syntax. Representations of Space.
http://otp.spacesyntax.net/applying-space-syntax/building-methods/representations-of-space/

[4] Gehl, J. Public Spaces Public Life.
https://gehlpeople.com/talks_article/public-space-public-life/

[5] Yang, L. & Huang W. (2019). Multi-scale analysis of residential behaviour based on UWB indoor positioning system-a case study of retired household in Beijing, China, *Journal of Asian Architecture and Building Engineering*, 18:5, 494-506, DOI: 10.1080/13467581.2019.1682000
https://www.tandfonline.com/action/showCitFormats?doi=10.1080%2F13467581.2019.1682000

[5] Gehl, J. (2011). *Life between buildings: using public space*. Island press.

[6] Hanson, J. (2003). *Decoding homes and houses*. Cambridge university press.

[7] Bai, N., Nourian, P., Xie, A., Pereira Roders, A. (2020). Towards a finer heritage management: evaluating the tourism carrying capacity using an agent-based model. In *RE: Anthropocene, Design in the Age of Humans - Proceedings of the 25th CAADRIA*. Vol. 1. 2020. p. 305-314. https://www.researchgate.net/publication/343685047_TOWARDS_A_FINER_HERITAGE_MANAGEMENT_Evaluating_the_Tourism_Carrying_Capacity_using_an_Agent-Based_Model

♟ 3.4 Classify

Data Format Revisited

As we have already discussed last week, we need a specific data format of data to study the spatial configuration and spatial functionality. It should be a graph/network of spatial configuration with labels of functions annotated on each node. The base of this graph, however, should reflect the shape of the walkable space, as a 2-manifold mesh (further reading).

What is then a 2-manifold mesh? For a comprehensive long story, you could refer to this paper:

https://www.researchgate.net/publication/324921216_Topology_On_Topology_and_Topological_Data_Models_in_Geometric_Modeling_of_Space

For a simpler understanding, a 2-manifold geometry in a continuous setting is a surface that is locally everywhere planar, i.e., topologically similar to a 2D Euclidean plane, but perhaps globally non-planar.

When we model the walkable space as a 2-manifold mesh, we can literally walk from a tile on the mesh to its adjacent tiles directly without any obstacle (see Figure 12).
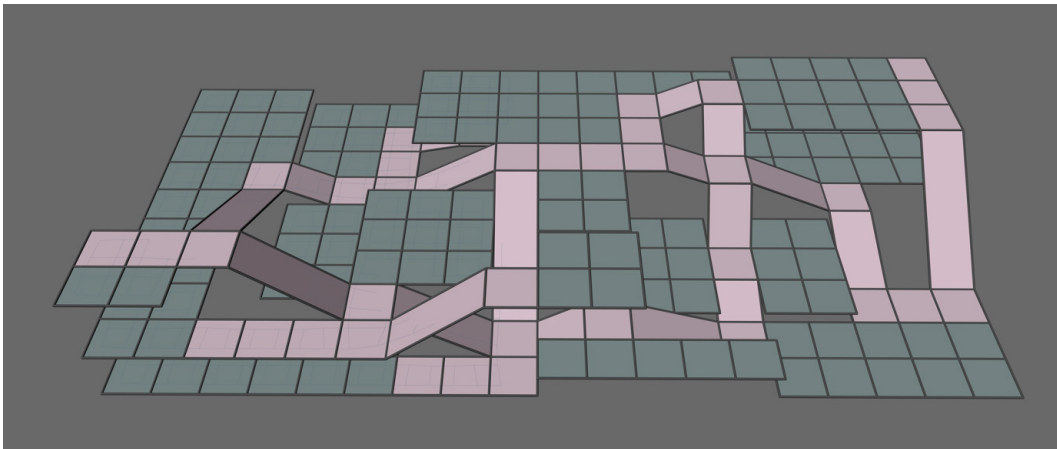
Figure 3.12 : An example of a valid 2-manifold and its "tile geometry" (Algebraic Topology)

Walkable Surface Mesh (revisited) and Why it Matters

The idea of design and analysis of spatial configurations is to model the shape of the walkable space with a correct topology (the connectivity structure) and then extract the topology of the shape of space as a graph/network. We propose a semantic subdivision of walkable spaces into 'walking, standing, and sitting' spaces (check the material of previous week).

It is important to note that we do not model the spaces that are not walkable, e.g. those occupied by immoveable furniture, or those whose ceiling heights are not sufficient, and we model elevators as standing spaces linked with 'hyperlinks'.

If you are interested in the use of these principles in generative design see this

lecture: Topo-Logical Design, pp.115-123. In the context of assessing the functionality of buildings, we model their spatial configurations according to these guidelines and they can be seen as the inverse of the generative design process mentioned in the referenced lecture notes.

What is a Valid Walkable Surface Mesh?

Note: in the process of modelling the walkable surface, the topological validity of the surface is critically important because without a valid topological surface we cannot compute spatial networks. However, geometric deviation and error is not very important (see an example in Figure 13), specially if we are not computing accessibility.
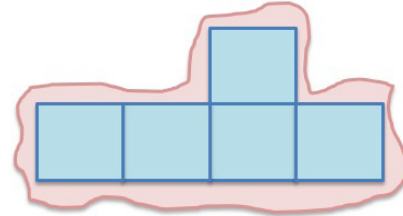
Figure 3.13 : The global precision of the model in terms of its correspondence with the floor plan is not critically important

The basic idea of generating the walkable surface is to put quadrilateral 'tiles' on the floor such that a human can walk from one tile to another. Thus, if a human cannot walk through an edge of a tile to another, e.g. because the other one does not have a sufficient ceiling height, or because there is a wall between the two quad tiles, then DO NOT make the two tiles adjacent. The walkable manifold mesh must be drawn such that it:

- must be a 'valid complex', i.e. the vertices of two adjacent faces must be exactly coincident (share the same positions) along the shared edges (see below in Figure 14 example of valid/invalid tessellation/complex)[1].

- Consists of only quadrangles (not necessarily rectangles)

- It is a 2-manifold mesh (see below in Figure 15 non-manifold mesh examples)
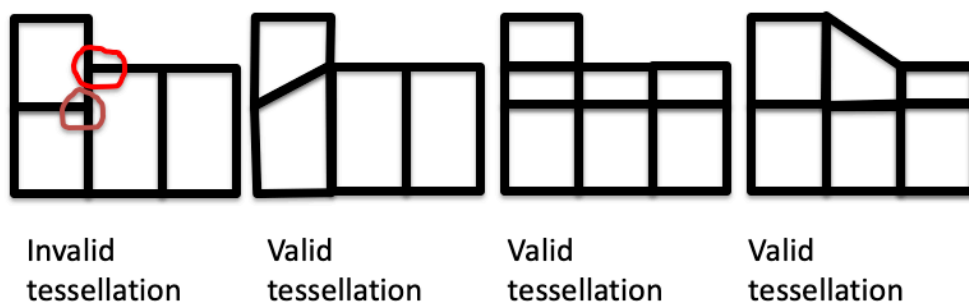
Figure 3.14 : Valid/Invalid Complex and tessellation in the sense of its geometric precision

---

1   Note: here you actually have two choices, a. drawing *a strictly valid mesh* such as is required in this bullet point, and later using grasshopper to *generate the edges automatically*; b. *not strictly obeying the requirement* here, but add edges *manually*. Both choices work, and they take eventually similar amount of working load. It is up to you to decide how to build your model, as long as we can later have a valid graph. The model tutorial *example_simple_graph.3dm* given is based on the choice b.
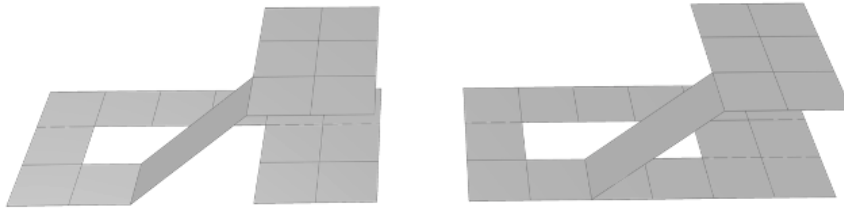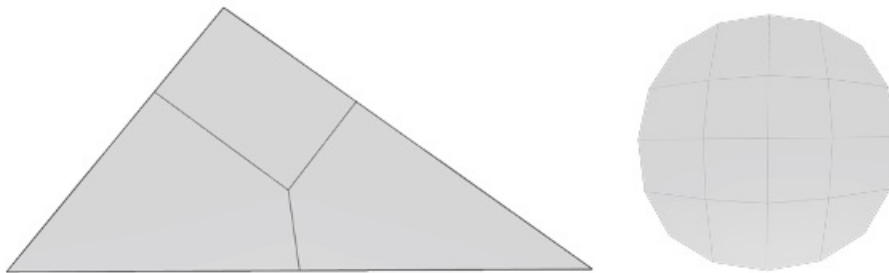
Valid (manifold) tessellation   Invalid (non-manifold) tessellation

Figure 3.15 : Valid/Invalid manifold tessellation

- A mesh edge can have either two faces incident to it or only one face (if it is on the border of the surface).

- Almost every shape can be approximated by means of quadrangles. See examples below in Figure 16.

Figure 3.16 : These two examples show how non-quadrangular shapes can either be 'quadrangulated/ quadrilateralized' accurately (as the triangle on the left) or be approximated by quadrangles (as the circle on the right).

In principle, multiple options can lead to the same final results of such a walkable mesh, and thus leading to a spatial configuration graph, which may include:

- Topological Skeleton Construction
- Constrained Delaunay Triangulation
- Voxelization
- Arbitrary Tessellation
- Manual Mesh Tessellation

In this exercise, we will guide you how to manually make the mesh tessellation and then derive a spatial network out of the mesh using Grasshopper. However, you are still encouraged to discover the other possibilities.

Exercise Tutorial

These are some tips and tricks on how to draw walkable surface meshes in Rhino 5 on Windows. For Mac versions or other versions of Rhino some things might be different.

Import your plan into Rhino using command "PictureFrame" and "scale " it to the proper size. Place the floor plans of different height into their correct position. We suggest you to make different layers for each plan:
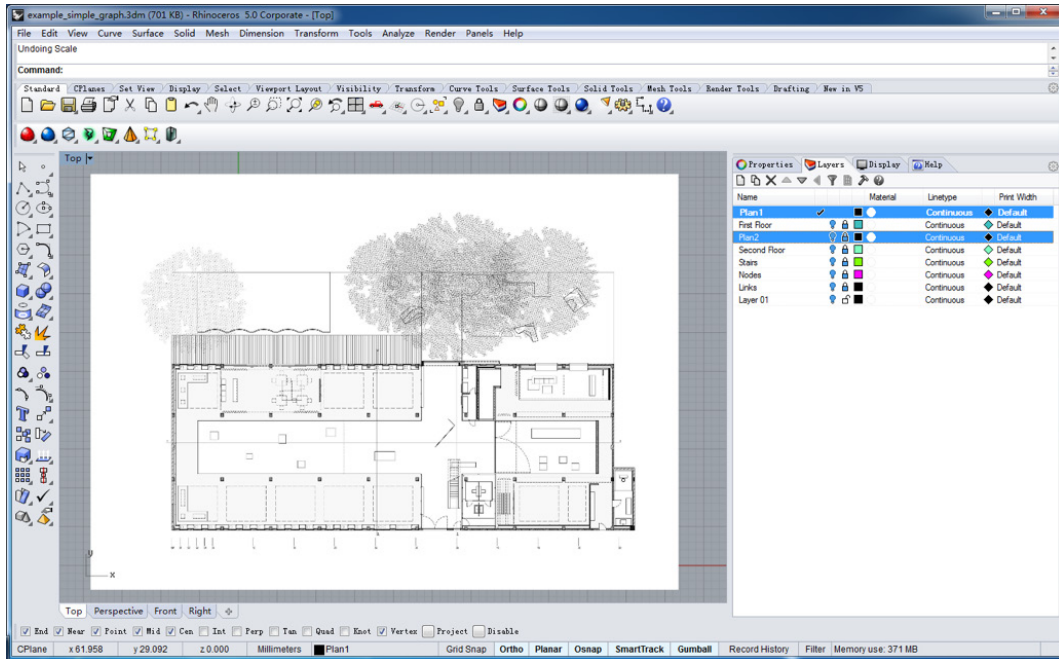
Add a new layer and call it Quad-Meshes (or add different layers for different plan height), then give the layer a distinct color, e.g. Turquoise or something like that. Then start drawing the quad mesh faces using the 3D Mesh face command. It is important to make a abstract quadmesh representing the overall "**outside world**", which later you will need to connect to all the nodes representing the entrance/exit.
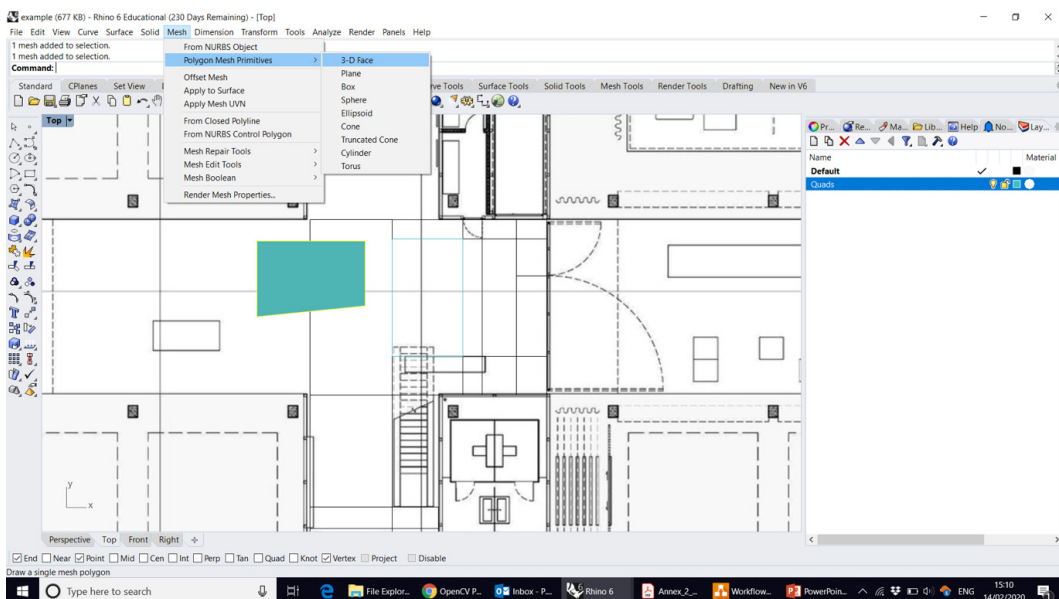
Make sure that the snapping option for mesh vertices is turned on:
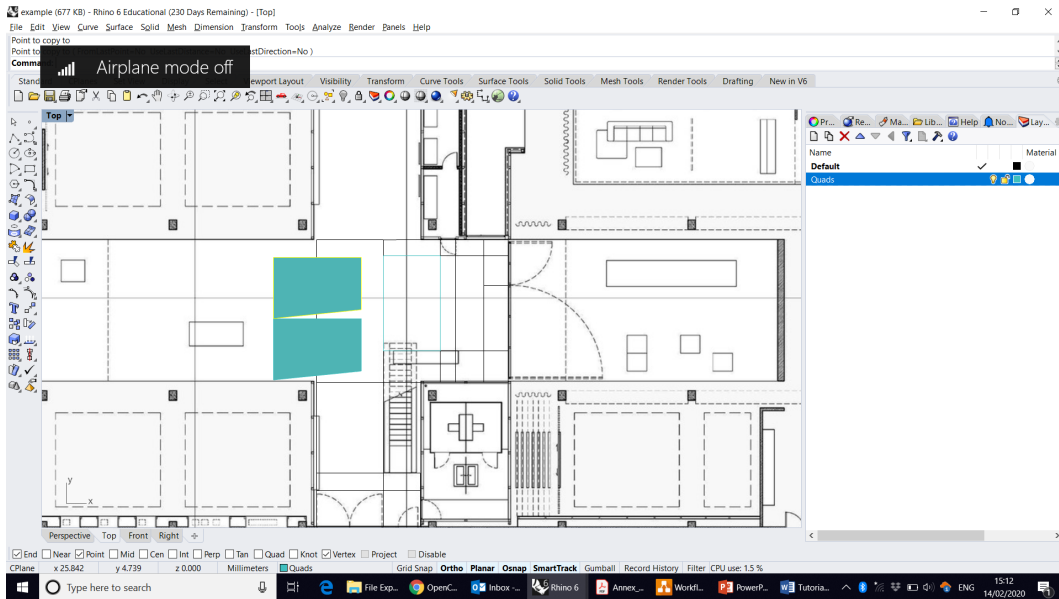
You can press Function+F10 to turn on Mesh Vertices in case you need to edit the mesh quads. Alternatively, you can access this tool via the command line by typing "PointsOn".
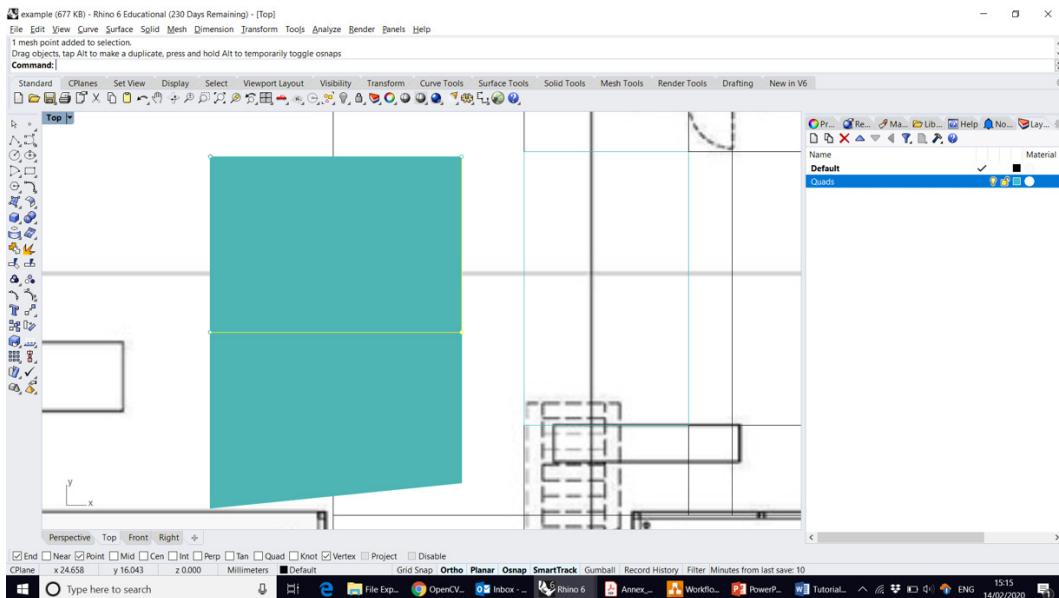
It might be handy to set the view style to technical:
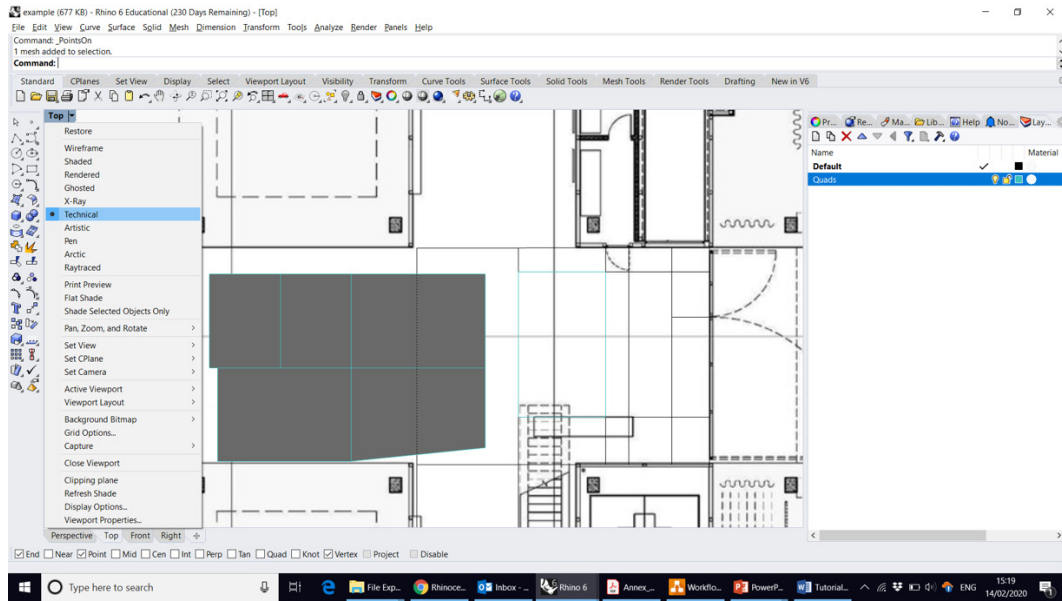
After drawing the meshes, add them into the grasshopper with button "set multiple meshes" and compute the centre points of all of them, sort the points to make the later labelling job easier:
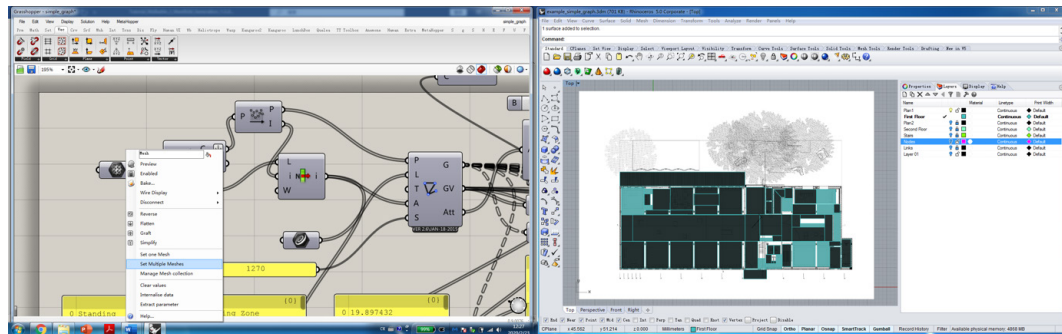
Create a new layer called "Nodes". Bake the sorted points in grasshopper back to rhino, and put the nodes into the layer "Nodes":
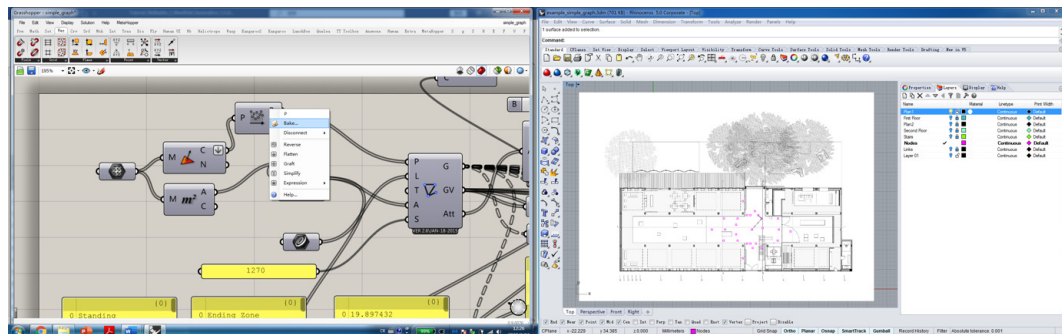
Create a new layer called "Links". Draw a link between the nodes if there is a direct connection between the spaces, i.e., people can walk across the space. Use "Line" tool/command to draw the links in Rhino. After drawing all the links, select all of them and use "add multiple curves" to add them into grasshopper. This is a very important

step, as you need to be careful of the topological relations/connections. It is very easy to miss one or two links at the beginning. However, it does not matter that much as you can always add the ones that you have missed in the beginning later. But make sure to re-add all the links to grasshopper when you make any changes. Remember to connect entrance/exits nodes to the outside-world node. It will be used to demonstrate the accessibility of the building.
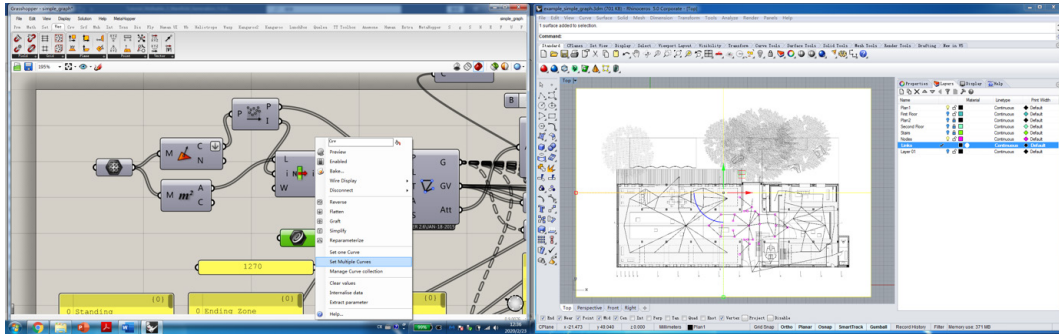
Input the links and nodes that you have into the tool "GraphFromNodes&Links" and output the default values into the tool "DiskoGraphDrawing" of SYNTACTIC library and you will see a default graph with indices of each node displayed (you need to set a plane in Rhino for the graph to display).
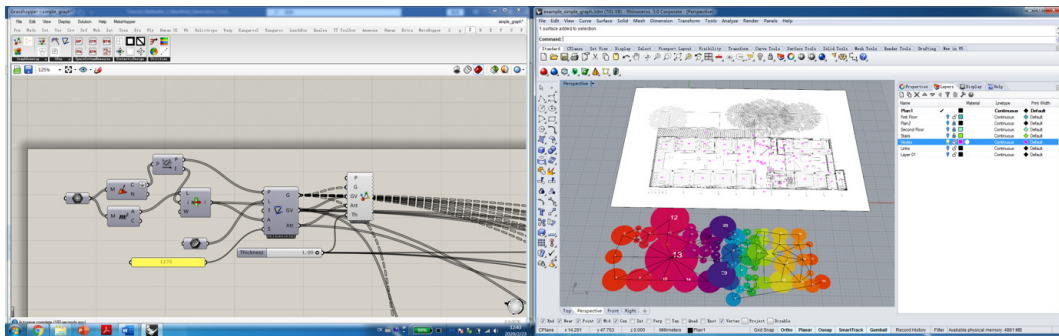
Now that you have the topological nodes and the plan displayed next to each other, you will need to open you excel sheet Reuse_Progress_Document_CASENAME_1.1.xlsx and label each node with their function type (sitting/standing/walking) and their function name from the list you have in the last week.

Later you can copy-paste the labels that you make into grasshopper panels and you can then change your display with a better denotation. You can also copy-paste the data/information from grasshopper into excel to prepare the Area column in the node list and From/To columns in link list, which will later be used in Gephi.

Play with the grasshopper example given to you. In Grasshopper, you can see where a component comes from (which menu/plugin) by pressing Ctrl+Alt+ Clicking LMB (Left Mouse Button). You have full freedom to discover what are the tools doing if interested.

Key References

[1] Masengarb, J., Rehbein, K., & Norris, B. (2008). *The architecture handbook: a student guide to understanding buildings*. Chicago Architecture Foundation. pp. 230-239.
https://discoverdesign.org/sites/default/files/2018-08/CAC_Bubble_Diagrams.pdf

[2] Nourian, P. (2019). Configurative Design A Generative Approach to Digitization, Digitalization, and Digital Transformation in Architectural and Urban Design, lecture note. pp. 115-123.
https://www.researchgate.net/publication/336799509_Configurative_Design_A_Generative_Approach_to_Digitization_Digitalization_and_Digital_Transformation_in_Architectural_and_Urban_Design

[3] UCL Space Syntax. Representations of Space.
http://otp.spacesyntax.net/applying-space-syntax/building-methods/representations-of-space/

[4] Hanson, J. (2003). *Decoding homes and houses*. Cambridge university press.

[5] Nourian, P. (2019). Topology and Topological Data Structures in Geometric Modelling
https://www.researchgate.net/publication/324921216_Topology_On_Topology_and_Topological_Data_Models_in_Geometric_Modeling_of_Space

🎅 3.5 Analyze

Recall in the section 3.2 we introduced you three indicators, i.e., **Vitality w.r.t. Diversity**, **Efficiency w.r.t. Accessibility** and **Effectiveness w.r.t. Centrality**. All of them were equipped with some mathematical equations. We promised that we will explain the meaning to you later. That is exactly what we will do in this and next weeks.

First let's dig in the topic of **Effectiveness w.r.t. Centrality** and discuss about some basic knowledge of Graph Theory and Social Network Analysis.

Graph Representation

You have already seen an example of how we would normally represent a graph/network in Figure 2 on the bottom left corner. We called it a "relationship chart" of different function nodes, where each black grid means that the two functional nodes are directly linked with each other. However, the official name of the chart is actually an "Adjacency Matrix". The following Figure 17 show you several different representation methods of a Graph $G = (V, E)$, where G means the graph as a whole, V are all the nodes (vertices), and E are all the links (edges). You should be already familiar with those concepts by now. Previously we were referring to the spatial network, where the nodes were places and links were connections. This week we will come back one step to the graph/network in social relationship. Here each node can be a person, and the link can be the relationship/friendship between the two people. Hope you can see the connection between spatial and social network by the end of this week.
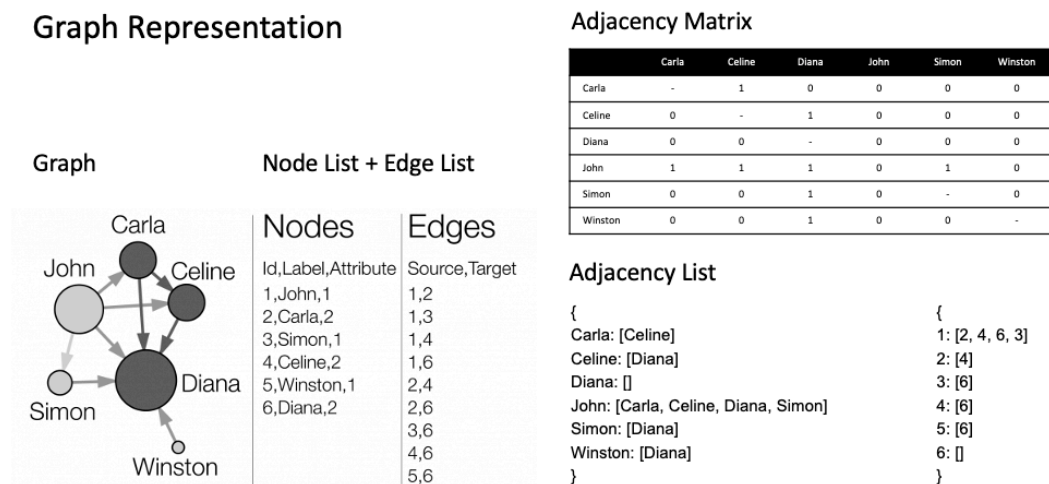

Figure 3.17 : Several ways to represent a graph – diagram, node list, edge list, adjacency matrix, and adjacency list

Though the representations seem different, they are all about the same kind of relationship between the seven people. In the excel file we give you, the sheet 2 and 3 are respectively a node list and an edge list. We choose to use this representation in this course because it is easy to interact both with Grasshopper and Gephi for your exercise.

Centrality Measures in Social Network

As you may have noticed in your excel file, we want you to compute four different centrality measures: degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. There are actually more centrality measures, but these four are the most basic and commonly used. We will introduce them one by one and show you what it particularly means. We will keep using the example above about the friendship in seven people, but instead of treating it as an original directed graph (one-side friendship), we will assume it is an undirected graph to make the calculation easier. For each centrality, we will provide you with its mathematical formula and show you how to do the math. But you are not required to be able to fully understand the equations as long as you understand the story behind. In your exercise, Gephi will do all the math for you!

- Degree Centrality – how many friends do you have

$$C_{\deg}(i) = \frac{\deg(i)}{|N| - 1}$$

The first centrality measure just simply counts the number of neighbours of a node and normalize with the total number of nodes in the graph. In a social network, it shows how many friends you have. It treats the people with the largest number of friends as the most important (or central). In this example, it is Diana who has the most friends.
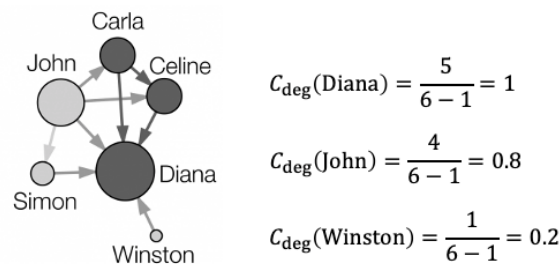

$$C_{\deg}(\text{Diana}) = \frac{5}{6 - 1} = 1$$

$$C_{\deg}(\text{John}) = \frac{4}{6 - 1} = 0.8$$

$$C_{\deg}(\text{Winston}) = \frac{1}{6 - 1} = 0.2$$

Figure 3.18 : Some calculation of degree centralities for the example social network

- Closeness Centrality – how close are you to everyone else in the network

$$C_{close}(i) = \frac{|N - 1|}{\sum_{j \in N, j \neq i} D_{i,j}}$$

The second centrality measure counts the reciprocal of the total distance of a node to all the other nodes in the network. In a social network, it shows how close you are to the other people. The less distance you are in friendship chains with all the other people, the more important you are. In this example, it is also Diana who is the closest to all the other people.
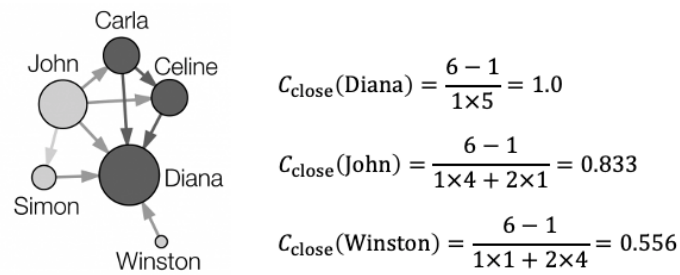
$$C_{\text{close}}(\text{Diana}) = \frac{6-1}{1 \times 5} = 1.0$$

$$C_{\text{close}}(\text{John}) = \frac{6-1}{1 \times 4 + 2 \times 1} = 0.833$$

$$C_{\text{close}}(\text{Winston}) = \frac{6-1}{1 \times 1 + 2 \times 4} = 0.556$$

Figure 3.19 : Some calculation of closeness centralities
for the example social network

- Betweenness Centrality – how many times you are on a shortest path of friendship chain

$$C_{betw}(i) = \frac{1}{\frac{(n-1)(n-2)}{2}} \sum_{j,k \in N \setminus \{i\}, j < k} \frac{\sigma_{jk}(i)}{\sigma_{jk}}$$

The third centrality measure counts the number of times a node happens to be on a shortest path between a pair of nodes in a graph. In a social network, it shows your position between different groups of people. The higher your betweenness centrality, the more likely you are the bridge between several "unconnected" subgroups. In this example, Diana is the only friend of Winston, so she also becomes the bridge of Winston and all the others.

$$C_{\text{betw}}(\text{Diana}) = 0.5$$

$$C_{\text{betw}}(\text{John}) = 0.1$$

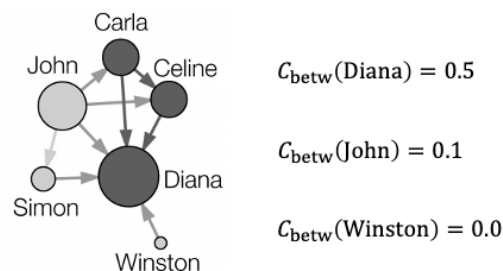$$C_{\text{betw}}(\text{Winston}) = 0.0$$

Figure 3.20 : Some calculation of betweenness
centralities for the example social network

- Eigenvector Centrality – how important your friends are in the network

The fourth measure is a bit complex in the sense of mathematics, so we omit the formula (the full story of spatial eigenvector centrality is explained here). But the idea is not difficult to understand: this measure not only captures how you are important, but also how important your friends are in the whole network. In a social network, those "secret" people "behind" the famous people can occur with a low degree centrality but high eigenvector centrality. A related concept of this centrality is the Google's PageRank algorithm, where the portals connecting to other important sites will also be regarded as critical. In this example, we will see that John also has a high eigenvector centrality because both he and his friend Diana are "important".
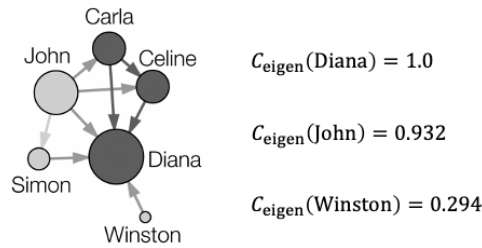
$$C_{eigen}(Diana) = 1.0$$

$$C_{eigen}(John) = 0.932$$

$$C_{eigen}(Winston) = 0.294$$

Figure 3.21 : Some calculation of eigenvector centralities for the example social network
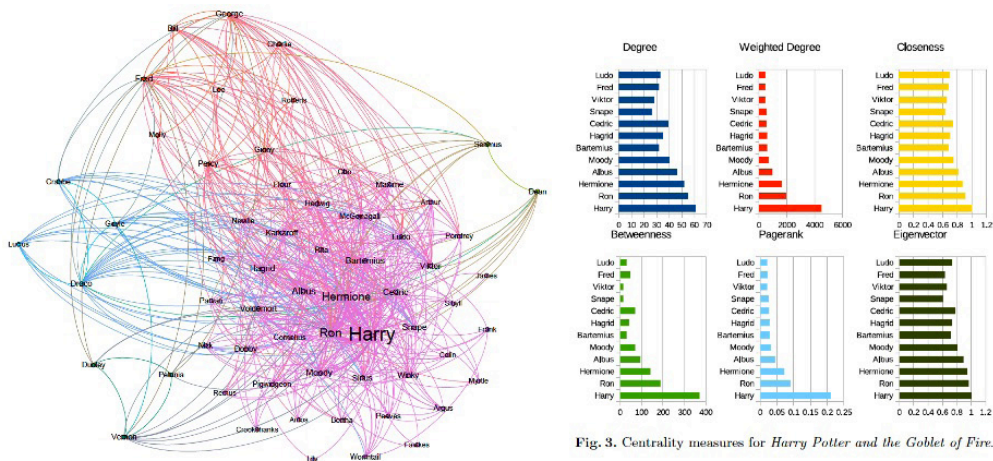

Figure 3.22 : The social network and centrality measures in Harry Potter and The Goblet of Fire

Now that you understand the meaning of the centrality measures in the social network, you are able to check this fun article represented in Figure 22 which measures the social network relationship in *Harry Potter and the Goblet of Fire*. There are also examples for *Twilight, The Stand, The Lord of the Rings*, and *Marvel* movies. Feel free to choose your best movie/novel/TV series to help you understand the concept better.

Centrality Measures in Spatial Network
Then, what about in space?

Basically, the core idea is still the same as if with a social network. You can check in Figure 23 the best-fit functions in a spatial network inside a building.

- Degree centrality concerns the relative number of immediate connections to other spatial nodes, thus most probably fits the function of spreading information/people. Shops, entrance hall, etc. are some examples which should have a high degree centrality.

- Closeness centrality concerns the relative closeness of a spatial node to all the other nodes, thus fits the function of introduction better. Service areas, ticket counter, toilets, etc. are some typical examples which should have a high closeness centrality.

- Betweenness centrality concerns the extent to which a node happens to be in the best path from one node to another in the network, acting like a bridge. Such nodes thus fit the function of bridges/corridors the best. Bridges, buffer zones, etc. are some examples which should have high betweenness centrality.

- Eigenvector centrality concerns with the connections to other important places, thus reflects the extent of influence. An operation centre is an example which should probably have a high eigenvector centrality (further reading).

Connected to many people	Close to many people	In between many people	Connected to important people
Degree Centrality	*Closeness Centrality*	*Betweenness Centrality*	*Eigenvector Centrality*
Spread	**Introduction**	**Linkage**	**Influence**
Shops	**Service Areas**	**Bridges**	**Operational Centre**
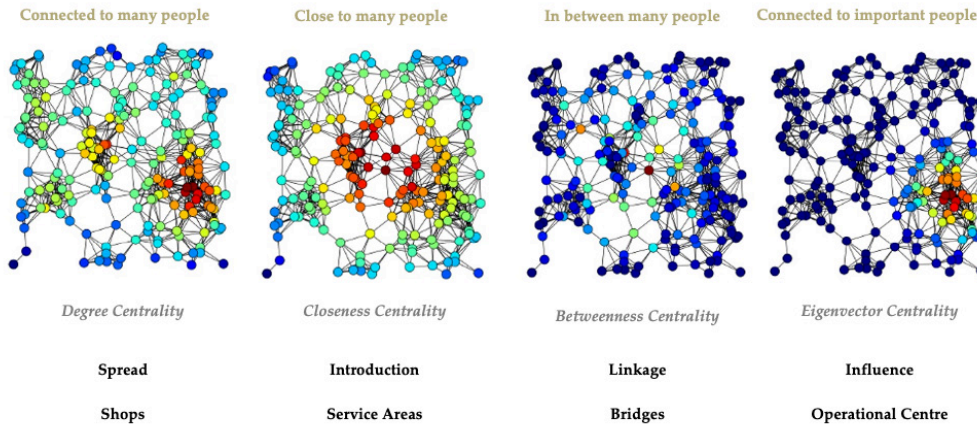
Figure 3.23 : Four archetypical centrality measures in a spatial network in building and their (exemplary) fitting functionalities

The centrality indicators of spatial network may not exactly mean the golden criteria for attributing different functional spaces, nor do they constitute necessary and sufficient conditions for the functionality of a "rational good design". However, they can construe some intrinsic rules as to whether a building is comfortable enough for users in terms of the chances of encounter and avoidance with various 'network voyagers', be it friends, acquaintances, or strangers. The most important take-away from this methodology is that you can use it to evaluate the match of relative spatial potential and activities in the spatial network analysis.

Here is another example of such evaluation. Suppose we would like to evaluate two different spatial configurations of the design for a Regional Government Office: a flat and a hierarchical organization (see Figure 24). Which one is probably more "right" in terms of spatial functional configuration? You may have an intuition for the answer, but it can be hard to explain.

When we draw out the plan and calculate the centrality measures for both scenarios in Figure 25, we may find that in Scenario B, something strange happens: the office manager has a more influential position than the regional manager according to most measures. Is this right? It is then up to you as designer to decide and adjust. Furthermore, the design idea can be easier to explain to the users.

If you also know Space Syntax, you will find that the centrality measures we use here have some close relationship with the concept there such as connectivity, intensity, and choice. You can dig into the topic to compare what is different in space syntax and make your own judgement on which one makes more sense. However, it is out of the scope of this course. If you are interested in using space syntax analytic methods,
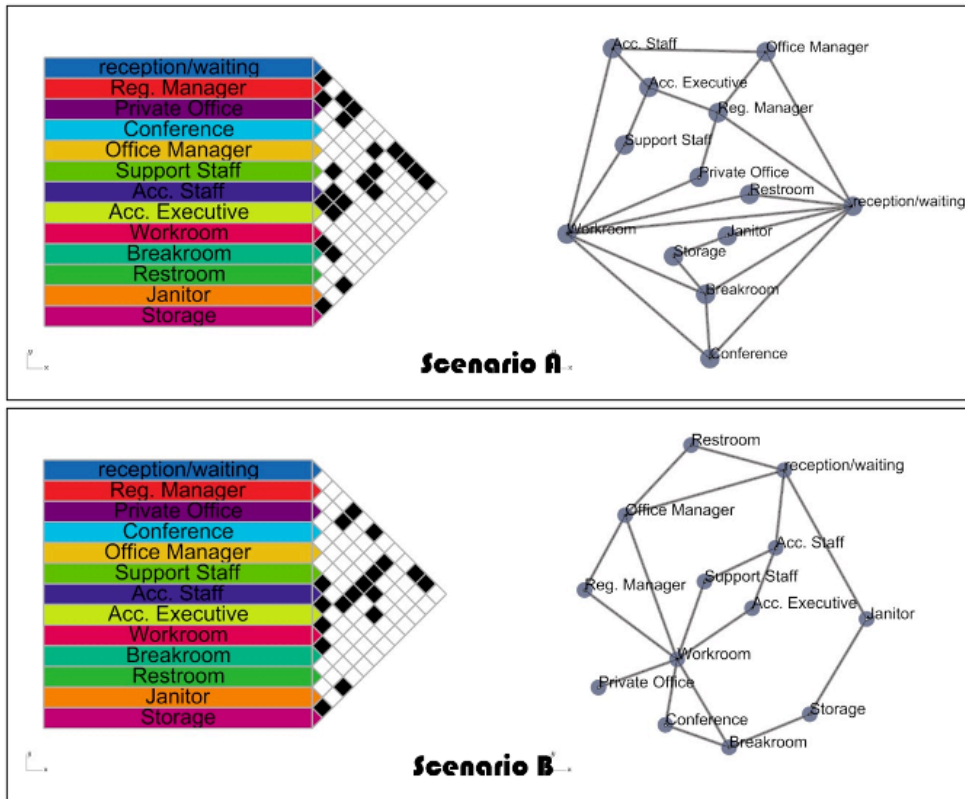
Figure 3.24 : An exemplary design scenarios for a regional office with different spatial configurations
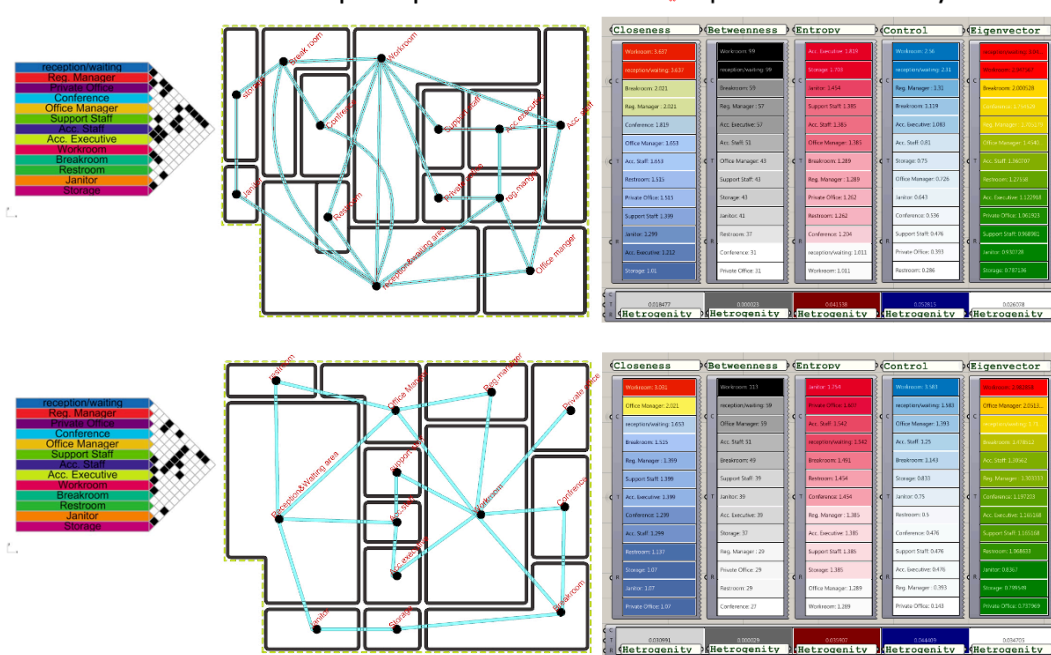

Figure 3.25 : The plans and centrality measures for both scenarios

please note that the centrality measures introduced here have somewhat different names in space syntax and that they are computed in slightly different ways. The comparative study of these indices falls out of scope of this reader but for a simple comparison note that the closeness centrality is almost the same as the 'integration' index in space syntax terminology and the betweenness centrality is almost the same as 'choice' index in space syntax terminology. The differences are mainly due to the

visibility-oriented approach of space syntax methods in large scale spatial analysis and the accessibility-oriented nature of our methods, which is similar to the original architectural space syntax methods proposed for the study of the structure of human settlements in the book Social Logic of Space by Bill Hillier and Julienne Hanson.

Exercise Tutorial

- Basic Tutorial of Gephi

Download and install Gephi from https://gephi.org/. It is a free, easy, and powerful software to analyse networks/graphs.

You can find tutorial at https://gephi.org/users/ and http://www.martingrandjean.ch/gephi-introduction/.

The following manual is based on Gephi 0.9.2 for Mac. For Windows versions or other versions of Gephi some things might be different.

- The Data Format for Gephi

As is discussed in our lecture, there are various ways to represent a network/graph, it is also the case for Gephi. We suggest you to use the Node List + Edge List representation. In order to make your importing correct, make sure to do the following steps in your weekly progress excel sheet before move on to Gephi:

In "Detailed Node List" sheet, make sure the columns ID, Function Type, Function Name are complete. Delete the second-row description written in red.

In "Link List" sheet, change the column names "From" and "To" into "Source" and "Target", as that is required for Gephi.

- Network/Graph Analysis in Gephi

Click on "Import Spreadsheet" in Data Laboratory panel and select your weekly progress excel file.

Select "Detailed Node List" sheet and import as "Node table". Keep everything as default and finish importing the nodes.
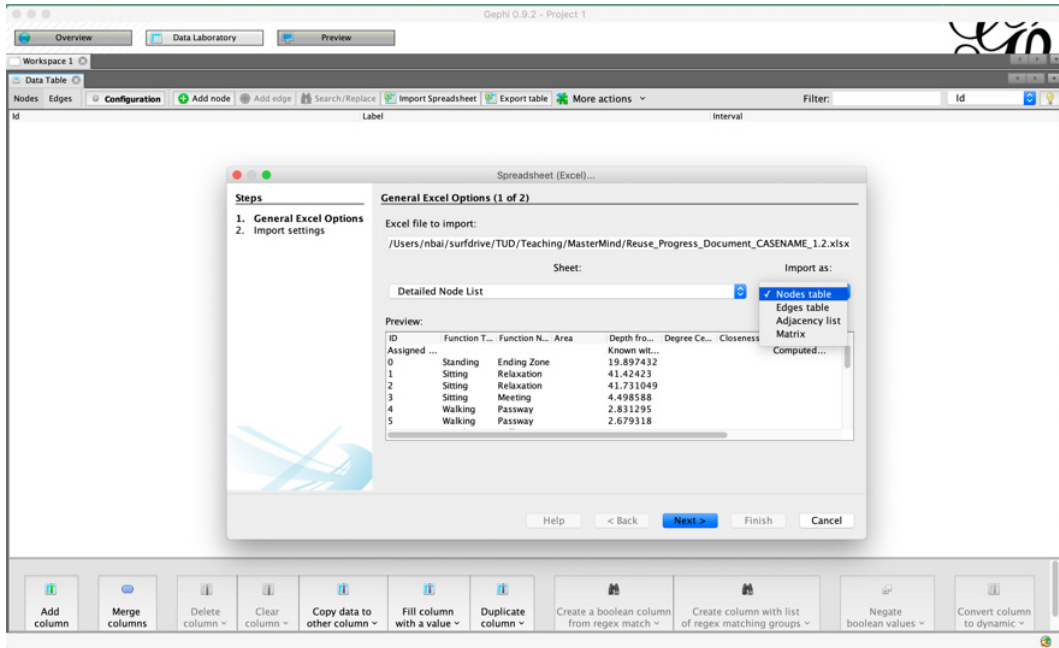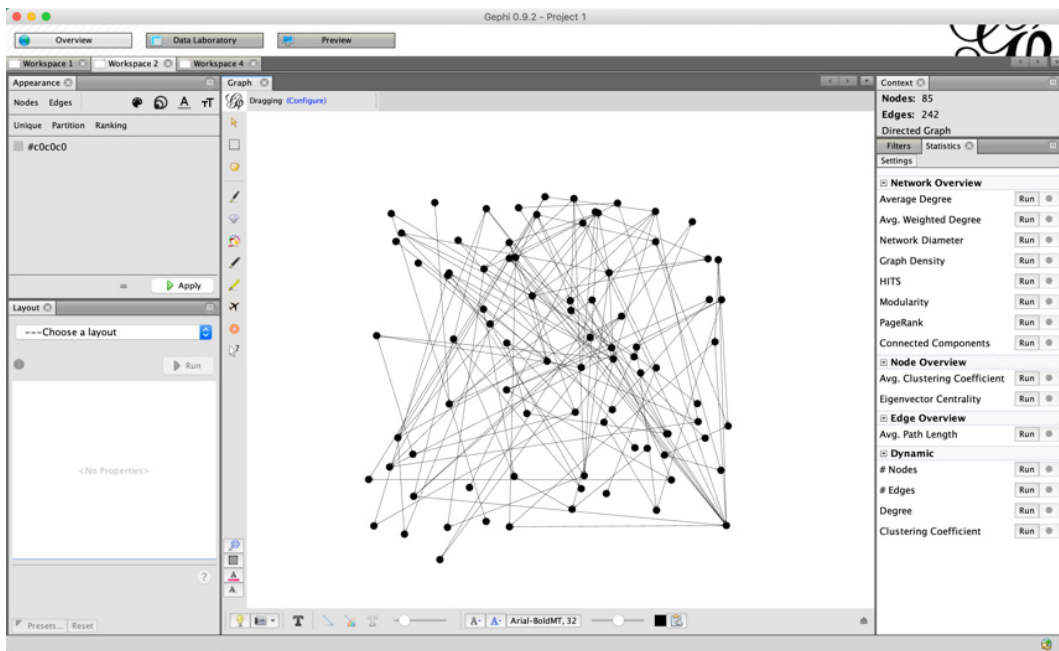

Do the first step again. This time select "Link List" sheet and import as "Edges table". Keep everything as default except for select "Append to existing workspace" in the last window. Keep the graph type as "Directed" to avoid error, we are able to do analysis as if it is undirected later on.
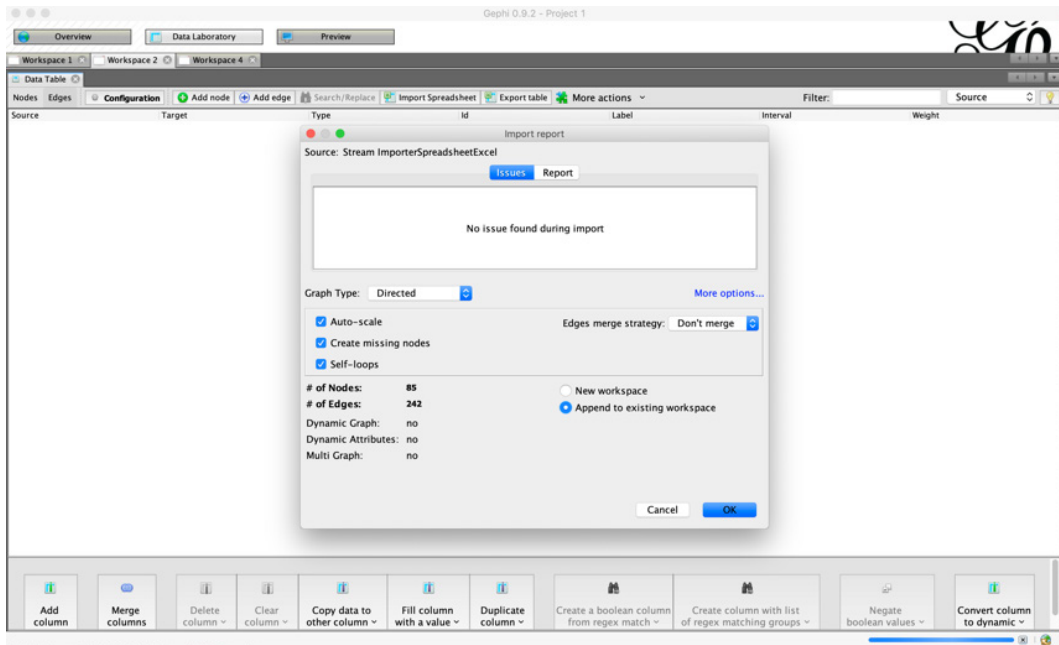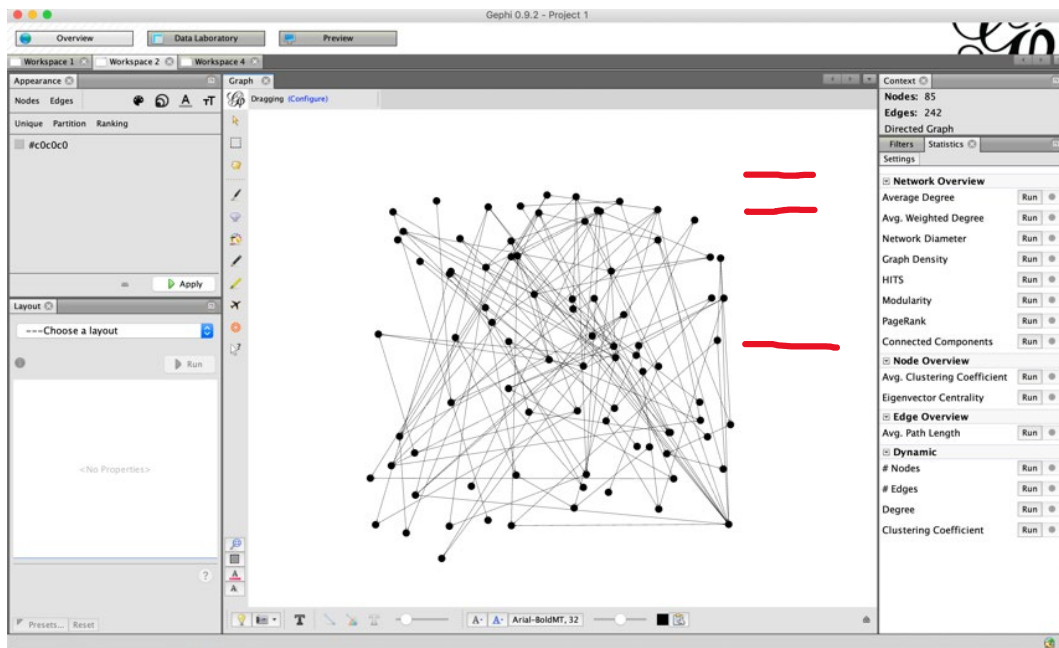
Now in **Overview** panel you will be able to see the initial state of your first graph.

Click the "Run" button for "Average Degree", "Network Diameter", "Eigenvector Centrality" on you right and let Gephi compute all the centrality values for you.

When computing the "Network Diameter", select "Undirected" and "Normalize Centralities in [0,1]". When computing the "Eigenvector Centrality", select "Undirected".
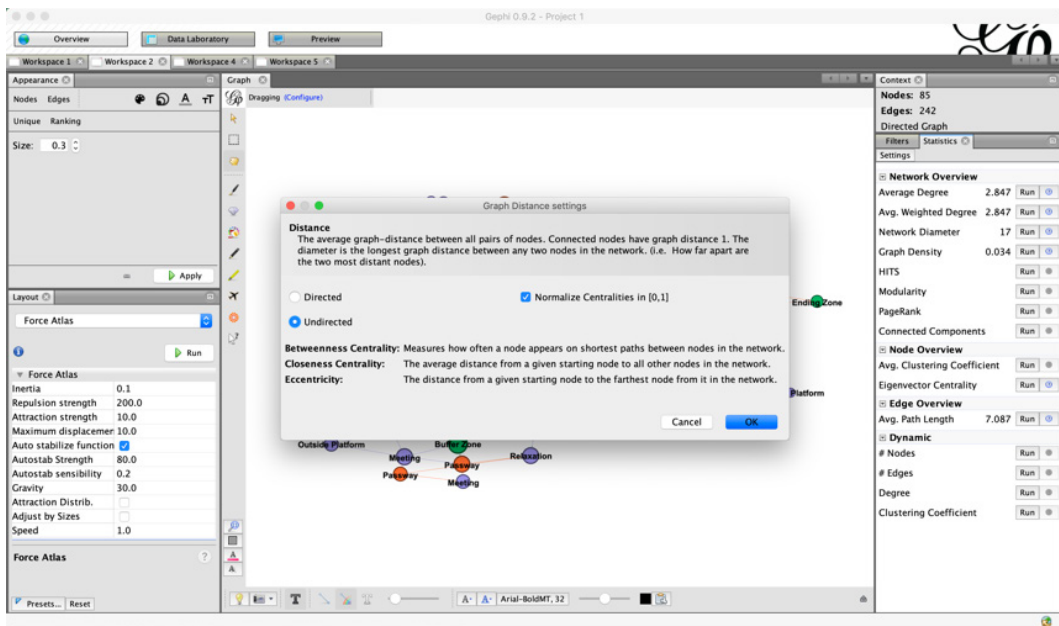
Save some of the pop-up report if you like. You may want to add them into your presentation. Record the "Average Path Length" value if you choose to make your assessment on Accessibility based on that.
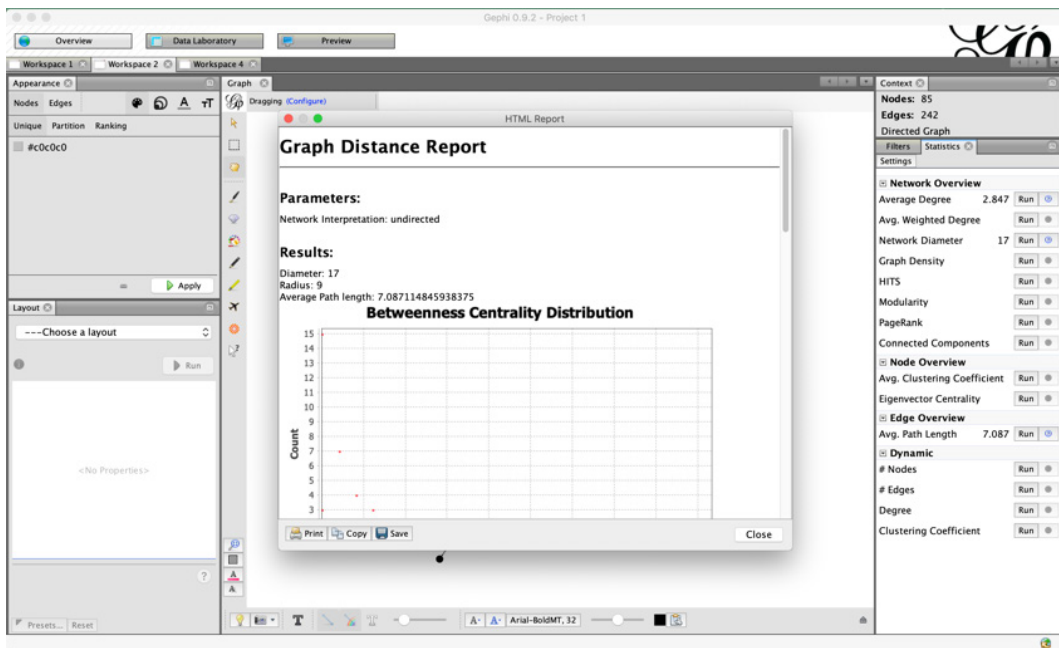
Go back to the **Data Laboratory** panel, and you will see that now you have all the required centrality values (Degree Centrality is here replaced with Degree).

Click on "Export table" and click on "Options..." button. Make sure you choose the Table "Nodes" and Field Separator "Tab".

You can now import this csv file in excel using "Tab" as Delimiters. Then you can copy-paste the four columns of required centrality values into your weekly progress sheet.
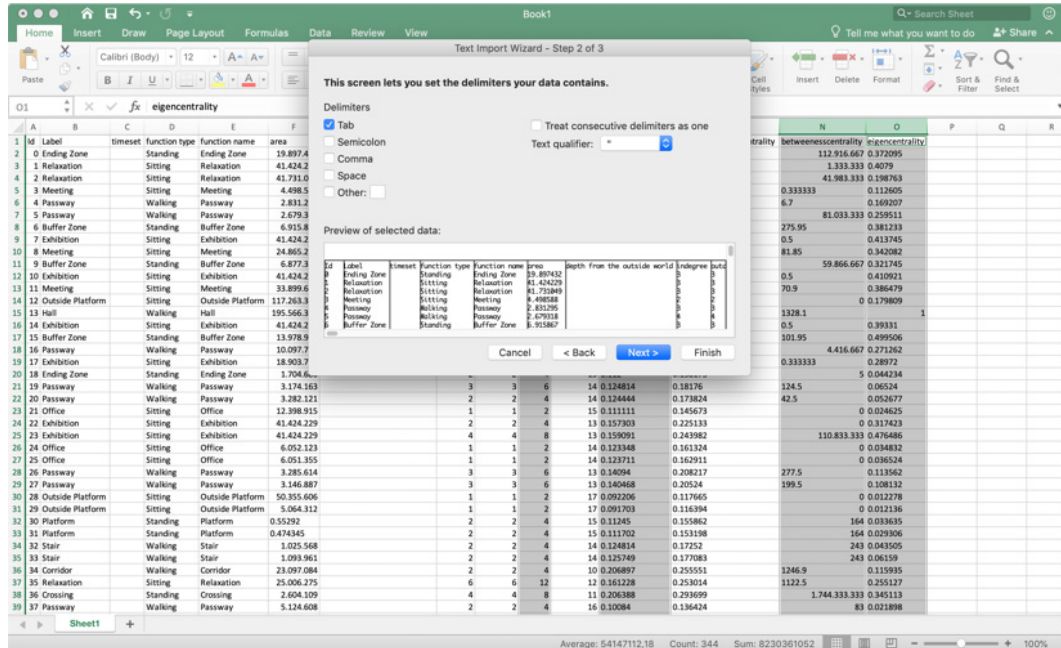
NOTE: Gephi exports the csv file with the standard of decimal points rather than decimal comma (see this link for more information), which means that the numbers may be recognized incorrectly in your excel. Keep this in mind and check what the occasion is for you. You may want to replace all the decimal separator to fit your own computer.

• Network/Graph Visualization in Gephi (optional)

You can also play around with the visualization tools on the left in **Overview** panel. Here are some suggestions what you can do to explore.

Change the size of nodes by the ranking of any of the centrality values.
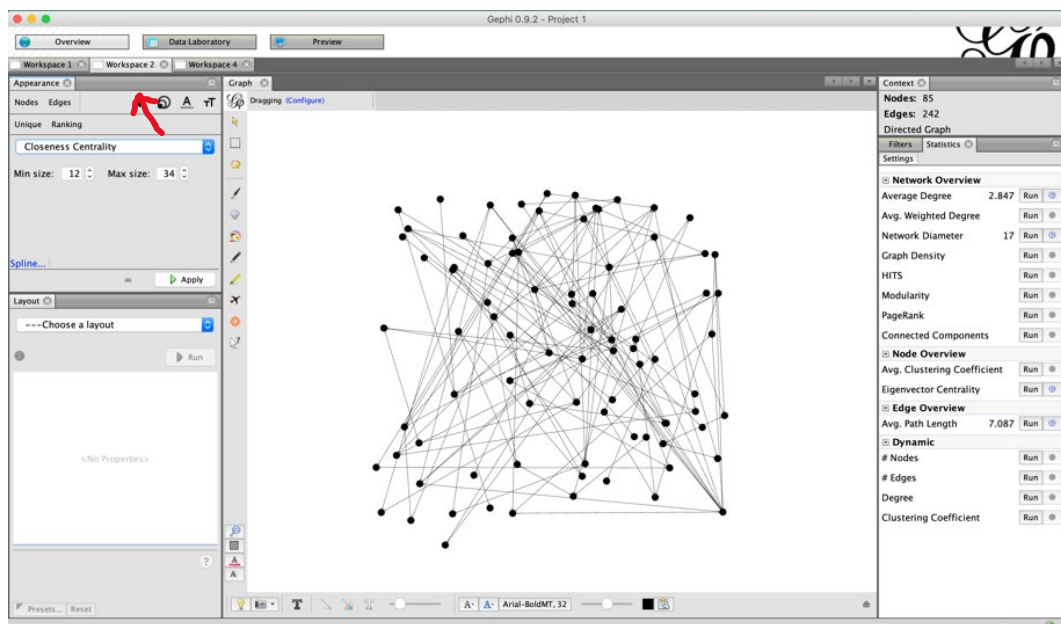
Change the colour of nodes by the partition of different function type or function name.
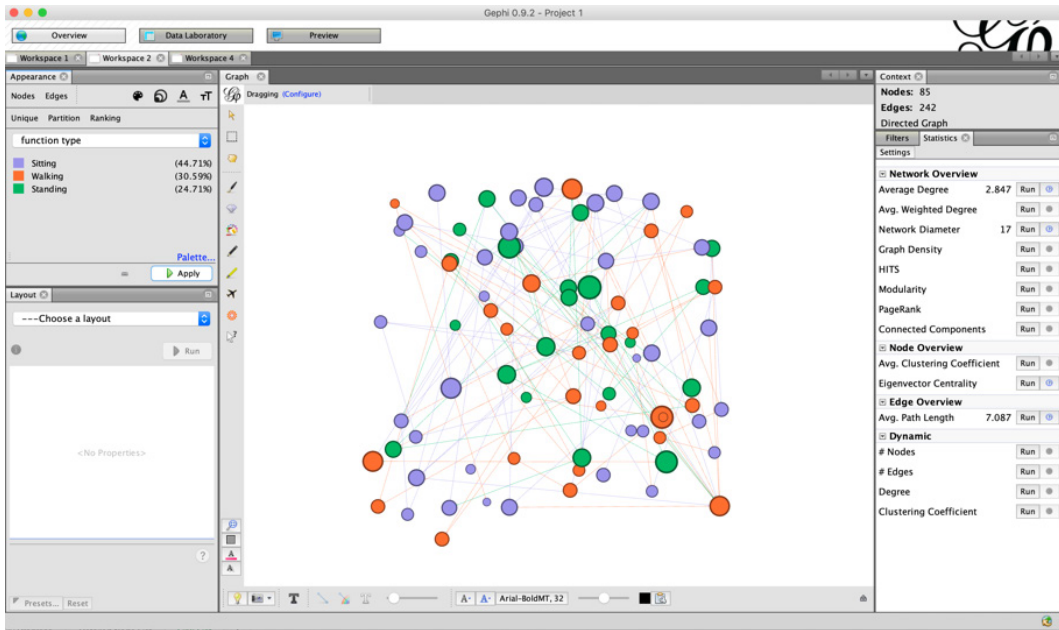
Copy the function name column into label in the **Data Laboratory** panel and turn on the labels for each node in **Overview** panel and set the label size in a reasonable range.
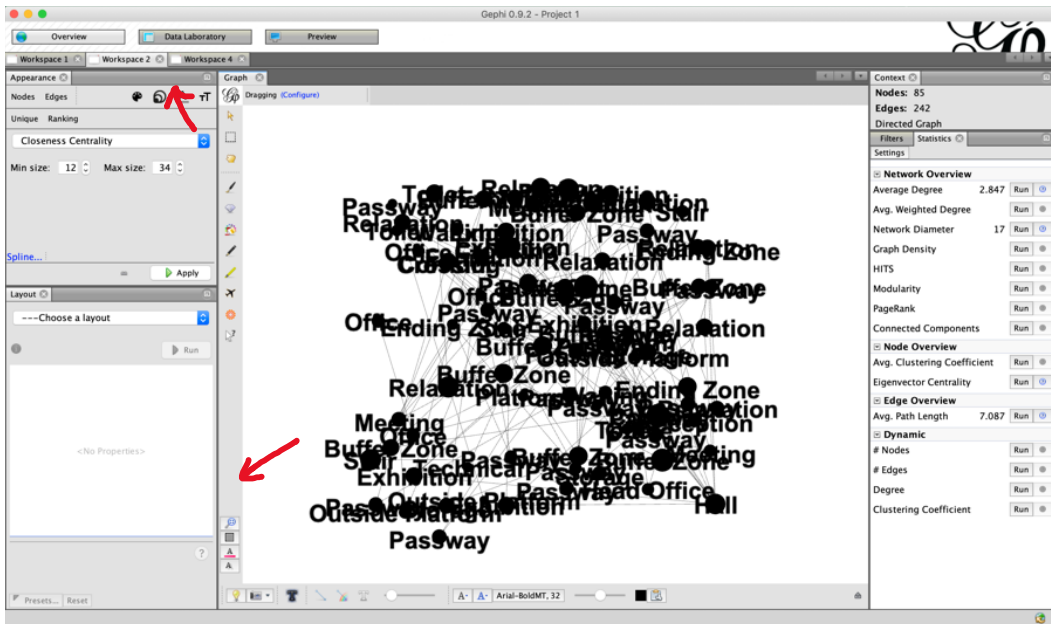
Try different layout tools to see what happens.
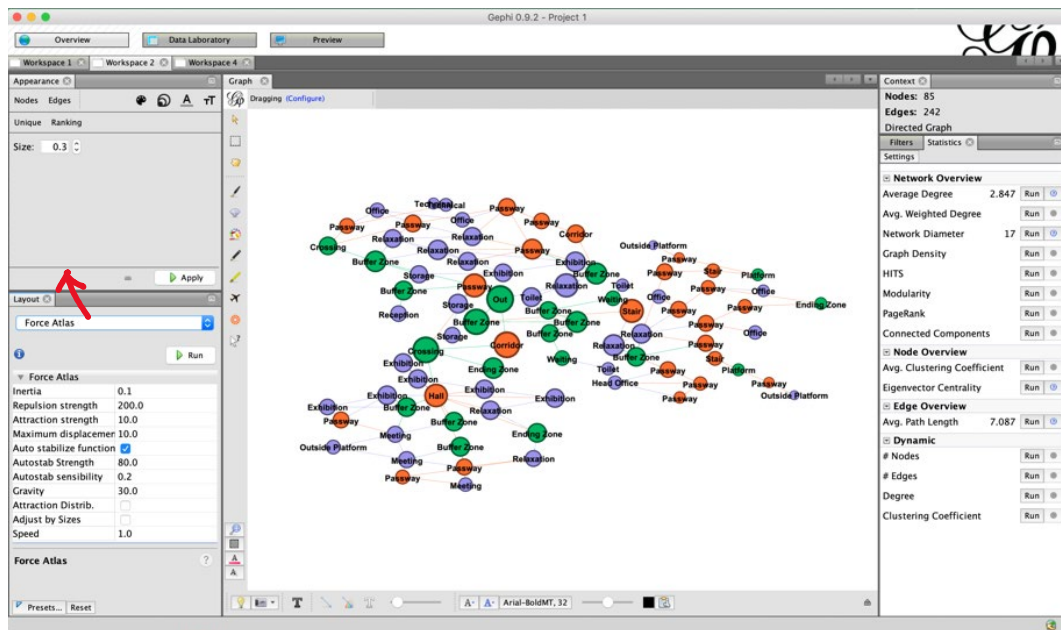
If your labels overlap annoyingly, use "Label Adjust" can be helpful.
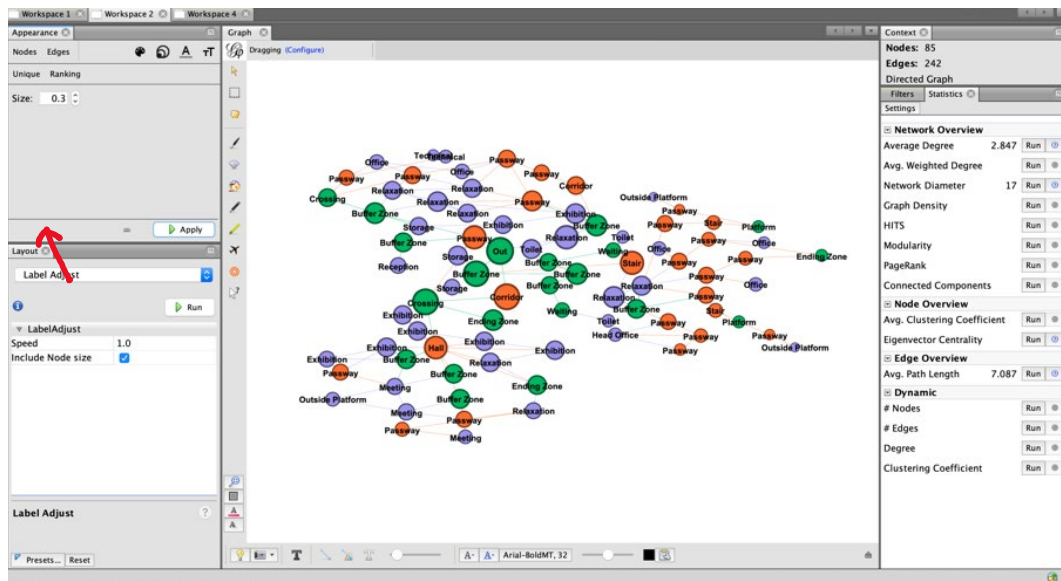
Figure out be yourself what can be a good presentation and visualization for the information that you would like to transfer.

Key References

[1] GEPHI – Introduction to Network Analysis and Visualization http://www.martingrandjean.ch/gephi-introduction/

[2] Easley, D., & Kleinberg, J. (2010). Networks, crowds, and markets (Vol. 8). Cambridge: Cambridge university press. https://www.cs.cornell.edu/home/kleinber/networks-book/

[3] Albert-Laszlo Barabasi. (2016). Network Science. http://networksciencebook.com

[4] Bonato, A., D'Angelo, D. R., Elenberg, E. R., Gleich, D. F., & Hou, Y. (2016, December). Mining and modeling character networks. In International workshop on algorithms and models for the web-graph (pp. 100-114). Springer, Cham. https://arxiv.org/pdf/1608.00646.pdf

[5] UCL Space Syntax. Analysis of Spatial Relations. (tab 1-3) http://otp.spacesyntax.net/overview-2/analysis-of-spatial-relations/

[6] Social Networks in Novels and Films. https://anthonybonato.com/2016/08/03/social-networks-in-novels-and-films/

[7] Nourian P, Rezvani S, Sariyildiz S, van der Hoeven F. (2016). Spectral Modelling for Spatial Network Analysis. *SimAUD 2016.*
https://www.researchgate.net/publication/303944600_Spectral_Modelling_for_Spatial_Network_Analysis

[8] Nourian, P, Configurative Design Computational Space Planning, Layout, and Form-Finding in Architecture," doi: 10.13140/RG.2.2.26063.94880/1.

🎯 3.6 Assess

In this course we are looking at a special definition of assessment in the sense of the difference made by the design for retrofitting (reuse plan). So far, we have been doing analyses on the first (and probably the most complicated) indicator of effectiveness represented by centralities. In this section, we will first quickly introduce the concept of the other two indicators and how could you possibly measure them.

Vitality with respect to Diversity

Recall that in the beginning of the course, we gave you the further definition of diversity:

$$\text{Diversity} = -\sum_{i=1}^{n} p_i \ln p_i \,,$$

$$\text{where } p_i = \frac{N_i}{\sum_{i=1}^{n} N_i} \,, \; N_i \text{ denotes the number of POI of } i_{th} \text{function}$$

$$\text{Equilability} = \frac{\text{Diversity}}{\ln n}.$$

As shown in the formula above, the concept of diversity is perhaps the easiest to compute, as it gives you a single real number after computing, based on a definition called 'entropy' from Claude Shannon, who is known as the father of the so-called information-science. Entropy, in a manner of speaking, is a measure of how 'varied/ messy' is the frequency distribution of the items within a set, assuming that the more so, the more the 'information content.

The concept of Diversity Index was originally used in ecology, and is later adapted in many more fields. Urban planners, for example, also use this concept to judge the degree of land-use mix in the urban environment, which also suggests the vitality of the city. The example below showed in Figure 26 gives you an intuition how is Diversity index applied by urban planner to assess the spatial vitality.
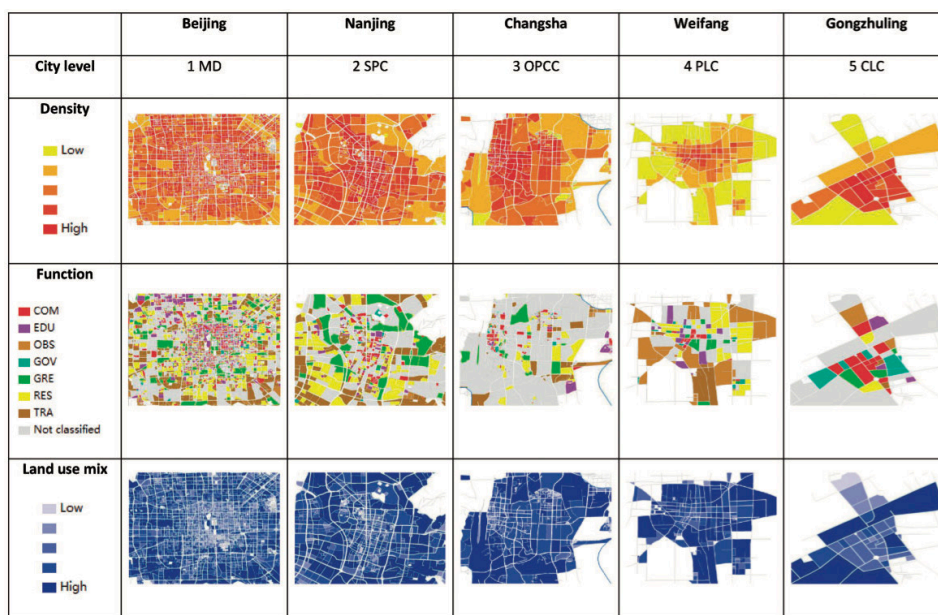

Figure 3.26 : An example of using Diversity Index to evaluate the land-use vitality in Different Chinese cities. (Liu and Long, 2016)

Efficiency with respect to Accessibility

The measure of accessibility, on the other hand, was defined by the given formula:

$$\eta = \sum_i \sum_j T_{i,j} D_{i,j} \text{ ,where } T_{i,j}, D_{i,j} \coloneqq \text{flow rate and distance between } i \text{ and } j$$

This is the original sense of temporal efficienct, i.e. for the places people go across more often (a higher flow rate), are the distances also short or at least not too long? However, this can only be measured if you have the real-world data of human behaviour. Here is a research done in a home where an old couple live in (check Figure 27). The researcher measured the behaviour pattern of the couple using UWB devices. And in this case, you can really compare the spatial configuration and the human movement together to compute the temporal efficiency.

$$y = \beta_0 + \beta_1\chi_1 + \ldots + \beta_\rho\chi_\rho + \varepsilon$$
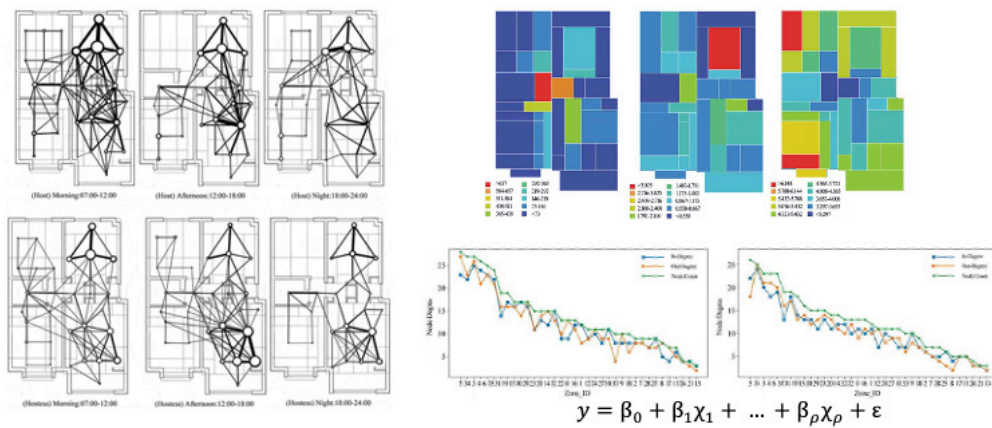
Figure 3.27 : An example of using spatial tracking techniques to capture the real-time flow of people's movement which can be used to compute the temporal efficiency in a building. (Yang and Huang, 2019)

However, in our condition, we are not able to know the real-time behaviour of users in our building case, especially for the before-renovation phase. Here we can use an alternative way to get an idea of how is this place accessible. As we have already generated the spatial configuration graph in the previous step, we can easily get the distance from any given node to all the other nodes (we call this depth). If we pick one critical node (we suggest you to pick the node representing the outside world, unless you are sure why you want to choose some other node), then we can know how far should people walk if they want to move from this place to other places. This also approximates the accessibility in some sense.

An even simpler option to measure the accessibility can be using the average path length of the whole network:

$$l_G = \frac{1}{n(n-1)} \sum_{i \neq j} d(v_i, v_j), \text{ where } d(v_i, v_j) \text{ is the distance between node } v_i \text{ and } v_j$$

Using Gephi or any graph analysis software, we can easily compute the average path length between any pair of nodes in the graph.

Making Comparisons

Now that we have all the three indicators computed, the question is how to compute a single value with respect to the effectiveness of centrality distributions, the efficiency of accessibilities, and the vitality of the diversities in the entire spatial configuration. These three values are, in our case of reuse evaluation, supposed to indicate the difference between the 'before' and 'after' cases.

Well in the case of retrofitting, as the term literally suggests, it could very well be that the before and after situations are incommensurate such as apples and oranges. This is primarily due to the highly likely difference between the functional labels of the spaces in both cases (i.e. a different allocation) or even the addition/removal of nodes and links within the previous spatial configuration.

Increased/Decreased Vitality with respect to Diversity

The definition of diversity provided before is already in a shape to be used for this assessment. It does not even provide a challenge because of the incommensurability of the before and the after situations.

The difference made between the before and the after situations will be simply the diversity of the posterior situation minus the diversity of the prior situation, thus either a positive value indicating increased diversity or a negative value indicating decreased diversity.

Increased/Decreased Efficiency with respect to Accessibility

The definition of the accessibility that we gave before already provides a single aggregate number which can be compared between the before and after situations. However, the case of accessibility is currently out of scope of our project in its original sense, since we are not really collecting the data of the actual flow of people. In this exercise, two other options are given to measure and assess the accessibility: average path length, and the depth difference from the outside.
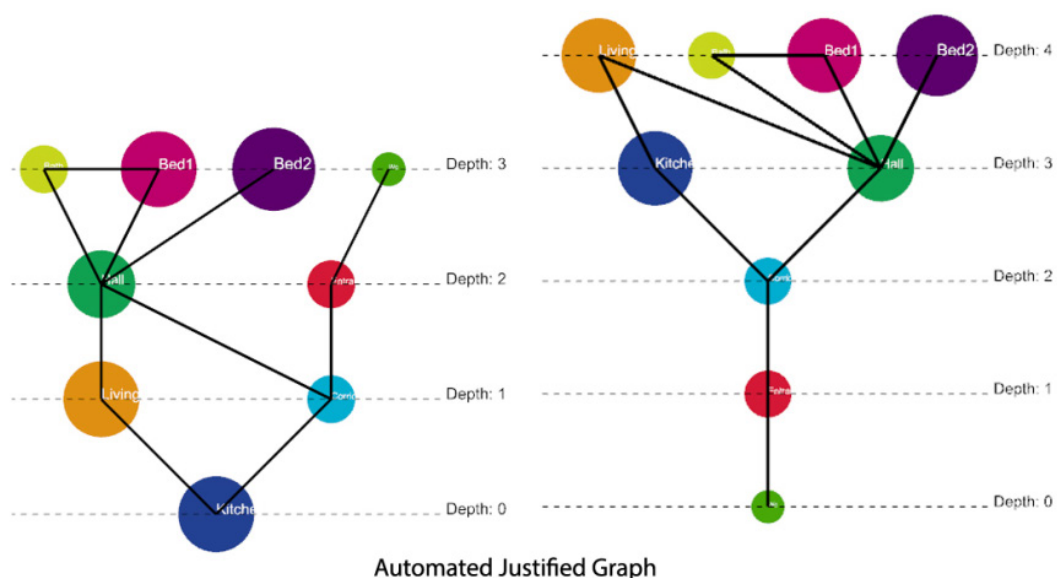

Automated Justified Graph

Figure 3.28 : An example of two depth distribution patterns

If you choose to compare the average path length, this is again a single real number value, so you can make assessment by only comparing the two values. The shorter the average path length is, the more accessible this space is theoretically.

However, we do encourage you to compare the pattern of depth distribution from the outside. For example, suppose we have transformed two plans into networks and generated the depth of all the nodes to the "outside world" using Syntactic in grasshopper, yielding two patterns of depth distribution, as shown in Figure 28. For the both patterns, the node at Depth 0 is the outside world, and other spaces have different depths. For the left pattern, two nodes have depth of 1, two have depth of 2, and four have depth of 3; while for the right pattern, one node has depth of 1, one has depth of 2, two have depth of 3, and four have depth of 4. Now we have all the data, how can we make a comparison of the two patterns? Which one is better? You may consider using the mean (average) of the depths to compare the two patterns. Sometimes it can be feasible, but not always.

One important message we want you to remember here is that only comparing the mean (or average) of two groups of values is not always a valid comparison. Here in this case, we have to make a statistical t-test, and use the corresponding p value to tell us if these two groups of values are different. Only when the p value is smaller than 0.05, we can claim that it is valid. But here, when we conduct the t-test as shown in Figure 29, we can see though the right "after" pattern has a higher mean than the left "before" one, because of a p value larger than 0.05, we can only say that there is no significant change before and after when you make the assessment.

t-Test: Two-Sample Assuming Equal Variances		
	Before	*After*
Mean	2	2,777777778
Variance	1,25	2,194444444
Observations	9	9
Pooled Variance	1,722222222	
Hypothesized Mean Difference	0	
df	16	
t Stat	-1,257237114	
P(T<=t) one-tail	0,113355343	
t Critical one-tail	1,745883676	
P(T<=t) two-tail	0,226710686	
t Critical two-tail	2,119905299	

$p>0.05$, **no** significant difference

Figure 3.29 : The result of t-test comparing the depth values from the two different patterns shown in figure 28

For those of you who are advanced in statistics or interested: t-test is a statistical tool to judge whether or not the difference of two samples of values are out of coincidence. A p-value smaller than 0.05 shows that the difference is not occurring because of randomness or coincidence, thus a comparison can be valid, as given by the following definition:

$$t = \frac{\overline{X_1} - \overline{X_2}}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}, \text{ where } s_p = \sqrt{\frac{(n_1 - 1)s_{X_1}^2 + (n_2 - 1)s_{X_2}^2}{n_1 + n_2 - 2}}$$

Increased/Decreased Effectiveness with respect to (matching) Centralities

For the centralities, however, we need to have a qualitative sense of what is desirable and what is not. Thus, we need to work with a rational/desired ranking of centralities before computing them (by the assessor) and a list of centralities as computed. Then the assessment process is defined in terms of the match between the desired ranking of centralities and the actual ranking of centralities, as to which we will use a rank correlation to figure out the degree of match or mismatch, respectively as a positive or a negative number. In this sense, then the prior and posterior situations are not compared with one another and thus we will not have the incommensurability issue. Instead, the rank correlation coefficients or the posterior situation are subtracted by the rank correlation coefficients of the prior situation.

For simplicity and considering that all these relative differences are dimensionless, then we can average all four such differences to get a comprehensive sense of improvement or deterioration in the use of space. The case of this assessment, however, will always depend heavily on the way the assessor (or the designer) assumes the desired ranking of the centralities to be.

To make this assessment reproducible, the assessor can ask the architect to intuitively provide a desired ranking of the centralities beforehand both before and after renovation, of course, based on a short definition of the centralities[2]. For obvious reasons, the case of degree centrality can be left out of this comparison because it will simply be trivial to guess and see the difference in degree centrality. However, the other three archetypical centralities can be interesting to compare. For each centrality you ask the architect to fill in a questionnaire with such a question: "In your view, how should the ranking of spaces be in terms of this centrality?"

- Closeness Centrality: the extent to which a space is [to be] central in the sense of being close to every other space in the configuration. In other words, how accessible should the space in question be if everyone took a shortest path?

- Betweenness Centrality: the extent to which a space is [to be] central in the sense of being on a path between many other spaces. In other words, how likely should it be to see someone passing through the space in question?

- Spectral Centrality [Eigenvector Centrality]: the extent to which a space is [to be] important in the spectrum of accessibility in the sense of being connected to other important spaces. In other words, how central should the space in question be even if everyone took a random path in the spatial configuration from somewhere to somewhere else?

After you obtained the desired centrality rankings either from the architects or from yourself, you can compare the ranking with the actual computed centrality measures both before and after the renovation using the Spearman's Rank Correlation. It will

---

2   **Note:** if you find this too difficult, you may also consider doing the estimation yourself as the assessor. However, it would be more convincing to have the architect make the estimation, and later check if this intension was eventually realized with your analysis. It shall be a fun challenge for you to explain the ideas of centralities correctly to the architects.

give you a number *r* called correlation coefficient, ranging from –1 to 1. A *r* value closer to 1 shows that the two groups of variables trend to change in the same direction with each other. A *r* value closer to –1 shows that they trend to change in the opposite direction. And r value close to 0 shows that there seems to be no relationship of the two groups.

$$r_{after} = 0.149, p=0.531$$

$$>$$

$$<$$
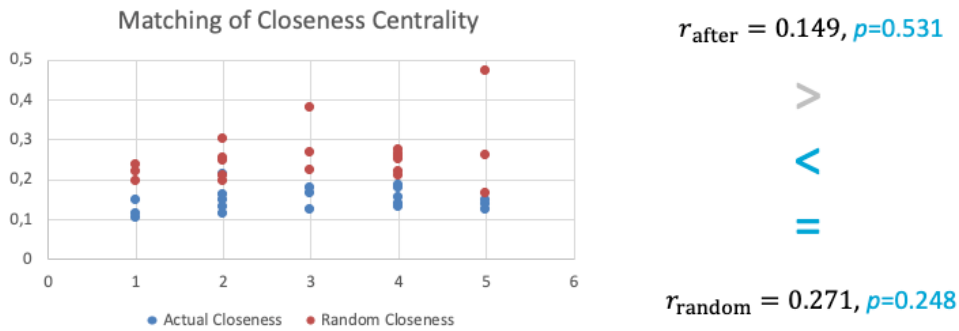
$$=$$

$$r_{random} = 0.271, p=0.248$$

Figure 3.30 : An example of comparing the desired centrality measures with the actual centrality measures both before and after renovation.

As an example, when you have the closeness centralities for all the functional types both before and after the renovation, you can plot them on the y-axis to show their relationship with the expected centralities on the x-axis, as shown in Figure 30. After calculating the correlation coefficients, we can compare the *r* values of before and after, as they are again single real number values. In fact, there is actually also a *p* value for any correlation, if the *p*-value is larger than 0.05, then the correlation is not significant or valid. However, this is out of our scope in this course.

Sometimes you may find out that the correlation coefficient value *r* does not seem right. Why is the correlation coefficient so low? Why is it close to 0 or even negative? Why are things getting worse when the architects do some nice intervention? When all such things against intuition happens, it is the time for you to go and check what is the thing that went wrong.

Figure 3.31 : An example of an unreasonable correlation coefficient value before and after renovation

For the example shown in Figure 31, you can see that we gave a high estimation for closeness centrality value for the "head office" and a low estimation for outside. However, it turns out that the head office has a low actual closeness centrality and the outside has a highest one. Now it is up to you to interpret the outcome. Is it because you made an improper estimation? Or is it because the spatial arrangement is bad? This is a chance to make your observation and argument more valid and acceptable.
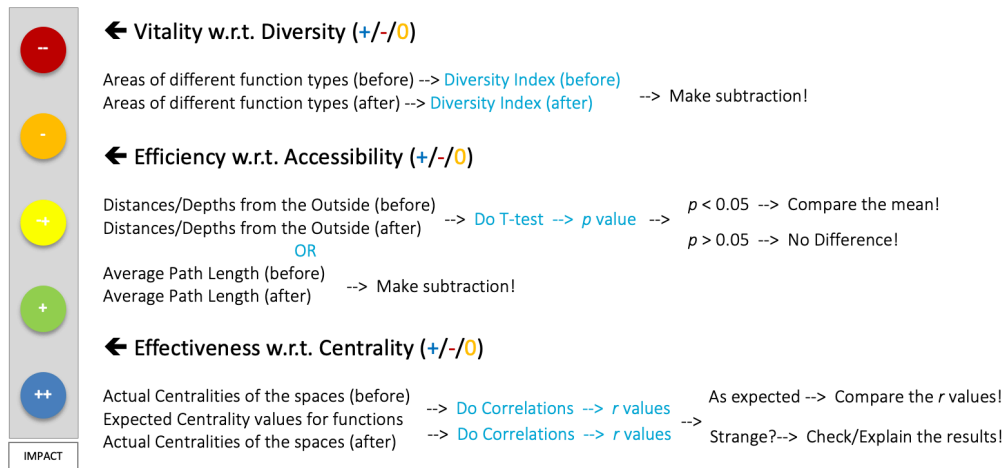
Figure 3.32 : Assessment guideline for all the three indicators

Wrap-up

As a conclusion, for all the three indicators, you can follow this flow chart in Figure 32 to make your assessments.

Most of the concepts and mathematical calculations discussed today are not mandatory for everyone, but you need to know how to interpret your outcome. For the students in our domain, you will have to provide us with the complete *weekly progress excel* with all the data required (shown in the black columns on the left of this slide). We can do the statistics and calculation for you and give you the values (as shown in blue in Figure 32). Then you need to use your understanding to interpret the values properly and give your own assessment for each of the indicators.

We would expect you have a sign-score for each of the indicators, which means that it should be either positive, negative or neutral. Use those signs to get your final code!

However, there are several things to keep in mind when you are doing some statistics like we discuss today. Make the proper interpretation and do not abuse the values you get.

Key References

[1] Liu, X., & Long, Y. (2016). Automated identification and characterization of parcels with OpenStreetMap and points of interest. *Environment and Planning B: Planning and Design, 43*(2), 341-360.
https://journals.sagepub.com/doi/pdf/10.1177/0265813515604767

[2] Frank, L. D., Andresen, M. A., & Schmid, T. L. (2004). Obesity relationships with community design, physical activity, and time spent in cars. *American journal of preventive medicine, 27*(2), 87-96.
https://www.sciencedirect.com/science/article/pii/S074937970400087X#BIB32

[3] Yang, L., & Huang, W. (2019). Multi-scale analysis of residential behaviour based on UWB indoor positioning system-a case study of retired household in Beijing, China. *Journal of Asian Architecture and Building Engineering, 18*(5), 494-506.
https://www.tandfonline.com/doi/full/10.1080/13467581.2019.1682000

[4] Diversity Indices: Shannon's H and E.
http://www.tiem.utk.edu/~gross/bioed/bealsmodules/shannonDI.html

[5] Wikipedia's page on Diversity Index.
https://en.wikipedia.org/wiki/Diversity_index

[6] Wikipedia's page on T-test.
https://en.wikipedia.org/wiki/Student%27s_t-test

[7] Wikipedia's page on Spearman's Rank Correlation Coefficient
https://en.wikipedia.org/wiki/Spearman%27s_rank_correlation_coefficient

[8] Nourian, P. 2016, On Evaluation & Optimization, a very short review of essential topics,
DOI: 10.13140/RG.2.2.16583.70565

♟ 3.7 Future Research

Design problems in architecture and built environment typically present complexity challenges that are different from pure engineering problems. This is mainly due to the fact that the so-called human-factors (and ergonomics) are necessarily parts of such problems, as to which they have been called 'wicked problems' [13], among other terms [14]. The multi-dimensional and the multi-criteria nature of such problems present spatial and differential complexities demonstrating their physical character while the multi-actor nature and the multi-value nature of them present consensual and rational complexities, demonstrating their human character. In other words, the problems in these fields (design/planning) are such that multiple human actors, possibly with different value-systems must be included in solving them, reaching a consensus [15]. This is why such problems are said to have double-complexity (human/physical) [16].

Complexity and Generative Sciences
Reductionist approaches to such problems have long been criticized, justifiably so, for their over-simplistic attitudes; declaring the necessity for approaches that are rooted in the relatively new umbrella domain called generative sciences for studying complex systems. There is yet much to be done for collecting and consolidating existing knowledge on the human factors affecting spatial qualities; not only to predict human comfort but also to understand it and explain it transparently and unambiguously. Being able to evaluate properly is key to design and planning practices. Even if some day we manage to train machines with Artificial Intelligence to predict comfort by fitting meta-statistical models, we shall still have to be able to understand the basic principles of human/spatial qualities in such a way that we can train ourselves to make more effective quality decisions. After all, the reason why we may want to model a phenomenon is not only to predict its dynamics but also to understand from the model and reach theories that can explain the mechanisms by which those dynamics come into existence in the first place [17]. Thus Explainability and reproducibility of knowledge will be essential to ensure towards developing open-science [18]. Additionally, it would be futile to try to rebuild such theories by ignoring existing theories but of course we need to critically revisit existing theories, embrace the complexity of the phenomena under study and move towards complexity-aware models of human-physical spatial systems, e.g. Agent-Based Models [19]. Two of the domain-specific fields of knowledge pertaining to such qualities and our spatial domain are Environmental Psychology and Ergonomics. When connecting these domains to the spatial subject matters of architecture and built environment, it is easy to see why accessibility and visibility analyses are central to many types of assessments.

Environmental Psychology and Ergonomics
The main issue of our field for going towards scientific design and planning is that we do not yet have a properly categorised understanding of our problems and evaluation frameworks. All computational methods are the means of problem solving. Arguably, then, before discussing which problem-solving methods is better than another one needs to specify the nature of the problem. This is where both the challenges and the interesting intellectual activities intersect: in other words, lots of work is there to be done. We need to work on two major areas in the so-called domain-specific

knowledge areas: problem-formulation, and solution-evaluation. Instead of making both the same, we would suggest to think about evaluation first. Reflecting on existing (and historical) examples and abstracting what makes them comfortable or uncomfortable would be the first major step. Of course it is essential to specify the type of comfort (thermal comfort, psychological comfort, ergonomic comfort, etc.). It is understandable that sometimes the fascination is essentially focused on the methodology or the technology but in the long run the focus on solving real problems helps to boost that fascination as well.

There are at least three scientific journals that publish articles regularly on these subject areas: Journal of Environmental Psychology , Journal of Ergonomics, and Environment and Behaviour.

In Environmental Psychology there are some pioneer figures that deserve more attention: James J. Gibson, Kevin Lynch, Lillian Moller Gilbreth, and of course Jane Jacobs.

A handful of important concepts from the field of environmental psychology that deserve more attention from architecture students are healing environments, defensible space theory, interior design psychology (in particular the idea of defensible space, ibid), and of course the idea of 'eyes on the street'.

Quite a few of these ideas are either about large scale environments or small scale environments where the intensities are such that they afford a scientific investigation; but they certainly apply in fundamental ways to the architectural scale as well. Back to the technical side of the story, the angle to look at such matters from a computational point of view has often been (for good reasons) the concepts of visibility and accessibility at various scales and various types of inter-relations. Of course the whole idea of the so-called Space Syntax theories is also rooted in these lineages of intellectual concerns about use of space and the effect of the shape of an environment on human behaviour. About the latter subject you can find much more through [20]; but there is much more out there especially on the subject of visibility. You can follow the footsteps of late Alasdair Turner for visibility studies in Space Syntax and their relation to comfort.

No reduction in dimensionality

We have explained in this course that walkable spaces are 2D manifolds. Even though many studies have tried to reduce the dimensionality of walkable space into networks consisting of points and lines, we must warn against continuing in that direction because it presents unresolvable scientific challenges in the study of accessibility on networks. A large pedestrian area in a city or a building is not exactly reducible into a bunch of points and lines, it can only be reduced into 2D cells for accessibility studies. Similarly, if the point of attention is visibility, it is clearly a 3D matter that cannot be studied on a floor plan, Visibility can be studied in 3D cells, e.g. on voxels. For learning more about voxelization algorithms and raster based analytic approaches you can check this paper [21], this presentation [22], and this library [23].

Epilogue

Lastly: Technology is the Answer but what was the Question?

The setup of the course is such that it separates solution-evaluation from problem-formulation and problem-solving in design. This is exactly what we need to be able to avoid subjective bias and the traps of logical fallacies. Critical Thinking skills are generally important for all academic endeavours but even more so for the study of human factors, especially due to avoid subjective biases, belief systems, esoteric/mystic approaches, propaganda, commercials, personality-cults and pseudo-science in general towards building scientific approaches to understanding spatial quality in architecture and built environment. There is much more for independent humans to do and achieve collaboratively together in this direction rather than big machines owned by corporations.

Epilogue

Lastly: Technology is the Answer but what was the Question?

References

[1] R. Fenn, *Geometry*. Springer London, 2001.

[2] C. Tremblay, "Mathematics for game developers," 2004.

[3] M. Batty, *Essential Engineering Mathematics*. 2011.

[4] D. Cherney, T. Denton, R. Thomas, and A. Waldron, *Linear Algebra*. 2013.

[5] M. Botsch, L. Kobbelt, M. Pauly, P. Alliez, and B. Lévy, *Polygon mesh processing*. 2010.

[6] H. Edelsbrunner and J. Harer, *Computational Topology, an Introduction*. 2010.

[7] R. Issa, *Essential Mathematics for computational design*, 4th Editio. Mc Neel, 2019.

[8] A. B. Downey, B. • Cambridge, • Farnham, • Köln, • Sebastopol, and • Tokyo, "Think Complexity."

[9] A. Downey, "Think Python How to Think Like a Computer Scientist 2nd Edition, Version 2.2.23," 2015.

[10] E. Matthes, *Python Cash Course*. 2016.

[11] P. Nourian, "Rudiments of Linear Algebra & Computer Graphics," 2019.

[12] P. Nourian, "Rudiments of Geometry and Topology for Computational Design," in *Fundamentals of Spatial Computing & Generative Design*, Preprint., no. September, Delft, 2020.

[13] H. W. J. Rittel and M. M. Webber, "Dilemmas in a general theory of planning," *Policy Sci.*, vol. 4, no. 2, pp. 155–169, 1973.

[14] K. Dorst, "The Problem of Design Problems," *Des. Think. Res. Symp. 6*, vol. 4, no. Creativity and Cognition Studio Press, pp. 135–147, 2003.

[15] N. Bai, S. Azadi, P. Nourian, and A. Pereira Roders, "Decision-Making as a Social Choice Game Gamifying an Urban Redevelopment Process in Search of Consensus," in *Anthropologic: Architecture and Fabrication in the cognitive age - Proceedings of the 38th eCAADe Conference*, 2020, pp. 555–564.

[16] P. Nourian, "Mathematical and Computational Modelling of Doubly Complex Systems Theoretical reflections on the theory and the practice of the Scientific Method in," 2019.

[17] J. M. Epstein, "Why model?," *J. Artif. Soc. Soc. Simul.*, vol. 11, no. 4, pp. 117–128, 2008.

[18] U. Toelch and D. Ostwald, "Digital open science-Teaching digital tools for reproducible and transparent research," 2018.

[19] J. M. Epstein, *Generative Social Science: Studies in Agent-Based Computational Modeling (Princeton Studies in Complexity): 9780691125473: Economics Books @ Amazon.com*. .

[20] P. Nourian, *Configraphics: Graph theoretical methods for design and analysis of spatial configurations*, vol. 14. 2016.

[21] P. Nourian, R. Gonçalves, S. Zlatanova, K. A. Ohori, and A. Vu Vo, "Voxelization algorithms for geospatial applications: Computational methods for voxelating spatial datasets of 3D city models containing 3D surface, curve and point data models," *MethodsX*, vol. 3, no. January, pp. 69–86, 2016.

[22] R. Schaffranek and P. Nourian, "Generative syntax in architecture and urban design," *Advances in Architectural Geometry 2014, UCL*, 2014. .

[23] S. Azadi and P. Nourian, "topoGenesis: an open-source python library providing topological structures and functions for Generative Systems and Sciences," 2020.

Colophon