Space Subdivision for Indoor Navigation

P5 Presentation MSc Geomatics

Marija Krūminaitė

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Motivation

What drives the need?

Large public buildings (airports, stations, malls, hospitals) → confusion and disorientation with high possibility of getting lost.

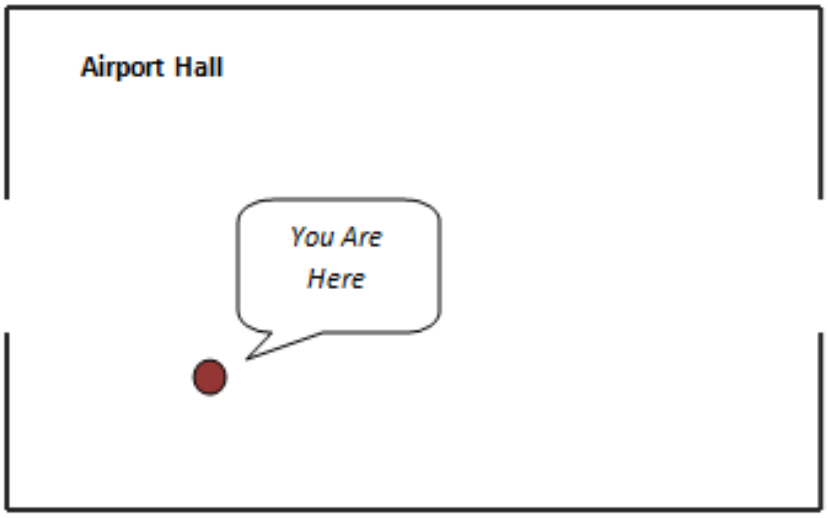
Indoor environment:

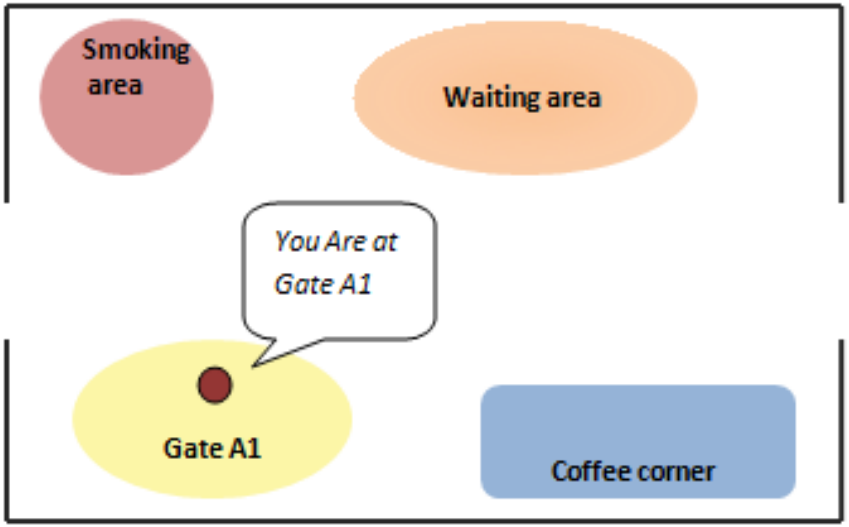
- physical, temporal, thematic constraints → retrieving and storing different information
- human-scaled → high level of detail is required.

Motivation

Typical problems

Rooms are represented as single indivisible objects → accurate localization and navigation is not enabled, no precise guidelines.

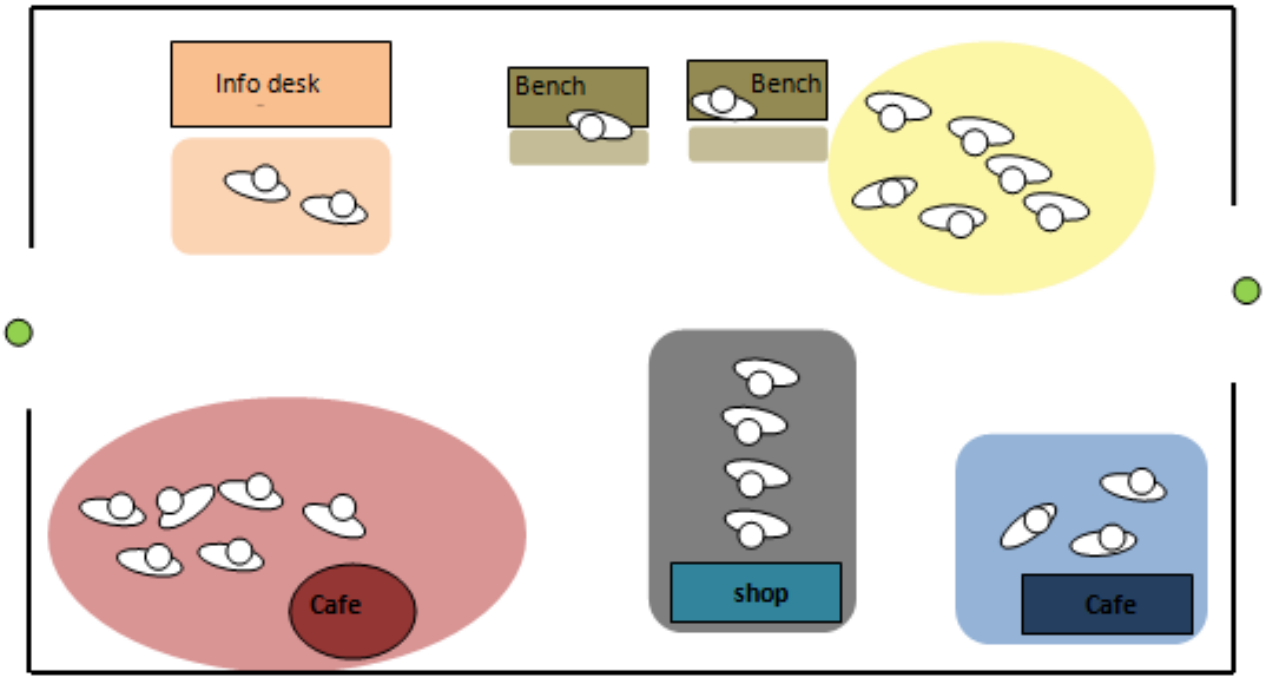




Motivation

Typical problems, cont.

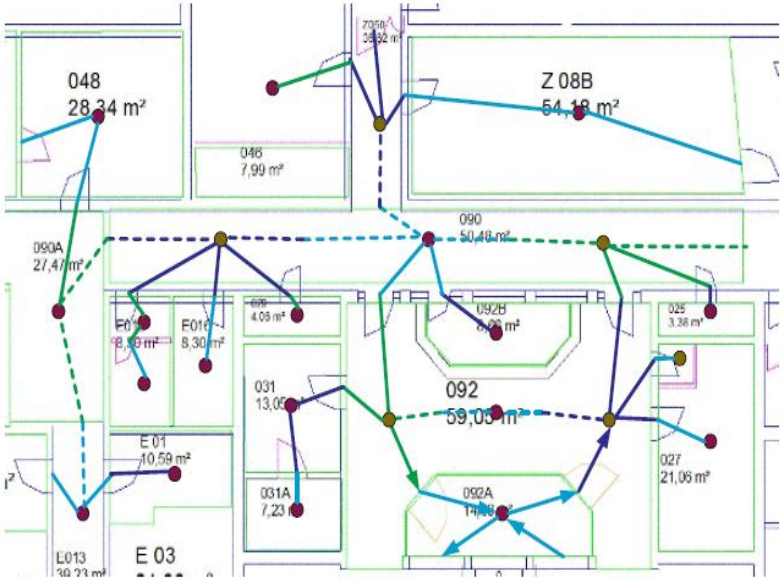
Presence of people and their behaviour within indoor environment are not taken into consideration → inaccurate navigation path.



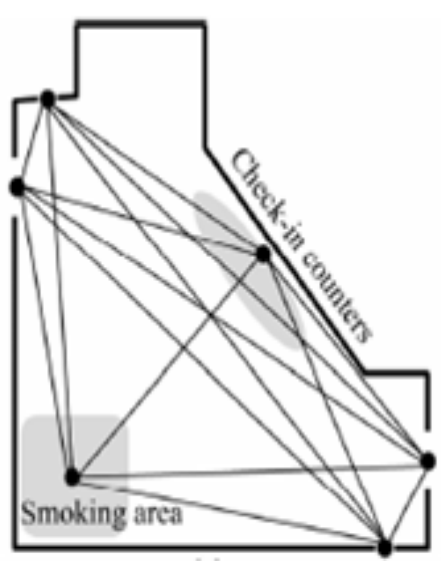
Motivation

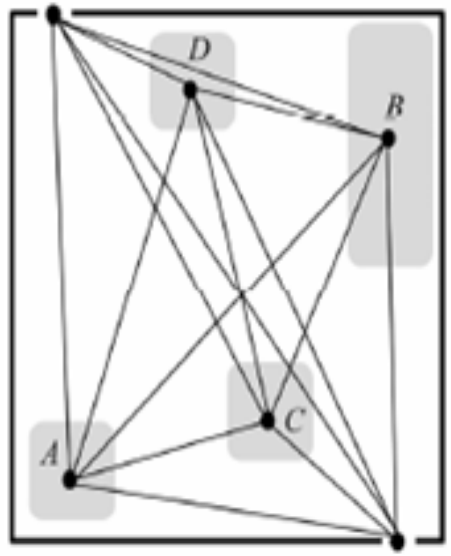
Typical problems, cont.

Attempts to determine particular spaces within a room or a hall.
However, there is no agreed uniform method to determine functional spaces



Lorenz, Ohlbach and Stoffel, 2006





Goetz and Zipf, 2011

Problem statement

The existing indoor models for navigation lack the indication of special areas with respect to human perception of the environment which results in coarse descriptive location information and inefficient navigation path.

Therefore:

The aim is to develop conceptual model for determination of functional areas within indoor space and to incorporate them in the navigation model to facilitate wayfinding process.

Research question

In which manner should the indoor space be subdivided to support more realistic abstraction of indoor environment and generation of navigation path while taking account of human perception of the environment and social aspects of human interaction?

Research methodology

Conceptual model

- Identification of criteria for partitioning based on human perception of the environment and human behaviour (literature review)
- Derivation of mathematical expressions to determine size of the functional areas (literature review)

Implementation. Subdivision of indoor space

- Space partitioning into navigable and non-navigable areas:
  - Based on conceptual model using GIS tools
- Navigable space subdivision:
  - Navigation network generation applying constrained Delaunay triangulation
  - Navigation path calculation using A* and path smoothing algorithm

Verification of the model

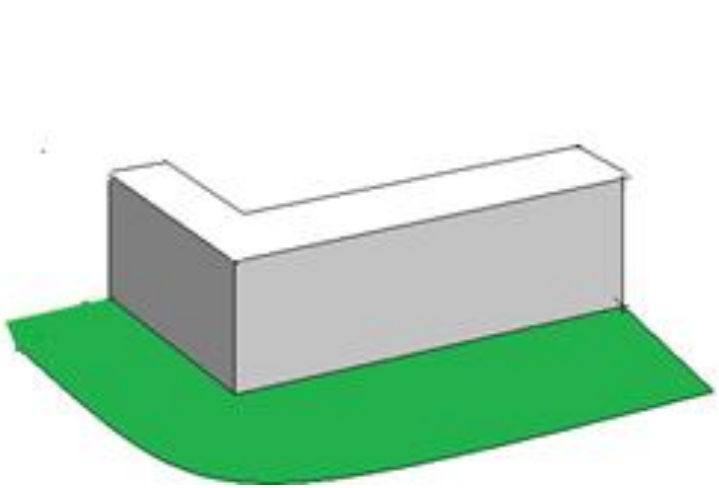
- Analysis of people distribution and movement trajectories from photographs and video records.

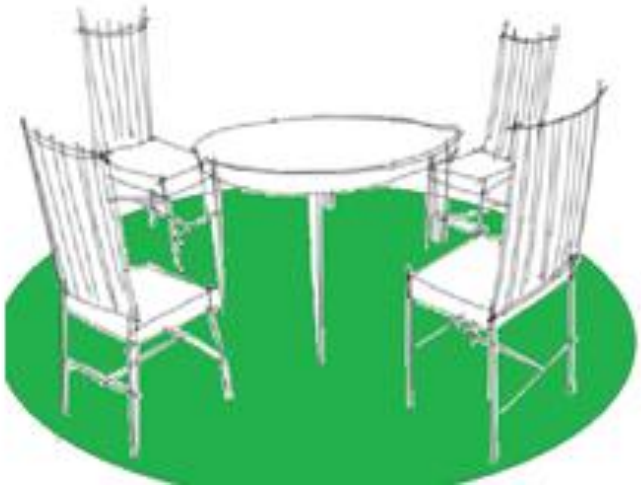
Determination of navigable area

Definition of functional area

Functional area – area where certain set of activities takes place; people are served by spatial unit or waiting for services provided by spatial unit

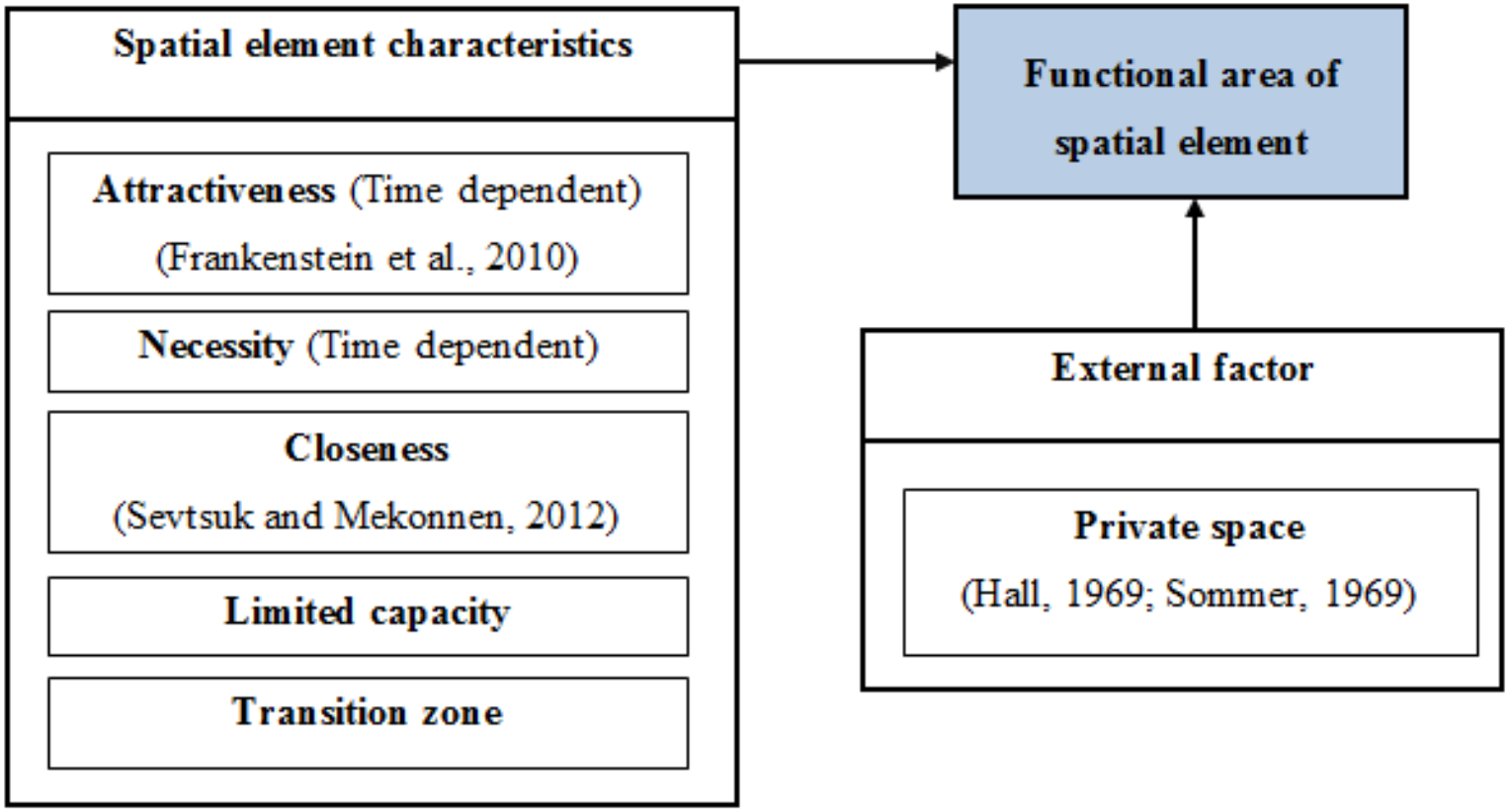
Functional areas are non-navigable areas.





Determination of navigable area

Conceptual model for determination of functional areas



Determination of navigable area

Criteria for determination of functional areas

Criterion	Measurement	Value range
Attractiveness *(Time dependent)*	How inviting is the structure of the object?	1 – non-attractive 2 – moderately attractive 3 – highly attractive
Necessity *(Time dependent)*	Is necessary to have this object in this environment? Is it an important/essential feature of this environment?	0 – non-essential object 1 – essential object
Closeness	How close object is to all other surrounding objects?	[0-1] 0 – object is far away from other locations 1 – object is close to other locations
Limited capacity	Does object have limited number of seats?	Yes – object has limited capacity No – object does not have limited capacity
Transition zone	Does object provide services in a distance? At what distance?	Numerical variable based on structure of the environment
Private space	What is the minimum distance that people keep not to violate others personal space in this environment?	Numerical variable based on type of the building (Hall's personal, social distances)

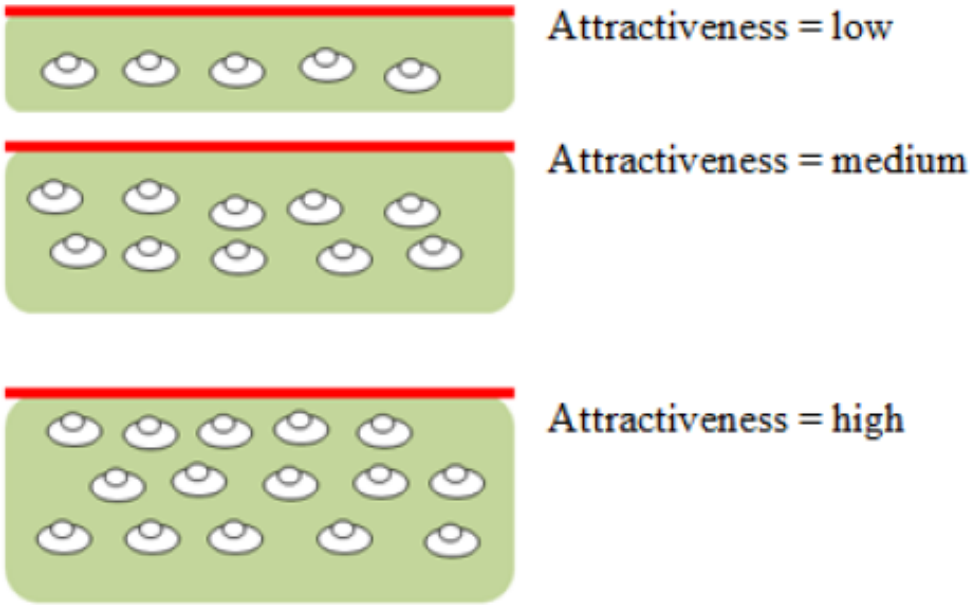
Determination of navigable area

Criteria for determination of functional areas, cont.

Change of object's attractiveness and importance over time.

Finite number of partitions:

- Peak and off-peak hour
- Lunch and dinner time
- 1st, 2nd, 3rd day of conference

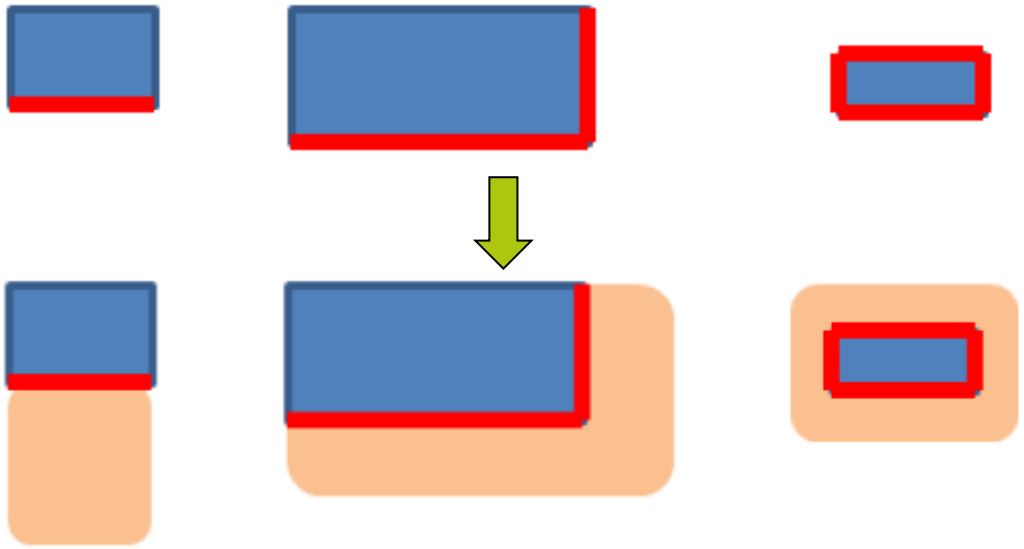


Determination of navigable area

Representation of functional areas

Functional areas appear in service directions.

- Lines represent service directions.
- Functional areas are line buffers.
  - Buffer area is non-navigable area.



Determination of navigable area

Case Studies

Study 1: Rotterdam Central Station:

- Large open space
- Different types of objects
- Dynamic environment
- Available data

Study 2: Faculty of Architecture and the Built Environment:

- Smaller open spaces
- More static environment
- Available data

Determination of navigable area

Delineation of functional areas. Case 1

Determination of navigable area

Delineation of functional areas. Case 1

None of optional parameters are applicable to the object, the functional area is determined by weighted human body projection on a horizontal plane and private space.

CASE WHEN limited capacity= 'no' AND transition area = 'no' **THEN**

subspace = human projection × ((attractiveness × time) + (necessity × time) + closeness) + private space

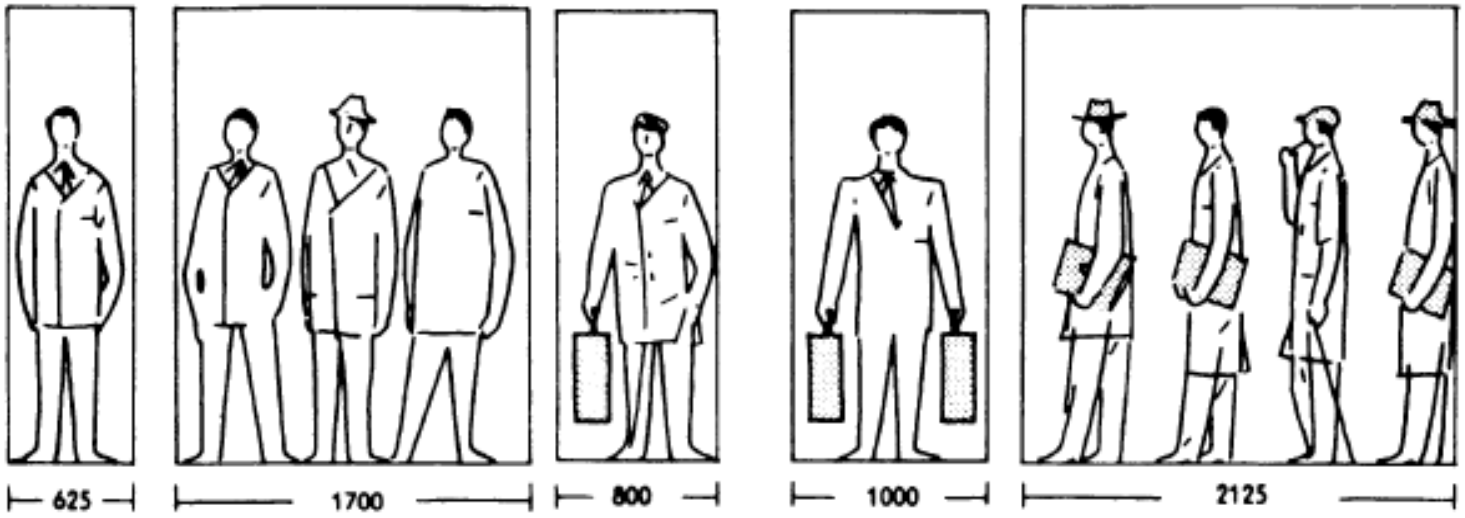
END

Determination of navigable area

Delineation of functional areas. Case 1

Human body projection – average space required for a single individual to avoid physical contact and disturbance of others.

Weight – summation of attractiveness, necessity and closeness values.



Neufert, E., and Neufert, P. (2012)

Determination of navigable area

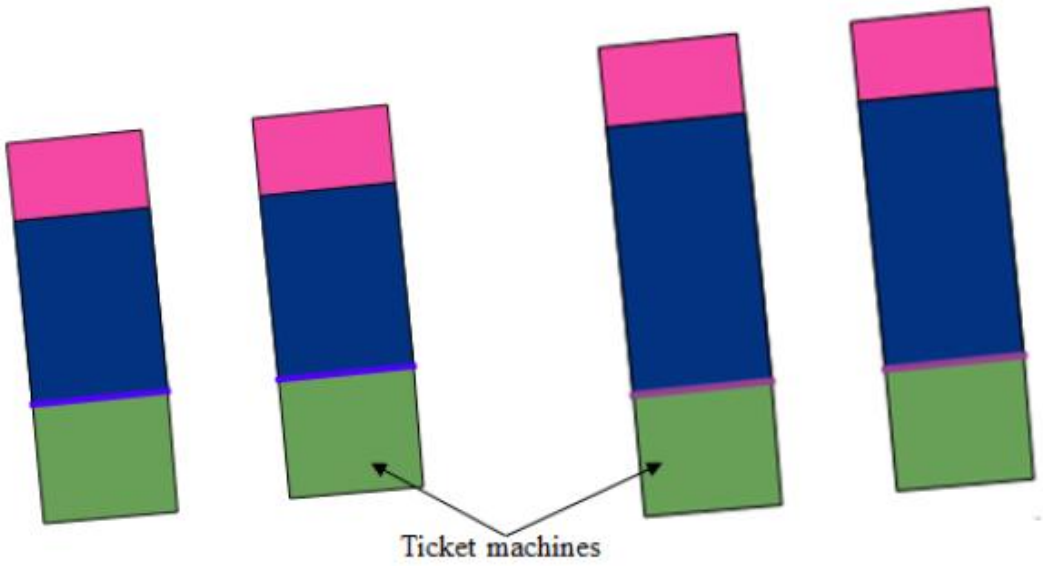
Delineation of functional areas. Case 1

Off-Peak Hour

Attractiveness: 2 (medium)
Necessity: 1(essential)
Closeness: 0.55
Private space = 0,9
Functional area:
0.6 × (2+1+0.55) + 0.9 = 2.10

Peak Hour

Attractiveness: increased 50%
Necessity: increased 50%
Closeness: 0.55
Private space = 0,9
Functional area:
0.6 × (3+1.5+0.55) + 0.9 = 3.00



Determination of navigable area

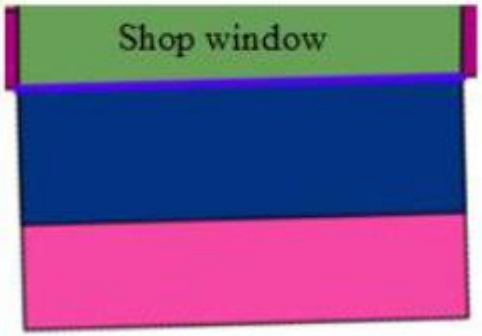
Delineation of functional areas. Case 1

Determination of navigable area

Delineation of functional area. Case 1

Off-Peak Hour

Attractiveness: 1 (low)
Necessity: 0 (non-essential)
Closeness: 0.94
Private space = 0,9
Functional area:
0.6 × (1+0+0.94) + 0.9 = 2.10

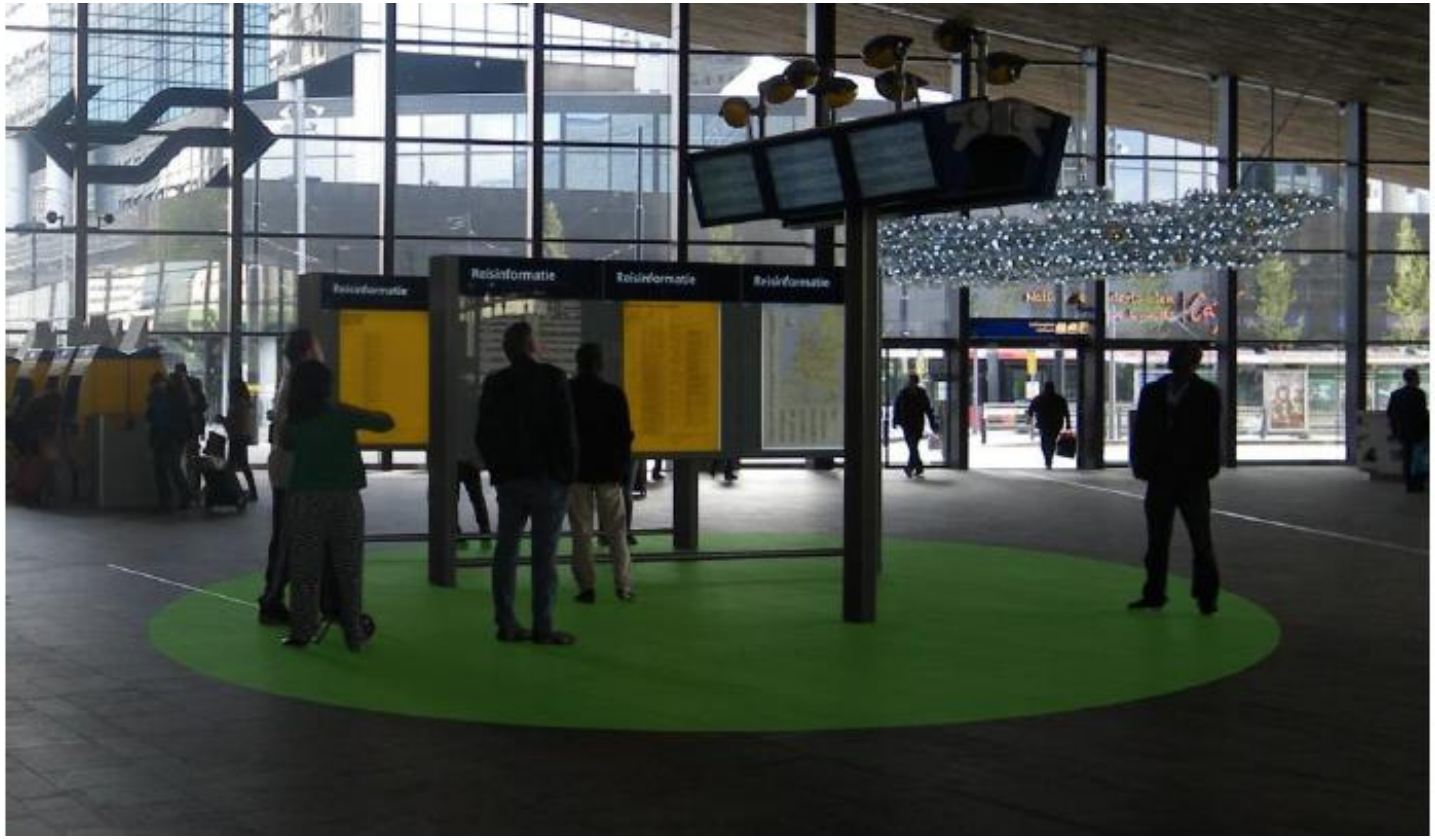


Peak Hour

Attractiveness: decreases 50%
Necessity: decreases 50%
Closeness: 0.94
Private space = 0,9
Functional area:
0.6 × (0.5+0+0.94) + 0.9 = 1.70

Determination of navigable area

Delineation of functional area. Case 2



Determination of navigable area

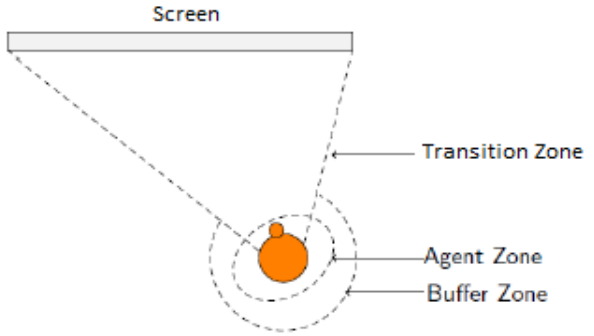
Delineation of functional area. Case 2

In case the *Transition zone* parameter is valid for the object, the functional area is determined by the transition distance, weighted human body projection on a horizontal plane and private space concept.

CASE WHEN limited capacity= 'no' AND transition area = 'yes' **THEN**

subspace = transition distance + human projection × ((attractiveness × time) + (necessity × time) + closeness) + private space

END



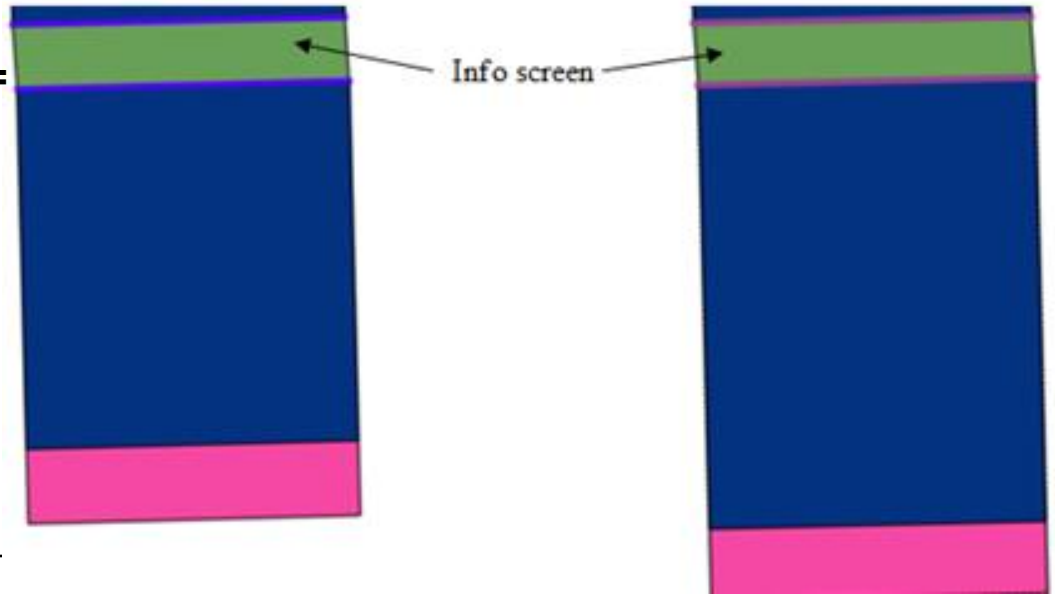
Lindner and Eschenbach, 2011

Determination of navigable area

Delineation of functional area. Case 2

Off-peak hour

Attractiveness: 3 (high)
Necessity: 1 (essential)
Closeness: 0.73
Private space: 0.9
Transition area: 1.5
Functional area: 1.5 + 0.6 × (3+1+0.73) + 0.9 = 5.20



Peak hour

Attractiveness: increases 50%
Necessity: increases 50%
Closeness: 0.73
Private space: 0.9
Transition area: 1.5
Functional area: 1.5 + 0.6 × (4.5+1.5+0.73) + 0.9 = 6.50

Determination of navigable area

Delineation of functional area. Case 3

Determination of navigable area

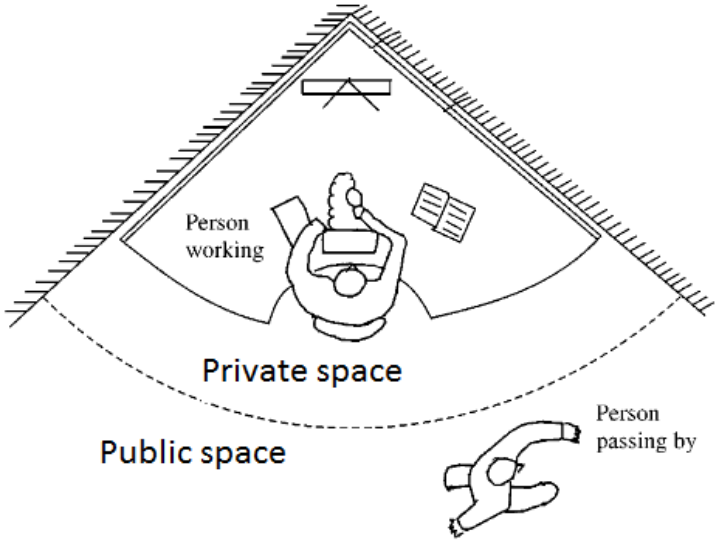
Delineation of functional area. Case 3

In case the optional parameter *Limited capacity* is applicable to an object, the functional area is calculated applying private space concept.

CASE WHEN limited capacity = 'yes'

THEN subspace = private space

END



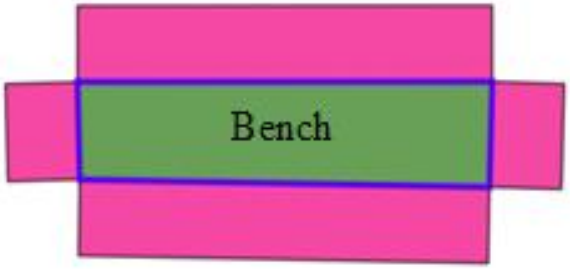
adapted from Junestrand, Keijer and Tollmar, 2001

Determination of navigable area

Delineation of functional area. Case 3

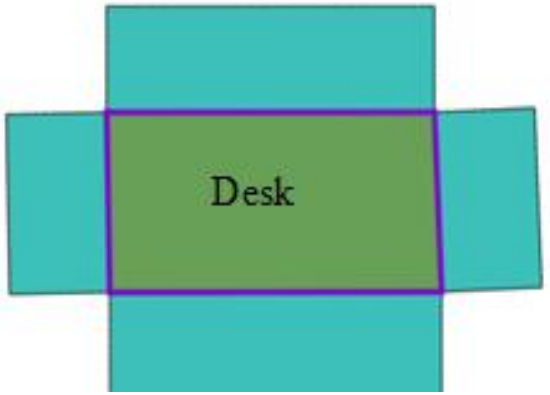
Rotterdam CS

Limited capacity: yes
Private space: 0.9
Functional area: 0.9 m



BK faculty

Limited capacity: yes
Private space: 1.2
Functional area: 1.2 m



Determination of navigable area

Delineation of functional areas. Special Cases

In cases where sub-spaces overlap and:

- sub-spaces have the same name → dissolve
- sub-spaces contain different names and have different weight values → priority given to object with larger weight
- subspaces have different names but the same weight values → the overlap is cut from the sub-spaces with larger area.

In cases where distance between spaces is 1 meter or less → aggregate sub-spaces

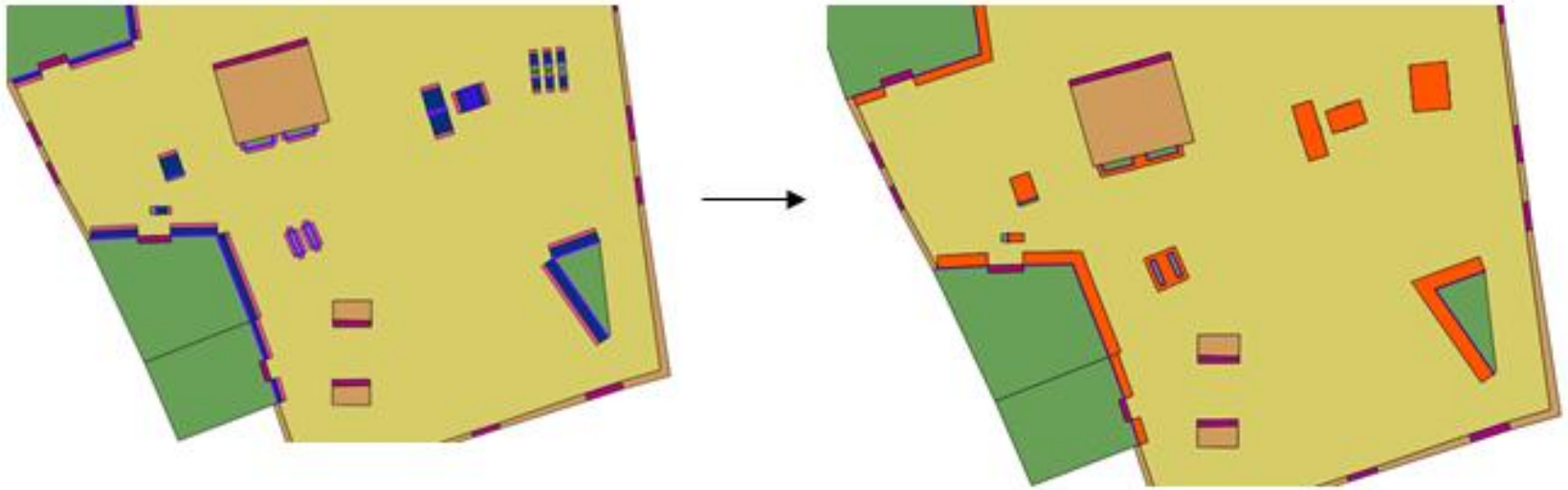
Determination of navigable area

Delineation of functional areas

Functional areas in RC station during off-peak hour.

Before overlap removal and aggregation

After overlap removal and aggregation



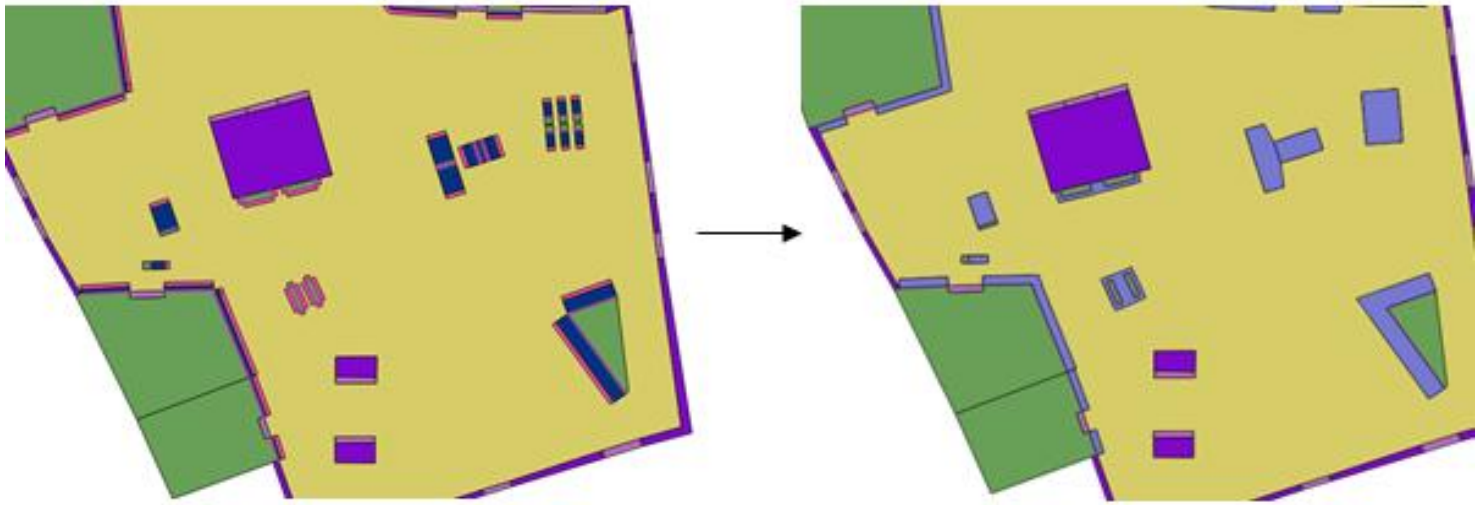
Determination of navigable area

Delineation of functional areas

Functional areas in RC station during peak hour.

Before overlap removal and aggregation

After overlap removal and aggregation



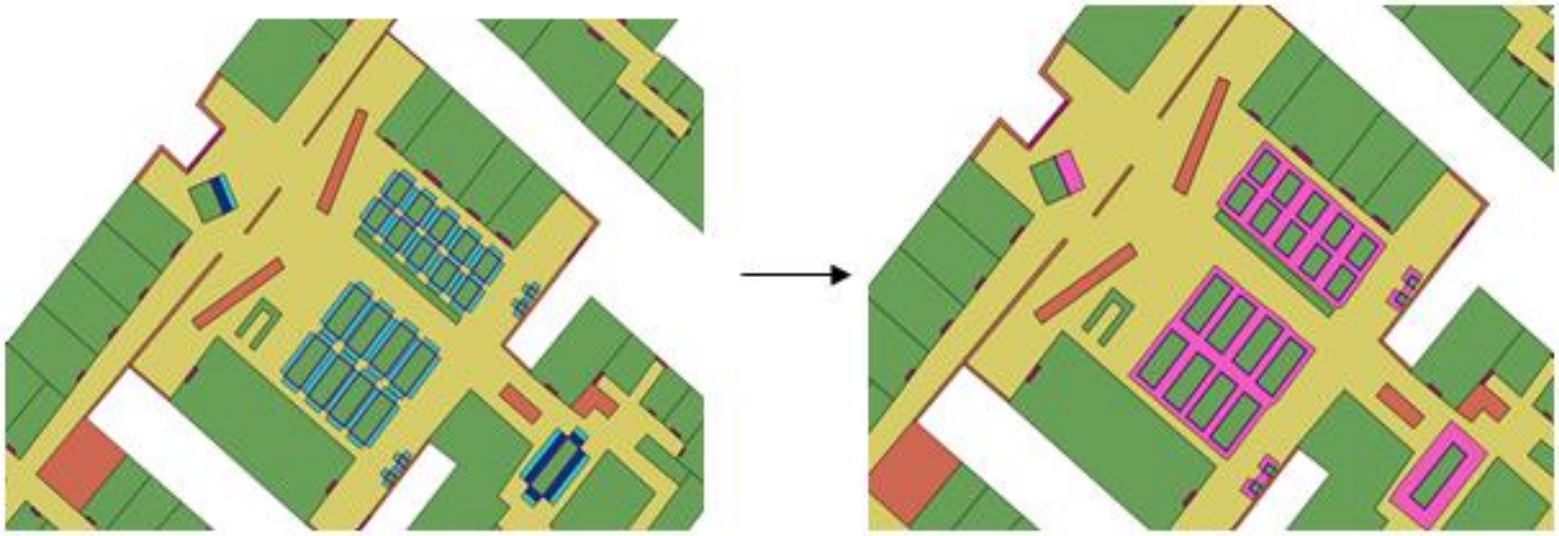
Determination of navigable area

Delineation of functional areas

Functional areas in BK faculty.

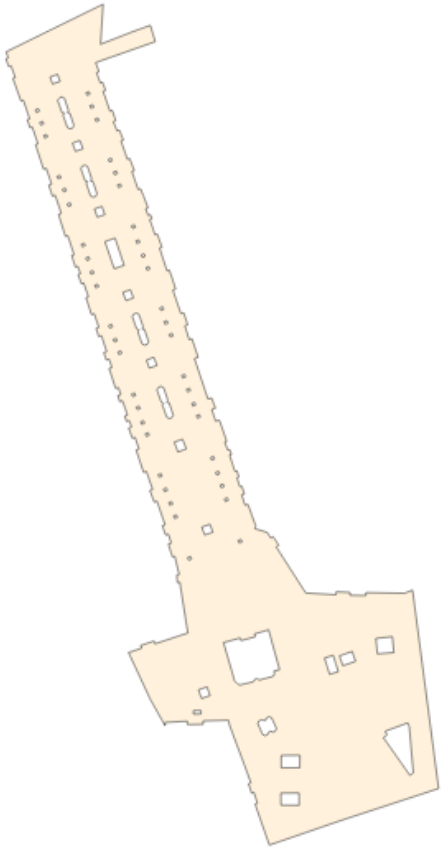
Before overlap removal and aggregation

After overlap removal and aggregation

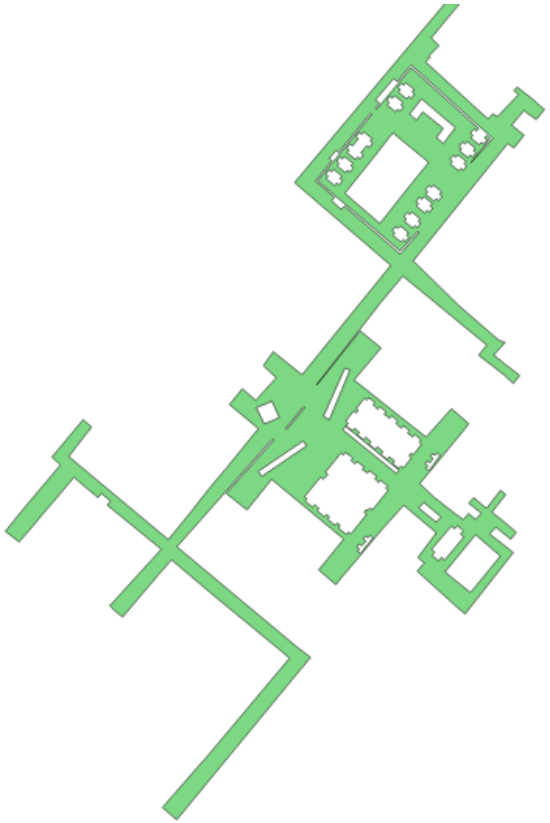


Determination of navigable area

Navigable area in RC (off-peak hour).



Navigable area in BK.



Navigable space subdivision

Navigation model

Network is chosen due to:

- ability to store geometric, topologic and semantic information
- high flexibility (insertion and deletion of network nodes)
- easy implementation and maintenance
- fast path calculations

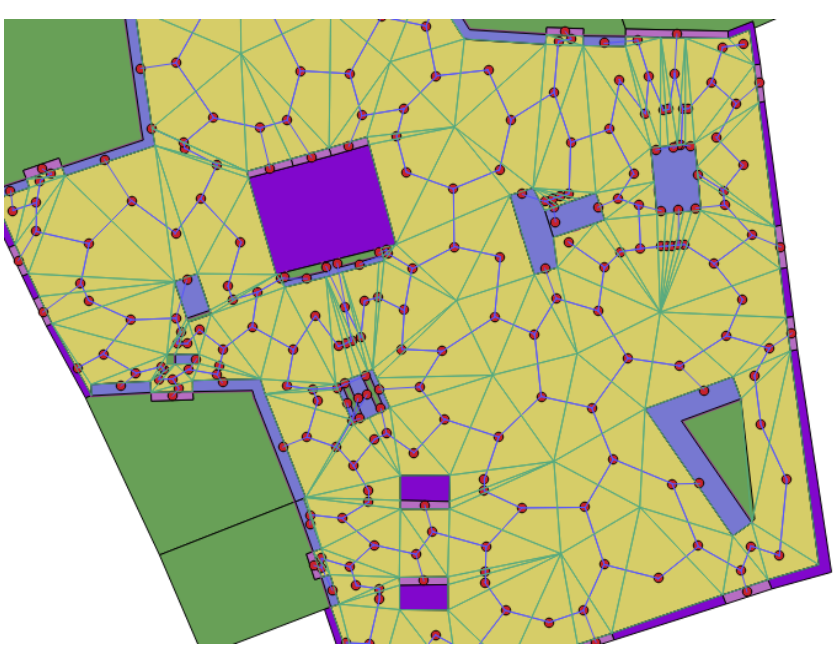
Constrained Delaunay Triangulation is used to build network due to:

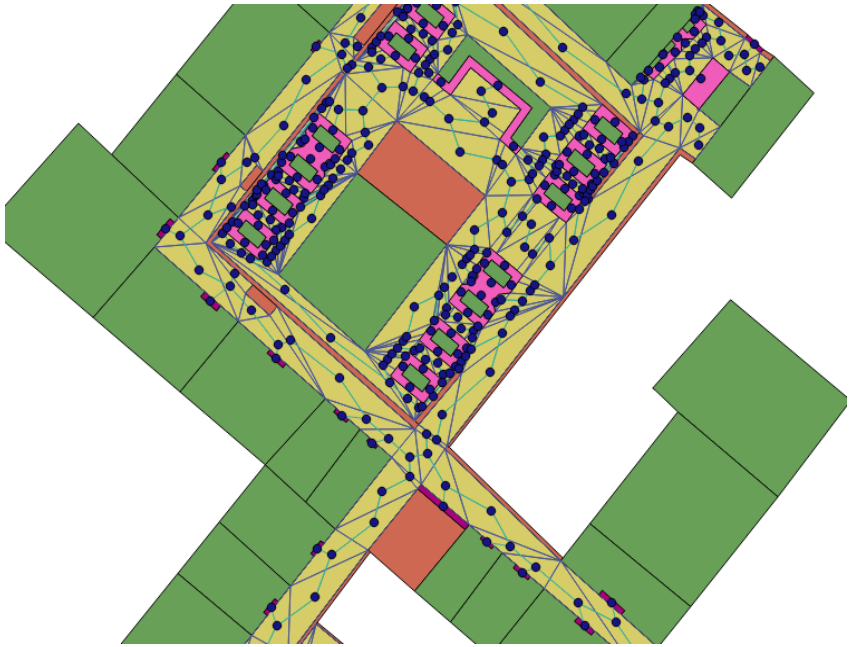
- full coverage of space (even small areas are mapped)
- preserves boundaries
- different constraints can be applied to derive suitable level of granularity
- provide paths that do not touch obstacles

Navigable space subdivision

Generation of navigation network

Network nodes: centroids of triangles, connectors and functional areas.



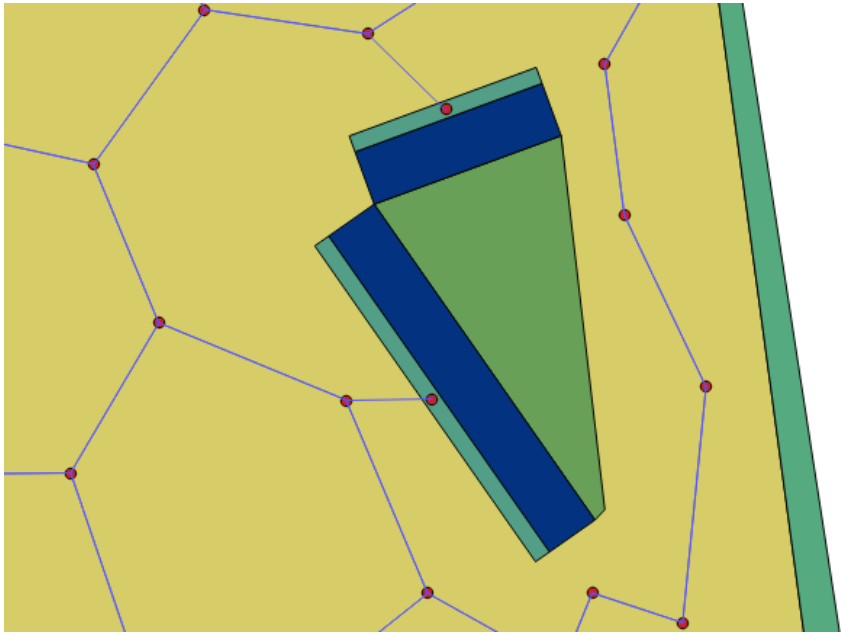


Navigable space subdivision

Generation of navigation network

Node of functional area = centroid of area determined by private space

Nodes of functional areas contain only 1 link

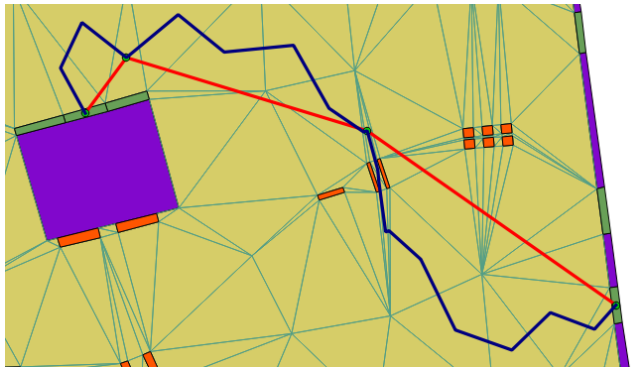


Navigable space subdivision

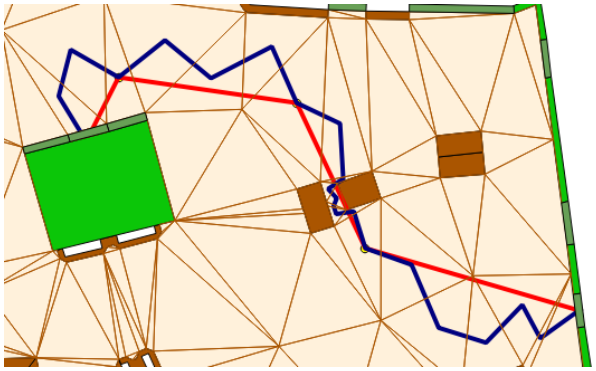
Derivation of navigation path

Indication of functional areas provide more realistic paths.

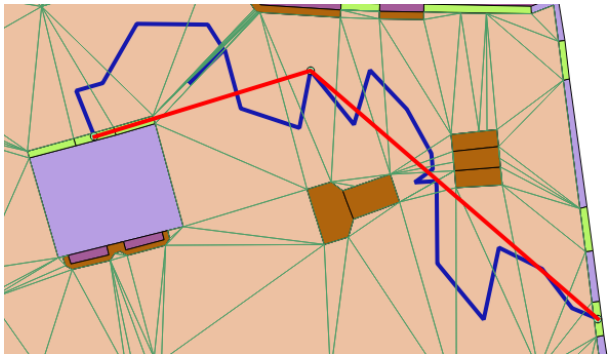
<u>Without functional areas</u>



<u>With functional areas</u>
Off-peak hour



<u>With functional areas</u>
Peak hour



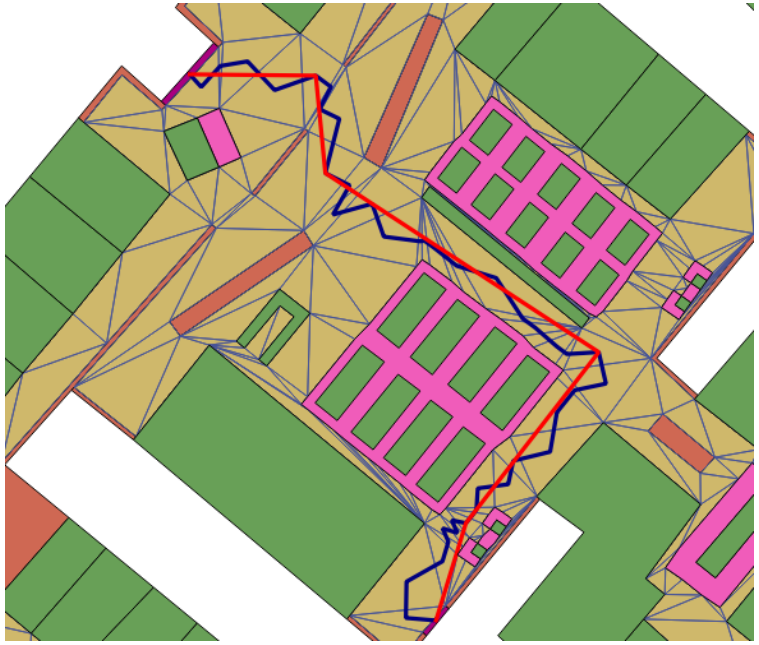
Navigable space subdivision

Derivation of navigation path

Indication of functional areas provide more realistic paths.

Without functional areas BK

With functional areas BK



Validation

Image analysis

Rotterdam Central Station:

- Photos taken from 2 positions (main hall and passage)

Faculty of Architecture and the Built Environment:

- Photos taken in the Orange Hall

Validation

Image analysis

Object (Number of photos)		Functional area from images (m)	Calculated functional area (m)	Result	Remarks
Ticket machine (120)	Off-peak	1.5	2.1	Partly supported	• small range of criteria values
	Peak	1.3	3.0	Not supported	• incorrect evaluation of time impact on attractiveness and necessity
Shop(58)	Off-peak	2.1	2.1	Supported	
	Peak	1.0	1.7	Partly supported	• high *closeness* value
Information screen (76)	Off-peak	3.8	5.2	Partly supported	• small range of criteria values
	Peak	4.9	6.5	Partly supported	• incorrect evaluation of time impact on attractiveness and necessity • wide temporal variation
Bench (15)		0.9	0.9	Supported	
Desk (34)		0.9	1.2	Partly supported	• wrongly assigned private space value due to incorrect evaluation of type and structure of the environment

Validation

Video analysis

16 participants; 2 different compositions of tables

- People prefer straight paths
- People prefer wider passages
- Aggregation of functional areas that are close to each other and compose narrow walkable passages provide better abstraction of the navigable area

Conclusions

In which manner should the indoor space be subdivided to support more realistic abstraction of indoor environment and generation of navigation path while taking account of human perception of the environment and social aspects of human interaction?

Two-step indoor space subdivision:

- Semantic: determination of navigable and non-navigable areas applying proposed model for determination of functional areas
- Geometric: generation of navigation model

The proposed criteria for semantic decomposition of space are appropriate to determine functional areas of objects and define navigable and non-navigable areas within indoor environment.

Conclusions

Object's attractiveness and necessity change over time.

- Change is influenced by many different factors.

Objects with limited capacity have constant functional areas and private space concept is an appropriate measure to delineate them.

- Private space highly depends on people within environment and type of the environment.

Indication of functional areas as *dead-end nodes* in a navigation network provides a more realistic abstraction of a navigable area.

- Non-navigable areas are eliminated.
- Aggregation of functional areas excludes narrow passages.

Navigation network alone does not provide a smooth navigation path.

Future work

- Investigation of different ranges of criteria values
- Improvement of closeness analysis
- Generation of different navigation models: grid, network derived from visibility graph
- Indication of repulsive forces
- Development of algorithm for automatic aggregation of functional areas
- Representation of functional areas in 3D models

Thank you for your attention!

Questions?

Back-up

Back-up 1.

Research questions

In which manner should the indoor space be subdivided to support more realistic abstraction of indoor environment and generation of navigation path while taking account of human perception of the environment and social aspects of human interaction?

- How properties of indoor environment influencing human distribution inside buildings can be applied to derive functional areas?
- How rules that people tend to follow during navigation inside buildings and their social interaction can be applied to generate navigable and non-navigable areas within indoor space?
- How to incorporate functional areas in a navigation model and provide more accurate navigation path?

Back-up 2.
Software

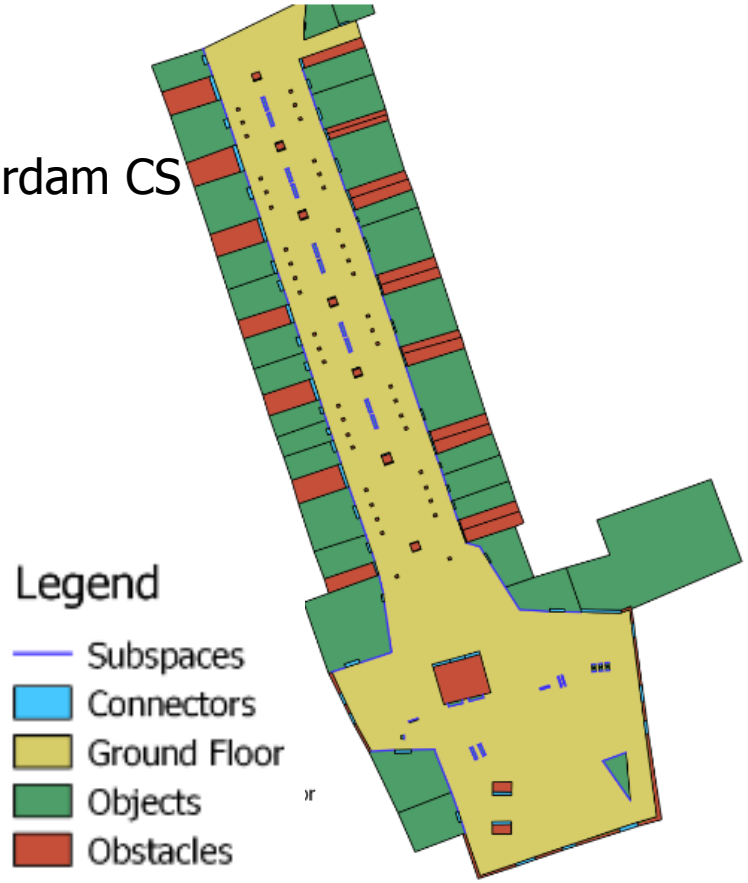
Used software:

- ArcGIS – data preparation, closeness to central locations analysis
- Python – creation of buffers, planar partition and navigation network
- PostGIS – storage of navigation network, path calculations

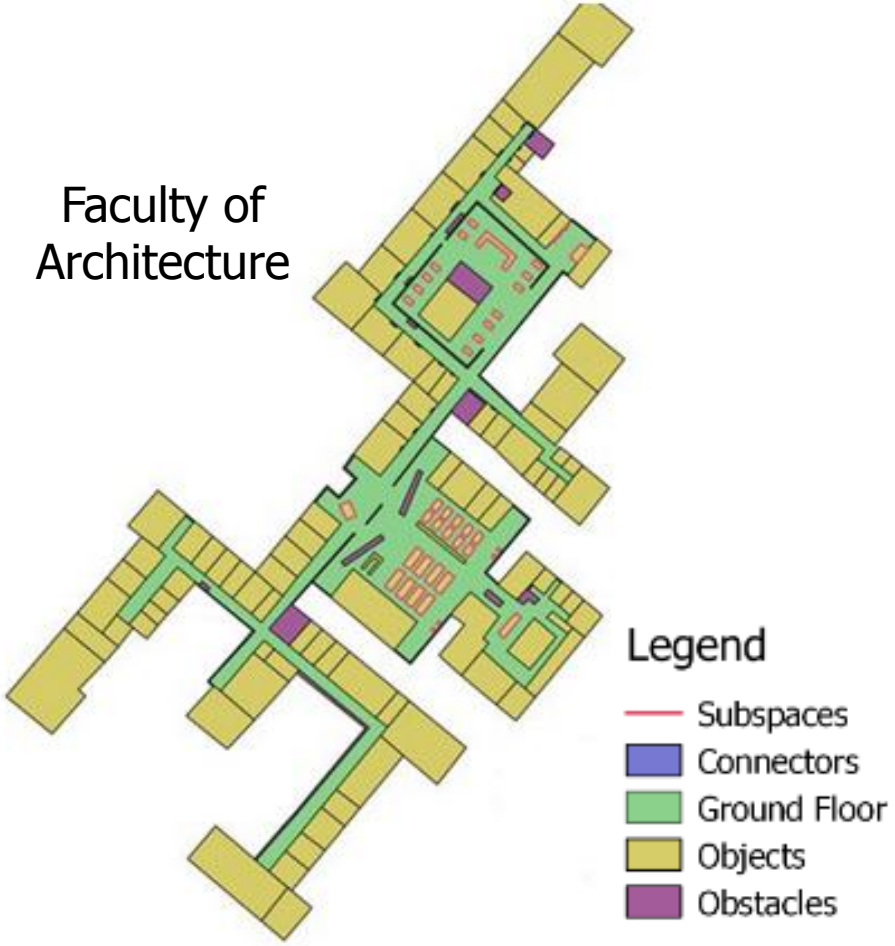
Back-up 3.

Data preparation

Rotterdam CS



Faculty of Architecture



Back-up 4.

Data preparation

Lines indicate in which directions functional areas expand or shrink.

Functional areas are calculated as *one side line buffers with flat cap.*

Attributes of Line Features (Functional areas):

- Type (room, shop, information desk, etc.)
- Name (BG010, AH to go, train information, etc.)
- Attractiveness
- Necessity
- Closeness to central objects
- Limited capacity
- Transition area

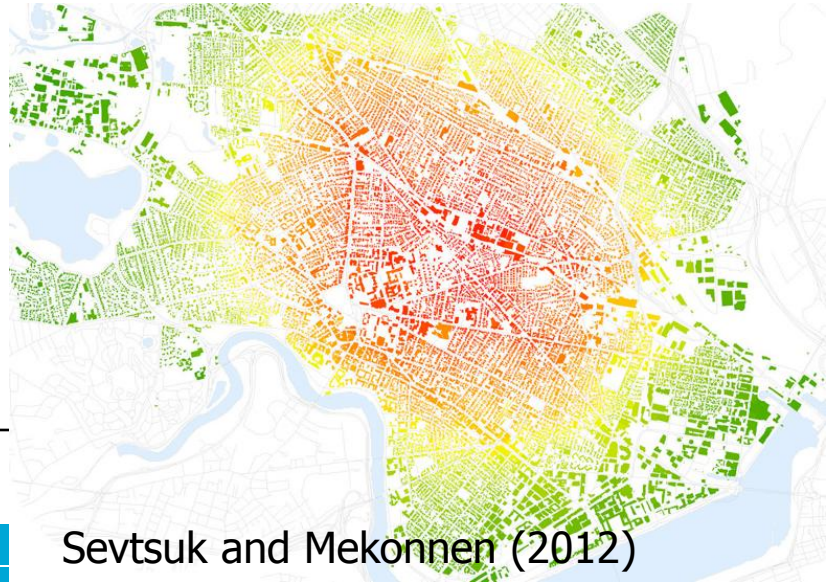
Back-up 5.

Criteria values

Attractiveness, necessity, limited capacity, transition zone and private space values are assigned with respect to type of the environment and function of the object.

Closeness – network centrality measure. Inverse of the total distance from object to all other locations that are reachable along the shortest paths.

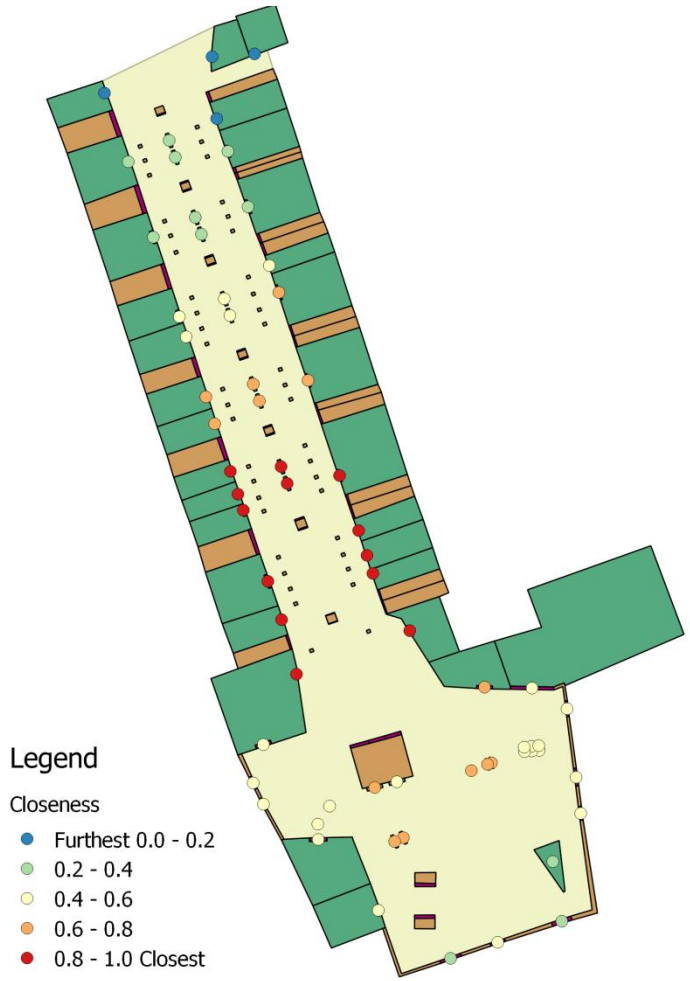
$$Closenesss^{r}\ [i] = \frac{1}{\sum_{j \in G-\{i\}, d[i,j] \leq r} (\mathrm{d[i,j]})}$$



Sevtsuk and Mekonnen (2012)

Back-up 6.

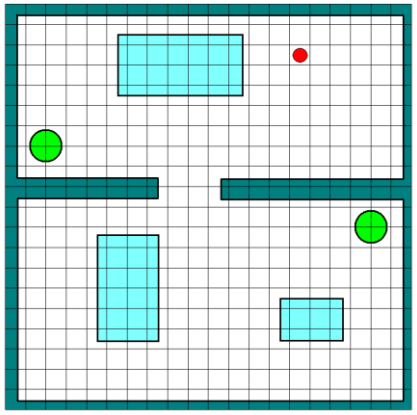
Data preparation. Closeness analysis



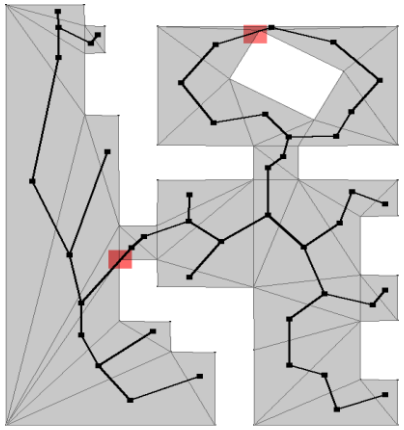
Back-up 7.

Navigation models

Method	Pros	Cons
Grid	· Accurate location data · High quality data · Easy to design and maintain	· Consumes excessive amounts of memory and processor time in large spaces
Network	· Easy to design and maintain · Efficient due to its compactness · High level of flexibility	· Not a high accuracy location data



Grid

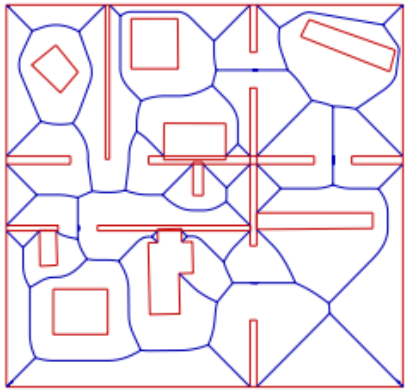


Network

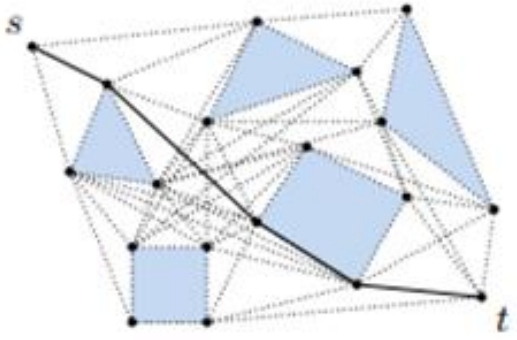
Back-up 8.

Options to create navigation network

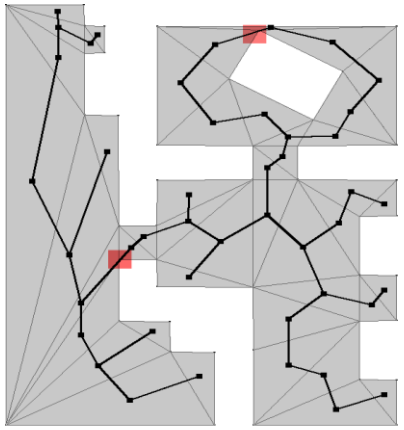
Method	Pros	Cons
Constrained Delaunay Triangulation (CDT)	coverage of the whole area; preserves shape; simple implementation	in some cases might provide coarse nav. paths
Visibility Graph	realistic navigation path	difficult implementation, time consuming calculations, paths touch obstacles
Medial Axis Transformation (MAT)	works well in long corridors	not suitable for large open spaces



MAT



Visibility graph



CDT

Back-up 9.

Derivation of navigation path

Path simplification:

Divide and conquer principle is adopted. If line segment is within the navigable space, remove the points in between.