A 3D delineation method for urban river spaces.

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1 Introduction

Rivers are often a prominent aspect of urban areas. Many cities around the world are build around a river due to the way it can serve civilisation, for example in transport opportunities. There is a tension with urban river spaces as there is both an artificial and natural aspect to it. The majority of rivers have in some way been altered by humans. Rivers within cities can alter city dynamics by its use, but also by serving as a barrier between parts of the city.
An accurate spatial description, or a spatial delineation, of urban river corridors (URC) is essential for a wide range of applications, including flood mitigation and public space design. The specific placement of boundaries can influence the understanding of the area or phenomenon in question. Boundaries are used to make decisions and therefore influence decisions to alter the urban space.

This thesis aims to develop a 3D delineation method for urban river spaces by adapting an existing 2D delineation approach. By adapting this 2D method, the aim is to develop a technique that is able to more accurately represent the spatial complexities of these areas. The method will make use of open data sources as much as possible. The delineation is based on visibility analysis, or isovists. As a starting point, an area in the Netherlands is taken, but the transferrability of the method to other countries and areas is explored.

1.1 Scientific relevance

A delineation is the precise description or exact position of a boundary. To gain understanding about fundamental urban questions such as the internal structure of cities, appropriate definitions are needed Duranton (2021). A delineation method is necessary when researching a specific area,

making exact what area and why this area is investigated. The way in which boundaries are drawn can influence the understanding of the phenomenon being questioned. Then these boundaries also influence the decisions made about this urban space to transform it in response to that phenomenon. The delineation of the river space can then act as a decision support model for monitoring, evaluating, and making design decisions for urban planning.
A 2D river corridor delineation method exists already. 3D information reveals additional knowledge of the area. A 2D map of a city cannot, for example, describe the walkability of a city as an important aspect of this is elevation differences. Flood mitigation research may benefit from a clearly defined area as the river space. As rivers are used as transport ways, a clear understanding of the river space can support transport planning.

CRiSp project
City River Spaces (CriSp) is a tool in development for automated and scalable delineation of urban river spaces with spatial-temporal big data. The result of this thesis could become part of the CRiSp project as a module for 3D delineation.

2 Related work

2.1 2D delineation method

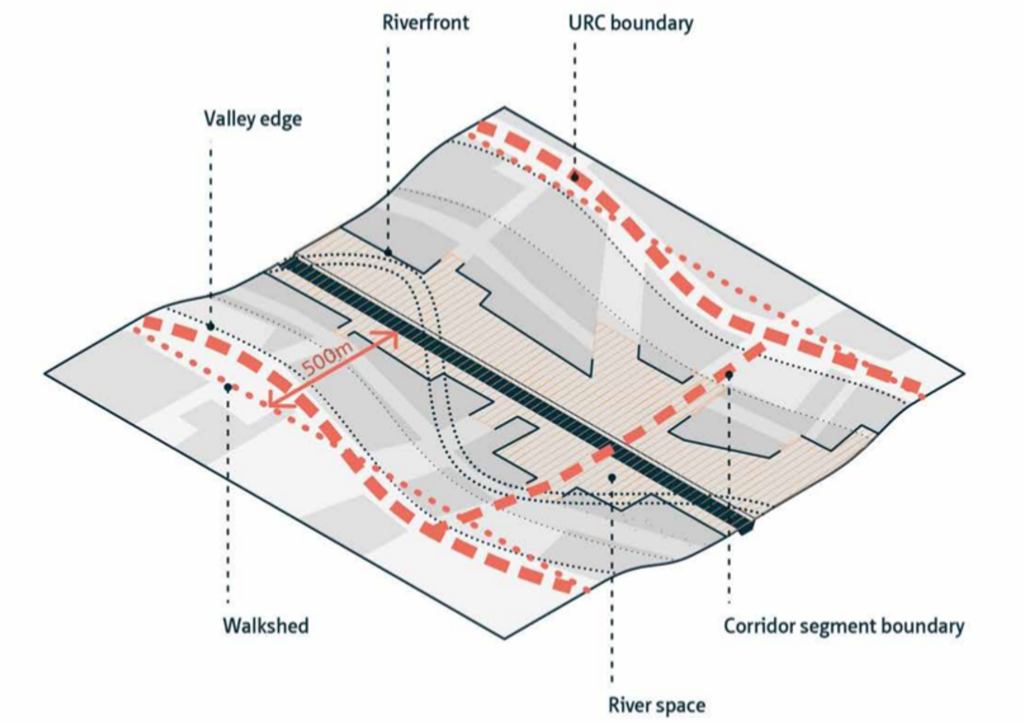


Figure 1: The 2D spatial delineation method of the URC (Image source: Forgaci, 2018)

The 3D delineation method for urban river spaces that will be developed in this thesis is based on an existing 2D delineation method, specifically the spatial delineation method of 2D urban river corridors (URC) developed by Forgaci (2018). The spatial definition of urban river corridors here is given from a spatial-morphological perspective, by which is meant that it is based on the physical boundary of a neighbourhood as seen in the urban fabric. It entails the spatial structures that help integrate the river within the urban environment. This implies it takes into account certain components of the relationship between the river and the city, such that any property of the URC concerns both the river and the city. The delineation that considers such configuration and composition of the

urban fabric, has an underlying social-environmental logic that is better aligned with the boundaries of a phenomenon than an arbitrarily chosen area.
Figure 1 shows an overview of the 2D delineation. The components are defined as following:

- **Valley edge**: Determined from, for example, a digital elevation model (DEM) using a method of river corridor delineation.
- **Walkshed**: An extension of the outer boundary, in this definition towards 500m.
- **Riverfront**: The space along the river delineated by the built front (Batiste e Silva et al. 2004; 2013).
- **URC boundary**: Determined by the main roads parallel, next to and outside the river valley.
- **River space**: The direct contact area between the river and the first line of buildings, including these buildings. Beige coloured in the image.
- **Corridor segment boundary**: Divide the URCs along major transversal traffic lines, most of the times when there is a bridge.
- **River**: Thick black line is the canal and the curved line is the natural trajectory of the river.
- **Streets** are shown in light gray, **buildings** in darker gray.

This thesis focuses on developing a 3D method specifially for the riverspace (the beige area in figure 1).

The 2D delineation method applied to Colentina in figure 2. Here the river space is light-green coloured. The river space is delineated in a way such that it represents the continuous space around the river, bordered by the first building line.

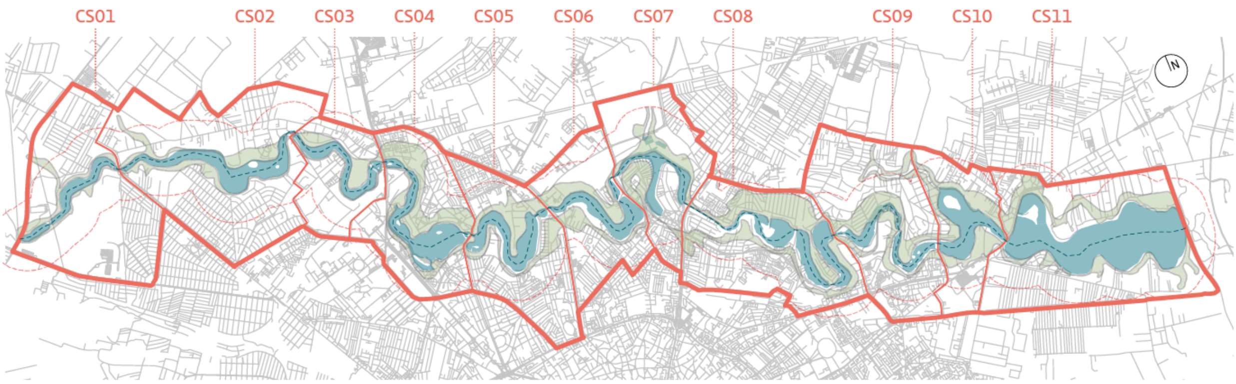
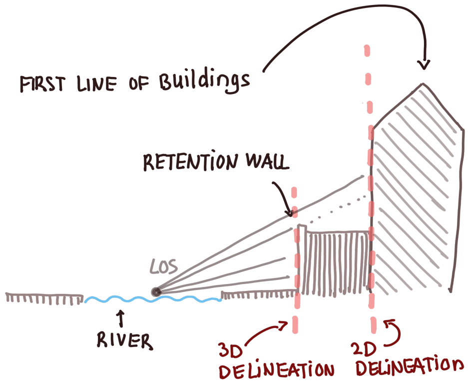


Figure 2: The 2D delineation of URC Colentina and its segments CS01-CS11 (Image source: Forgaci, 2018)

Methods and tools for river delineation in non-urban areas exist, but the method described above is the only one specifically for urban areas.

In the described 2D delineation method, the river space is defined as the direct contact area between the river and the first line of buildings, including these buildings. This does not take into account any 3D information of the area. For example, the first line of buildings can have a low height, which implies the second line of buildings is still visible from the river space which implies there is an interaction between the two. Another possibility could be that there is an object, like a retention wall of the river, or a hill, between the first line of buildings and the river that obstructs view and interaction which is not taken into account in the 2D method. To extract such information, visibility analysis methods can be used. Then visibility analysis is a way in which the river space can be delineated

(a) 'Oudegracht' in Utrecht with its retention wall shown. (Image retrieved from In de buurt)



(b) Difference between 2D and 3D delineation when there is a retention wall.

Figure 3: A canal in Utrecht with retention wall and the difference between 2D and 3D delineation of river space in such cases.

while taking into account the 3D spatial information of this area.

Figure 3a shows the 'Oudegracht' in Utrecht, The Netherlands, which is an example in which the 2D and 3D delineation of river space would differ if the 3D method is based on visibility. In the 2D delineation method for the river space, the boundary is determined by the first line of buildings. The retention wall next to the canal would block vision from the river to the are in front of the buildings. thus the area between the wall and first line of buildings would be included in the 2D method, but not in the 3D method (Figure 3b).

2.2 Isovist visibility analysis

Visibility analysis determines which areas are visible from a specific viewpoint, as well as the quality and extend of such views. Therefore, such analysis can take into account different factors such as

- Line of sight (LoS), see figure 4: Examine what can be seen from different points within the space
- Visual obstructions: Identifying elements that may obstruct or block views
- Visual connections: Assessing how different parts of the space are visually connected or disconnected from each other
- Visual hierarchy: Determining which elements or areas are more prominently visible and how they contribute to the overall visual experience.

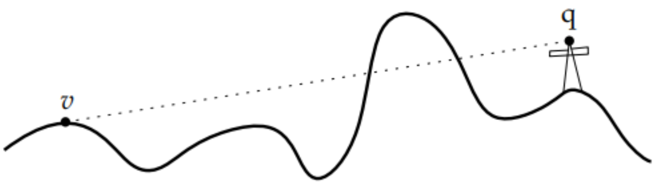
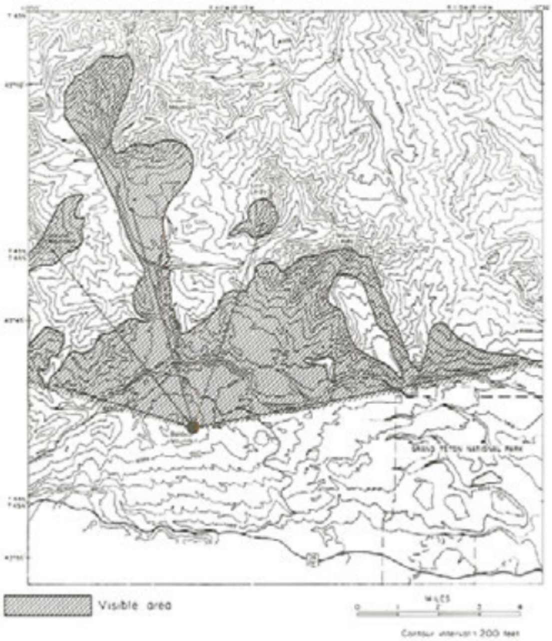
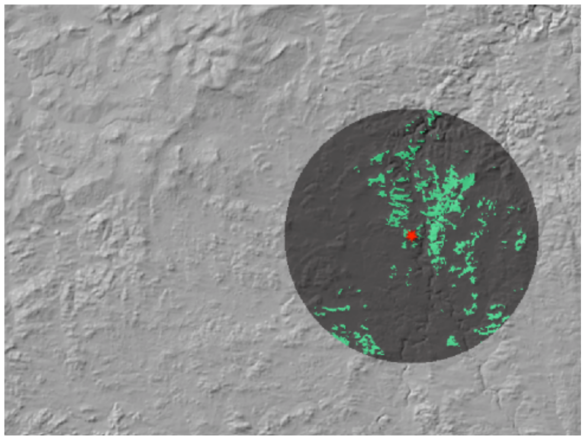


Figure 4: Line of sight between v and q, with q not visible. (Image source: Ledoux et al., 2022)

Isovist visibility analysis is a method used in architecture and urban planning to analyze and optimize the visibility within a space or environment. The concept of isovists or viewsheds was first introduced by Tandy (1967) as a way to convey the composition from an observer's perspective and facilitate visual analysis of the landscape. Benedikt (1979) introduced the concept in architectural studies, and defines isovists as the set of all points visible from a given vantage point in space and with respect to an environment. Figure 5a shows an early example of viewshed analysis. Figure 5b shows an example of a viewshed of a terrain, where this viewshed shown as the green area is disconnected.



(a) An early example of viewshed analysis. Visible terrain from a viewpoint in the Teton National Forest in Wyoming, USA (Image source: Lynch, 1976)



(b) The viewshed of the red viewpoint in which green means visible from this viewpoint. The maximum view distance in dark grey is set to 15 kilometer (Image source: Ledoux et al., 2022)

Figure 5: Viewshed examples

Isovists and viewshed are both concepts of spatial visibility, but the technical difference is that raster-based viewsheds represent the visible parts of space, considering horizontal and vertical viewing angles and elevation, while (2D) isovists are vector-based and take into account visible space in the horizontal plane (Nijhuis, 2015). Important is that the viewpoint can be defined directly from the elevation value of the specific point, or for example from the height of a person.

Isovists can be represented in different ways, such as visibility graphs, 3D polyhedral volumes, or 2D polygons. A visibility graph is a graphical representation used in computational geometry and computer science for modelling the visibility relationships between different points or vertices in a given environment. The environment is typically represented as a set of obstacles or vertices, with each vertex being a point in the environment. Edges are drawn between vertices if there is a line of sight or unobstructed view between them.

2.3 3D isovists

Related work concerns 3D isovists analysis for different environments, mainly indoor, using different methods. 3D isovists analysis research has been done for the study of public displays by Dalton et al. (2015) , comparing the use of 2D and 3D isovists of assessing display noticeability on a university campus. They used scanned isovists, providing a number of 3D scans and compared the numerical values to interview outcomes. It assesses the potentially added value of 3D isovists, and the validness of 2D isovists methods when 3D methods exist. They found that 3D-isovists appear to function like 2D-isovists, but mention that the simplicity of the spaces they are using may result in unfair

comparison.
A method to evaluate visibility from point clouds in indoor environments using a voxel-based structure was proposed by Díaz-Vilariño et al. (2018). The 3D isovists are created from the boundary of visible voxels from a specific viewpoint.
Krukar et al. (2020) argues that instead of volumetric 3D isovists, embodied 3D isovists should be used for 3D analysis when human perception of space is a key interest. This is argued from an indoor perspective. An embodied 3D isovist in this context is meant as spatial artefact, in which different parts of space are distinguished, such as above and below.

Morello and Ratti (2009) offers a definition of isovist in space as a shape in 3D, in which the computation is based on line-of-sight outcomes, see figure 7.

3 Research objectives

3.1 Objectives

The main research question of this thesis is:
How can urban river spaces be delineated in 3D using isovist analysis?

The goal of the research is to develop a method to automatically retrieve the needed data from open data sources, to perform visibility analysis taking the river as viewpoint, and eventually to use this to delineate the river space. The following sub-questions will be relevant to answer the main research question:

- Data question: What data is needed and available and what processing steps for this data are necessary to perform the isovist analysis? How can the data be automatically retrieved from open data sources?
- Algorithm question: What isovist algorithms exist and which one is most suitable for the delineation process? What input is needed for optimal 3D visibility analysis in urban riverspaces? How can the method be validated?
- Scale question: How can the algorithm be adapted to different regions on earth? Is it needed for the algorithm to be able to take different kinds of input?

3.2 Scope of the research

This thesis has its focus on the 3D delineation of the river space in urban areas. The 2D delineation will not be done but the method of Forgaci (2018) will be used for this.
The focus is on the algorithm itself, not the dataset that is used. Open data sources will be used as much as possible, and the availability of data will be part of the research.
No interface, such as a web application, will be build. Output will only be visualized in the method itself.
For certain research purposes, it would be ideal for the method to be optimised for global cross-case analysis. This would imply adapting and extending the method, and will not necessarily be part of this thesis. The starting point is an area in the Netherlands. Working from there, the method can be extended for other countries.

4 Methodology

The process is divided in different stages: the data retrieval, the data preparation, the delineation method, and the output of the method. Figure 6 shows the proposed methodology flowchart.

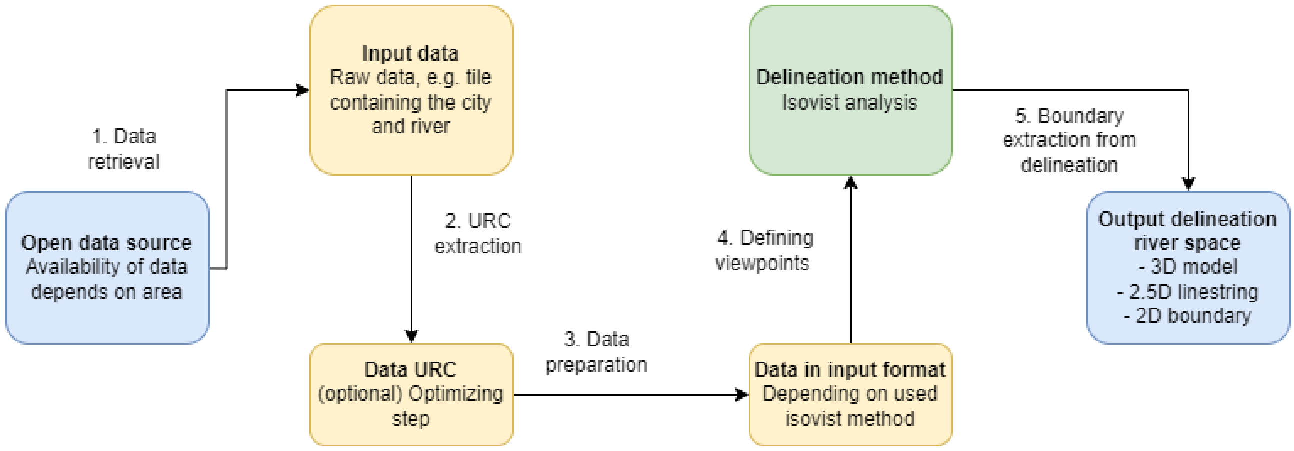


Figure 6: Methodology flowchart.

4.1 Data retrieval

Preferably, all that needs to manually be done for the input is to name the city and the river to be delineated. This requires the method to know where it can retrieve the necessary data. Data sources will first be defined for The Netherlands. To scale up the method, sources that are globally available need to be used. Data that is needed is some kind of elevation or height model of the city and the location of the river.

4.2 URC extraction

The area in around the river in which the river space delineation has to take place has to be defined. Following the method by Forgaci (2018), the outer boundaries of the URC are determined by the main roads parallel, next to, and outside the river valley. The river valley's edges are determined using a method of river corridor delineation from, for example, a digital elevation model (e.g. Vermont Agency of Natural Resources, 2007). The URC extraction is not fundamental to the method, but is more of an optimization step. If it's not necessary performance-wise, then this step can be skipped. This is depending on the algorithm used to perform the isovist analysis.

4.3 Isovist analysis algorithm

The delineation method is based on isovists analysis, which can be performed in multiple ways. The method has not been chosen yet. The preparation of data depends on the input requirements of the chosen method. This section describes some software options for the computation of isovists, specifically in three categories; scripts for isovist calculations, specific software developed for isovist, and options within GIS software. A method to compute 3D isovists is given by Morello and Ratti (2009). The technique is based on the Image Processing of DEMs using Matlab. They use this technique over existing computationl programmes specifically dedicated to isovist calculations for its flexibility of analyzing indicators and the short time it takes to do this. Simple algorithms are used based on the calculation of line-of-sight to obtain 2D isovists, isovistsfields and 3D isovists.
LoS are computed from a viewpoint covering a circular rotation of 360 degrees. A series of arrays are generated and are stopped when pixels with a value > 0 are found (Figure 7). An array is calculated containing the heights of the objects through the line, and an array with the distances from the viewpoint. The tangents of the heights to the distances are computed. Only the tangent which is bigger or equal to the one calculated on the previous point of the array are stored to discard buildings that are shaded by other buildings. The maximum values between the product of these maximum tangents with the corresponding distances to the viewpoint and the height of the buildings at this point are stored to visualize buildings that are behind other buildings but are still visible. Heights can then be distributed in a voxel space.

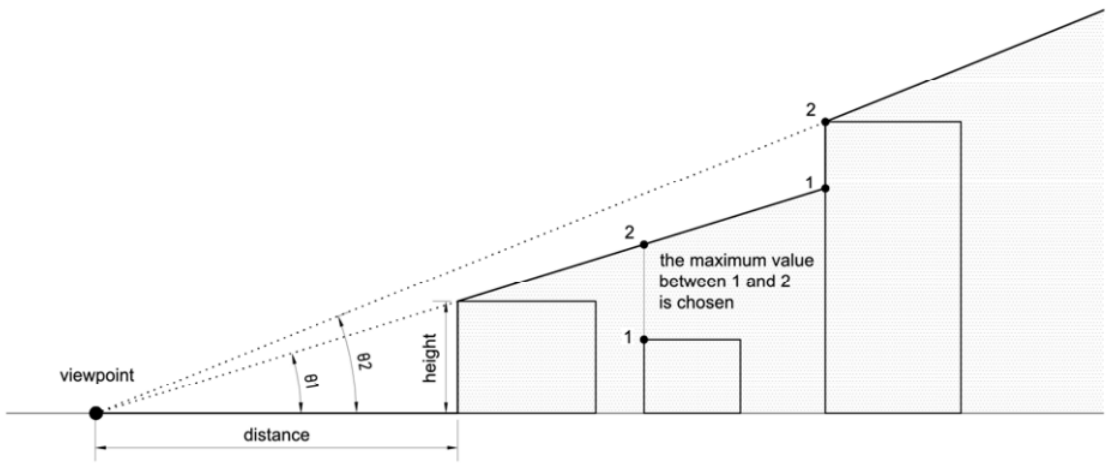


Figure 7: A computation of the 3D isovist on a DEM of visible and hidden spaces (Image source: Morello and Ratti, 2009)

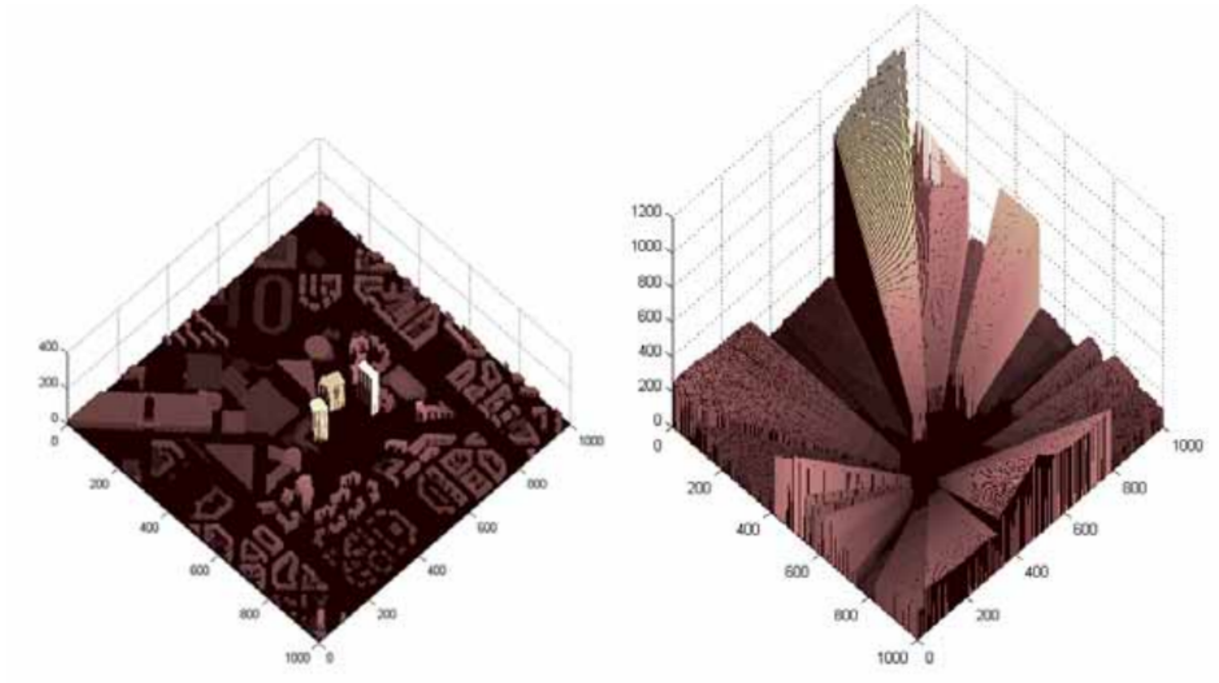
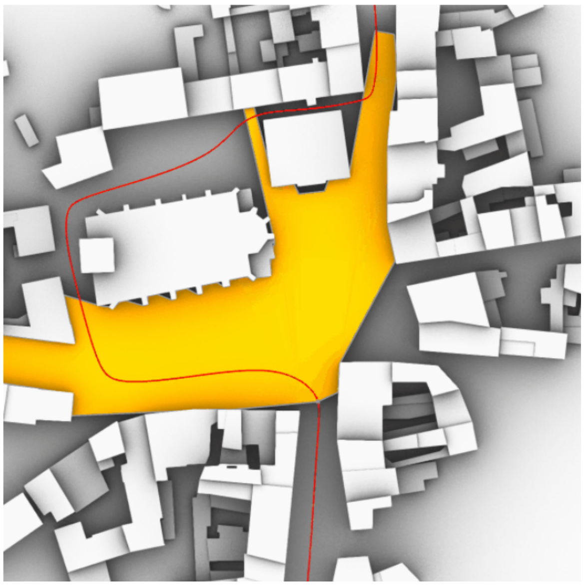


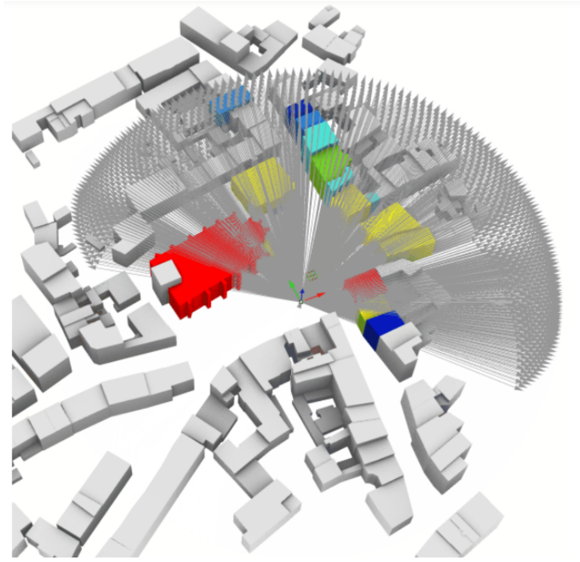
Figure 8: Example of a 3D isovist calculation on a DEM. Left: Milan Trade Fair masterplan DEM. Right: 3D representation of the isovist from a vantage point on the ground. (Image source: Morello and Ratti, 2009)

The DeCodingSpaces Toolbox for Grasshopper plugin for Rhinoceros is a free software released by the Computational Planning Group (CPlan) with the goal to increase quality and efficiency of architecture and urban planning. The toolbox offers visibility analysis tools including 2D and 3D isovist analysis, with the 2D isovist tool being based on the work of Benedikt (1979), and the 3D tool being an extension of this developed by the DeCodingSpaces team. The team offers a tutorial of the tool via their website.

DepthmapX is a spatial analysis software for spatial networks. DepthmapX is released as open source and was originally developed by Alasdair Turner as Depthmap (depthmapX development team, 2017). It can be used to produce point isovists and isovist paths.



(a) 2D isovist. Red line is the path.

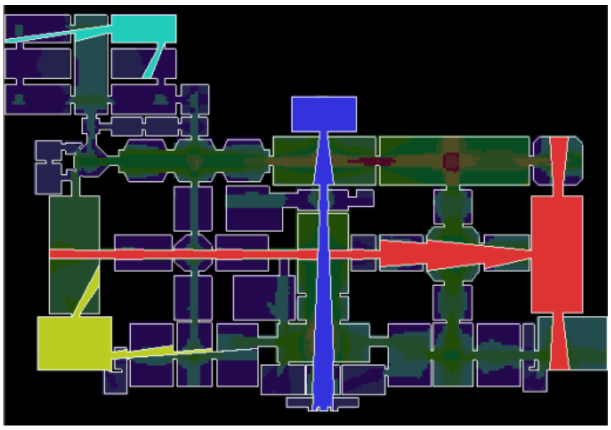


(b) 3D isovist

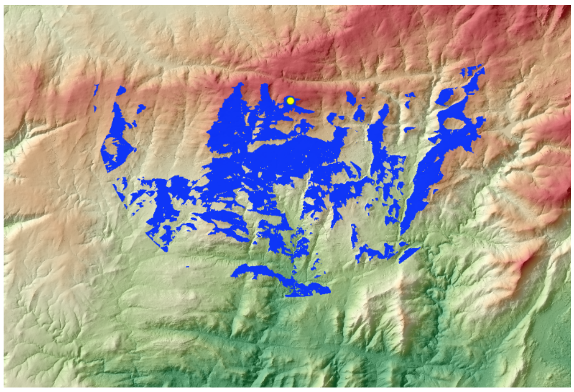
Figure 9: Isovist analysis examples from the DeCodingSpaces Toolbox for Grasshopper (Image source: Bielik, 2019)

Isovist_ App is a free multi-platform software tool for spatial analysis. It can operate on any scale, such as single rooms or urban street patterns. It can conduct point or path isovists, and additionally region isovist and isovist agent analysis. Output of the software can be coloured PDFs or numeric point data. The key isovist field measures correlate with equivalent methods that can be produced by DepthMapX methods, but with higher resolution and in less time. The Isovist _ App can import drawings in .dxf, .dwg and .svg formats. Drawings need to be prepared into a specific format.

Specific existing scripts to do isovist computations, e.g. script for R, could be used. This script only does 2D isovists, is quite limited, and it may not be the best option to try to extend this to 3D.
QGIS, and open source GIS software, has a plugin available to perform visibility analysis, including viewshed analysis. It requires a DEM of the area and is meant for terrains, see figure 10b.



(a) Depthmap isovist example (Image source: Pinelo and Turner, 2010)



(b) Viewshed analysis in QGIS. In blue is the visibility of a turbine in 10km area. (Image retrieved from GIS-course.com)

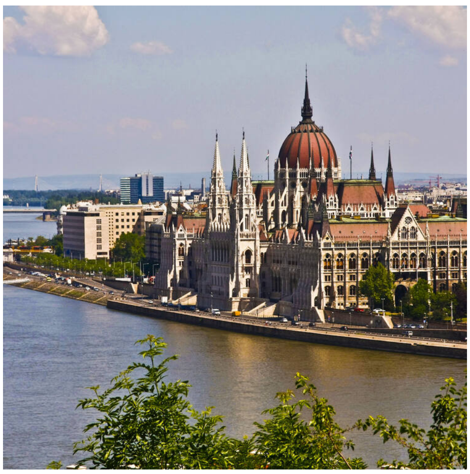
Figure 10: Depthmap isovist and viewshed analysis in QGIS

The isovists analysis requires defining the viewpoints from which it is performed. To delineate the river space, viewpoints should be defined from the river, for example the central river point. However, a problem that could come up by doing this comes from the fact that a river usually lays lower than the surrounding area, which would mean that the edge of the river blocks view from this

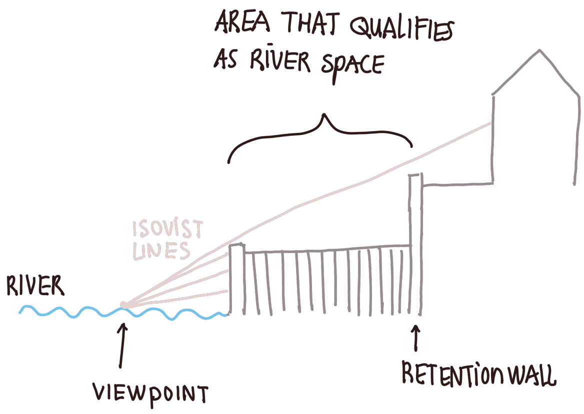
Method & Software	**Open source**	**Data requirements**	**Comments**
3D isovist calculation method proposed by Morello and Ratti (2009) using MatLab	Free license for MatLab via TU Delft	DEM	Flexible to adapt.
DeCodingSpaces Toolbox for Grasshopper in Rhinoceros 7	DeCodingSpaces is open source. Use of Rhinoceros 7 using a free license via TU Delft	The toolbox needs specific input. Grasshopper can import OSM files	2D and 3D isovists measures available
DepthmapX	Open source	Spatial network	Network based. Options for point isovists and isovist paths.
Isovist _ App	Open source	Drawings in .dxf, .dwg or .svg	Build more for architectural drawings.
Specific scripts for isovist calculation like this script for R	Open source	Depends on script	Only 2D isovists. Flexible to adapt.
QGIS plugin	Open source	DEM	Viewshed analysis developed for terrains

Table 1: Isovist algorithms. Blue: code or pure methods, Red: specific software for isovist analysis, Yellow: GIS software.

viewpoint, see figure 11. A solution to this would be to raise the viewpoint to the height of the edge,



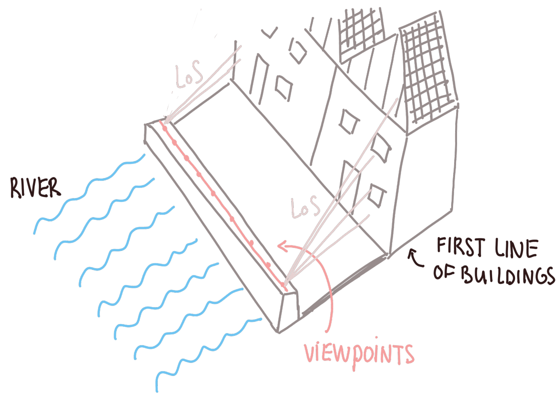
(a) Danube, budapest. The river lays lower than the land next to it.



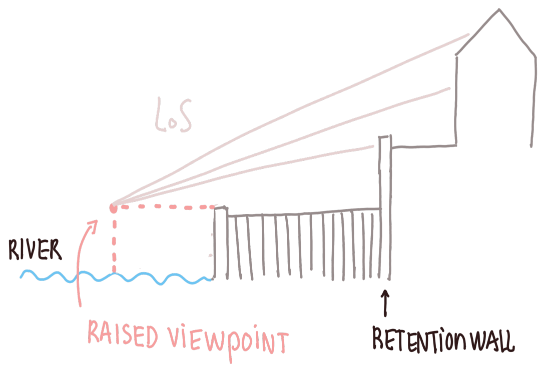
(b) The edge of the river would unintentionally block the isovist line.

Figure 11: Problem caused by the river laying lower than land.

or to move the viewpoint to the edge and perform the isovist analysis from both sides of the river outwards, see figure 12.



(a) Defining the viewpoint on the edge of the river embankment



(b) Raising the viewpoint in the center of the river

Figure 12: Potential solution to the problem caused by the river laying lower than land

4.4 Delineation output

The method will give the delineated river space as output. This delineation output needs to be extracted from the isovist analysis output. This output can have different formats, such as a 3D volume model, a 2.5D line string, or a 2D boundary. The format would depend on use cases.

4.5 Up-scaling

A potential problem regarding the up scaling or automation of the method is that every city develops a specific, potentially unique, relationship with its river which could make developing a method for an arbitrary city and river challenging.
An issue addressed before is the data availability around the world and the impact on the used algorithm and quality of the delineation. Preferably this research outputs a delineation method that adapts to available data sources for scalability reasons. Different countries have different geographical data available, with different levels of detail. For example, the Netherlands has point cloud data of the whole country, while other countries do not have this. The method would use whats available to produce comparable results between regions.

5 Time planning

The following Gantt chart shows the activities need to be done and the deadlines to be met to meet the objectives of this thesis.

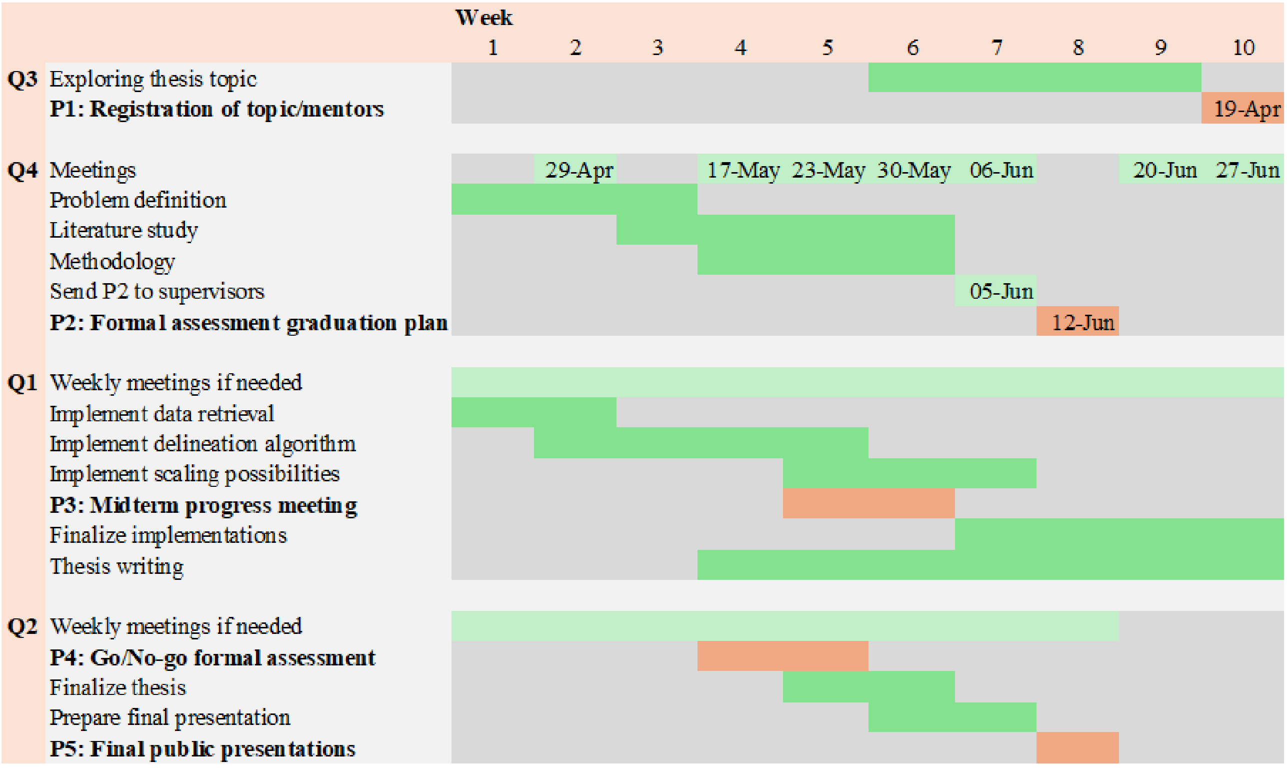


Figure 13: Gantt chart

6 Tools and datasets used

6.1 Data

This thesis aims to mainly use open data sources to make the work done as accessible as possible, which raises the question of data availability. The Netherlands has certain datasets openly available that other countries may not have.

Datasets that can potentially be used in the Netherlands, but also beyond are

- **3DBAG**: The detailed 3D Building models Automatically Generated for very large areas (3DBAG) is an up-to-date open data set containing detailed 3D building models of the Netherlands. It is automatically generated from building data from the BAG and height data from AHN. It offers multiple levels of detail (LoD2.2, LoD 1.3, LoD 1.2).
- **3D Basisvoorziening**: The 3D basisvoorziening dataset is a watertight 3D model of the whole Netherlands, also including terrain objects. In contrast to 3DBAG, this dataset also uses a yearly updated pointcloud created from stereo images.
- **Pointcloud data**: Actueel Hoogtebestand Nederland (AHN) is the actual height model of the Netherlands. It is available as .laz file. Besides the point cloud itself, they also provide a DTM and DSM model.
- **Digital Elevation models**: Potential sources could be Google earth engine, or OpenStreetMap (OSM) which provides detailed vector data including building footprints, roads, and water features. OSM data can be downloaded from their website as an .osm file.

6.2 Tools

Section 4.3 describes an overview of existing isovists analysis software. The algorithm used will be decided on later. Important factors in this choice are availability of the software (is it open source?) and capabilities. To extract the dataset from the source, to prepare the data for the algorithm, and the prepare the correct output, python will be used.

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