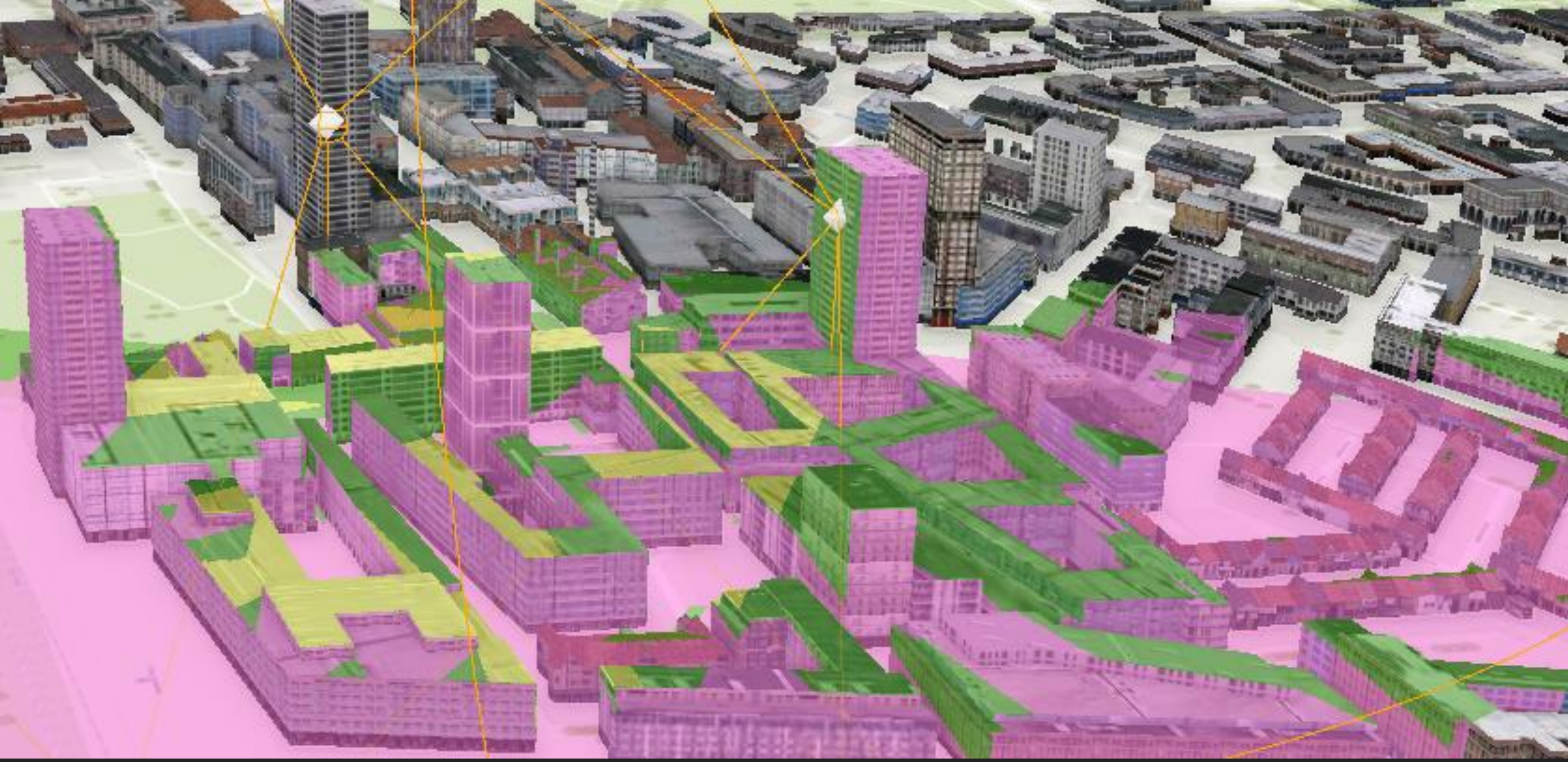
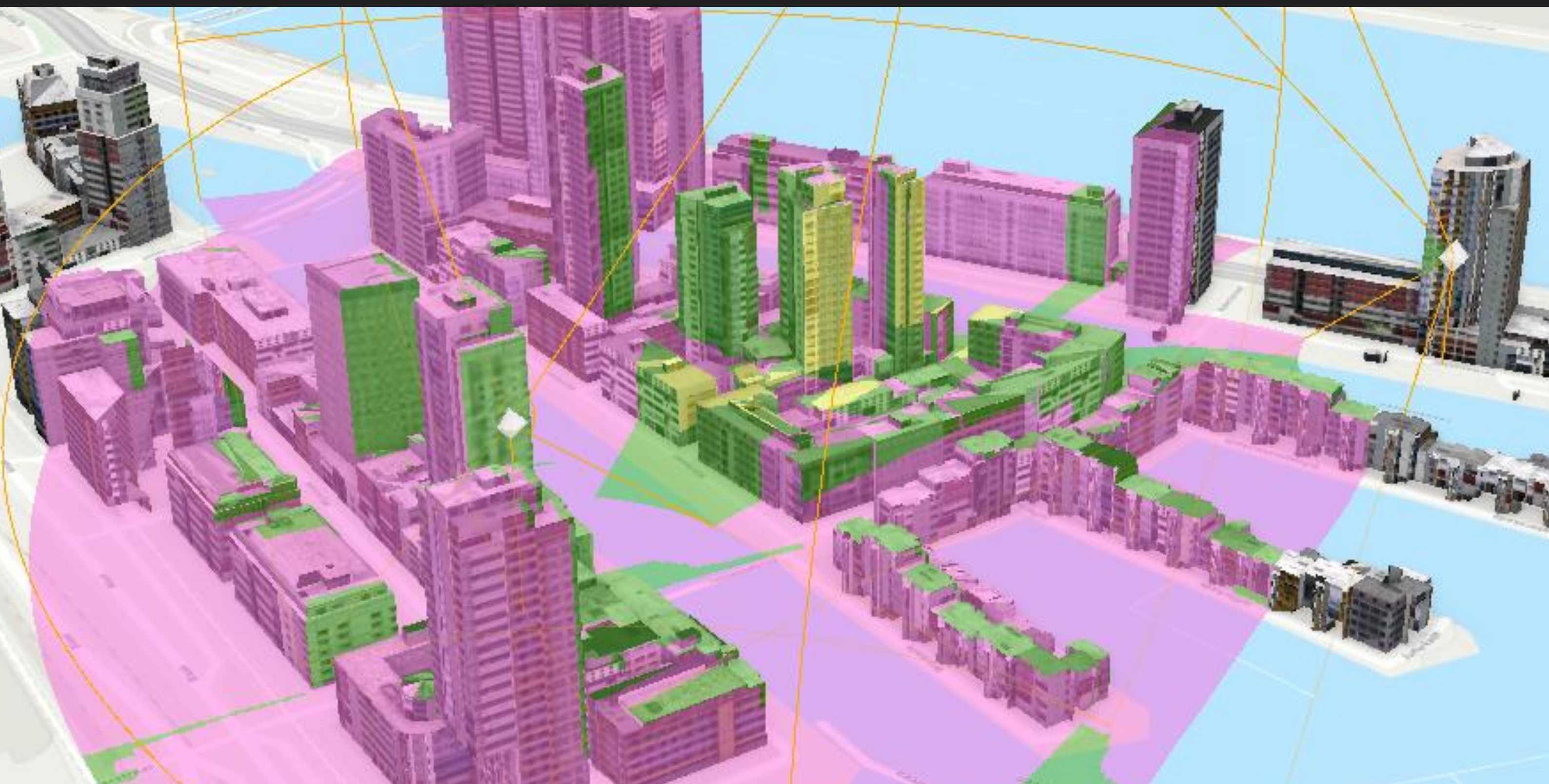


Master Thesis Report - MSc Geoinformatics

A comparative visibility assessment of high-rise building redevelopment for Carlsberg and Wijnhaven

Giota Zachariadou

Spring 2020



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Giota Zachariadou

Supervisor: Carsten Keßler

Thesis Report

MSc Geoinformatics

Aalborg University

The work in this thesis was carried out in:

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Abstract

Visibility analysis along with Geographical Information Systems has been constantly explored and facilitate the process of studying city structure and urban development, especially in high-rise city models, to prevent obstructions of the urban elements, as well as to create a pleasant and well-function environment for residents. Being able to apply such research and use the relevant tools, led in the implementation of a visibility assessment in two different case studies. Hence, this study focuses on the visual sense of the socio-spatial context of urban planning in two neighborhoods, Carlsberg in Copenhagen and Wijnhaven in Rotterdam.

Moreover, the research examines and applies different geoinformation techniques that can interpret the visual socio-spatial relationship based on the existing literature and available tools. The analysis of the study is performed with the use of five Key Performance Indicators (KPIs), density, scale, openness, high-rise buildings intensity and views to nature landscape from residential buildings. Additionally, the results were formed into a classification system to better comprehend the KPIs measurements as well as to address the comparison between the two case studies.

Finally, the project concludes with the discussion, conclusion and future development. The discussion presents the outcome of the study based on the research objectives, emphasizing on the obstacles and data limitations faced during the process. The conclusion summarises the work this thesis has implement, while future development the possible next steps of such research. Moreover, it introduces the additional processes that can carry out, in the direction of the evaluation of the results, along with accuracy improvement, and the scale of the analysis so to further strengthen the process as a part of the urban planning development.

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Urban Planning Terms

Building block	A shaped area (usually rectangular) in a city, surrounded by streets and regularly containing several buildings
Built form	The height, volume and overall shape of buildings in an area
Enclosure	When the building frontage height, street width and street tree canopy create a feeling of a contained space within the street
Land use	Defines the current or feature activity or purpose of the land
Level of Detail 2 (LOD2)	Level of design of a building, in 3D procedural modelling defining that the building has differentiated roof structures and thematically differentiated boundary surfaces
Main street	Street area containing retail and small business, capable to hold many local trips, and accommodate higher volumes of pedestrians.
Mixed-use area	An area with a combination of different land uses such as residential, commercial, retail or institutional
Public space	An area open to public access, providing public use or recreation function and usually owned and maintained by government or private agencies. Additionally, other privately held lands available for public access and use, are the building forecourt or a shopping centers
Urban fabric	The physical material of a building structure or city

Source: Biljecki, 2013 & Davidson and Dolnick, 2004

1. Introduction

High-rise buildings are constantly occupying a greater part of cityscapes, affecting not only the urban planning development but also the perception of space. Topography, surrounded uses, as well as the microclimate, can easily change from such development and influence the character of the city. Creation and existence of high-rise buildings in European cities are usually causing debates and disputes. It is usually stated that high-rise buildings are damaging the social functionality of the neighborhood. While in contrast, is sustained that the social interaction of well-connected public spaces, design in details and elements of high-rise buildings will increase prosper living environments (Hawez et al., 2016). Very often, indecisions in the planning development of high-rise buildings are based on insufficient knowledge of the spatial consequences of the urban landscape and therefore, its spatial consequences on geometric analysis is critical (Czyńska, 2014).

In this context, Virtual 3D city models and digital analytical techniques may radically facilitate the analysis of a city structure. It is of great importance to gain reflection on the impact of buildings height in the urban core and explore the visual effects of the volumetric coverage of high-rise buildings on the city's skyline and cohesion/consistency. Additionally, promoting scientific research on landscape and city planning is one of the rapid developments of geoinformatics practices. The use of these techniques results in faster analysis and greater accuracy of virtual city models. While GIS technologies have immensely been used for urban planning analysis and visualization, 3D geographic information systems and visibility analysis techniques offer great potentials for obtaining a deeper understanding of the city structure and efficiently analyse its elements.

The implementation of visibility analysis consists of several analytical methods. Such as visual impact range, view range and view angle analyses. All of these techniques have been successfully used in planning development, in order to apply guidelines for the construction of new high-rise buildings, measure the intensity and protect the old cityscape. However, there are few considerations when visibility analysis applies. It is essential to select suitable models for such analysis, concerning the accuracy, model recording and the nature of the landscape. Another important aspect considered in studying visibility analysis is the city scale. City scale can be examined in a global scale, by determining the effect of the building form in the entire city skyline, and in local scale with the partial external exposition within skylines and the internal views of public space (Czyńska, 2014).

In the exploration of urban planning development, visibility characteristics are mostly related to the socio-spatial context, emphasizing the involvement of the human factor in the planning process. In that context, a lot of researches attempt to study the different geometrical and visual characteristics connected to the human perception of space. Additionally, they indicate that visibility is linked to accessibility and that the relationship of the social-cultural aspect is related to the building form, using methods such as visual enclosure, exposure and openness (Fisher-Gewirtzman et al., 2011). Methods that have been practiced in the context of evaluating urban landscape. Another study parameter of visibility analysis is the apartments' views, which can influence the economic attractiveness of the urban core. It has been stated that the view to the surroundings and especially to natural environment areas has a great impact on the real estate values. To estimate such influence, it has been frequently used 'Spatial Openness Index' (SOI) a 3D visibility analysis model that can define the visible volume of the surrounding sphere (Fisher-Gewirtzman, 2012).

Thus, this thesis studies how a high-rise building development is affecting the visual sense of the socio-spatial context of urban planning at a neighborhood level by applying different visibility analysis techniques. More specifically, it focuses on two different city models, Copenhagen and Rotterdam, two neighborhoods with similar high-rise urban planning development, Carlsberg and Wijnhaven, respectively. By exploring the influence of visibility analysis, it attempts to compare the results of two different landscape neighborhoods, a water area like Wijnhaven contrarywise, Carlsberg a newly built and mostly green area. Additionally, to identify potential meaningful impacts in the planning development of the two neighborhoods in combination with the perceptual quality of space.

1.1. Structure of the report

This thesis attempts to study visibility analysis and high-rise buildings impact in urban planning development, through different GIS tools. Hence, this document has structured into five main chapters as shown in **Figure 1** below. The current chapter introduces the project, the problem statement and research questions. The second chapter presents the theoretical background of the research through a literature review of high-rise buildings impact and visibility analysis tools and practices in urban planning. Chapter 3 demonstrates the followed methodology, describing the concept of the study and the analysis and Chapter 4 the results and the comparison of the two case studies. In Chapter 5 the discussion of this study based on the research objectives are explained, and finally, in Chapter 6. draws the conclusion and the possible future development of this research.

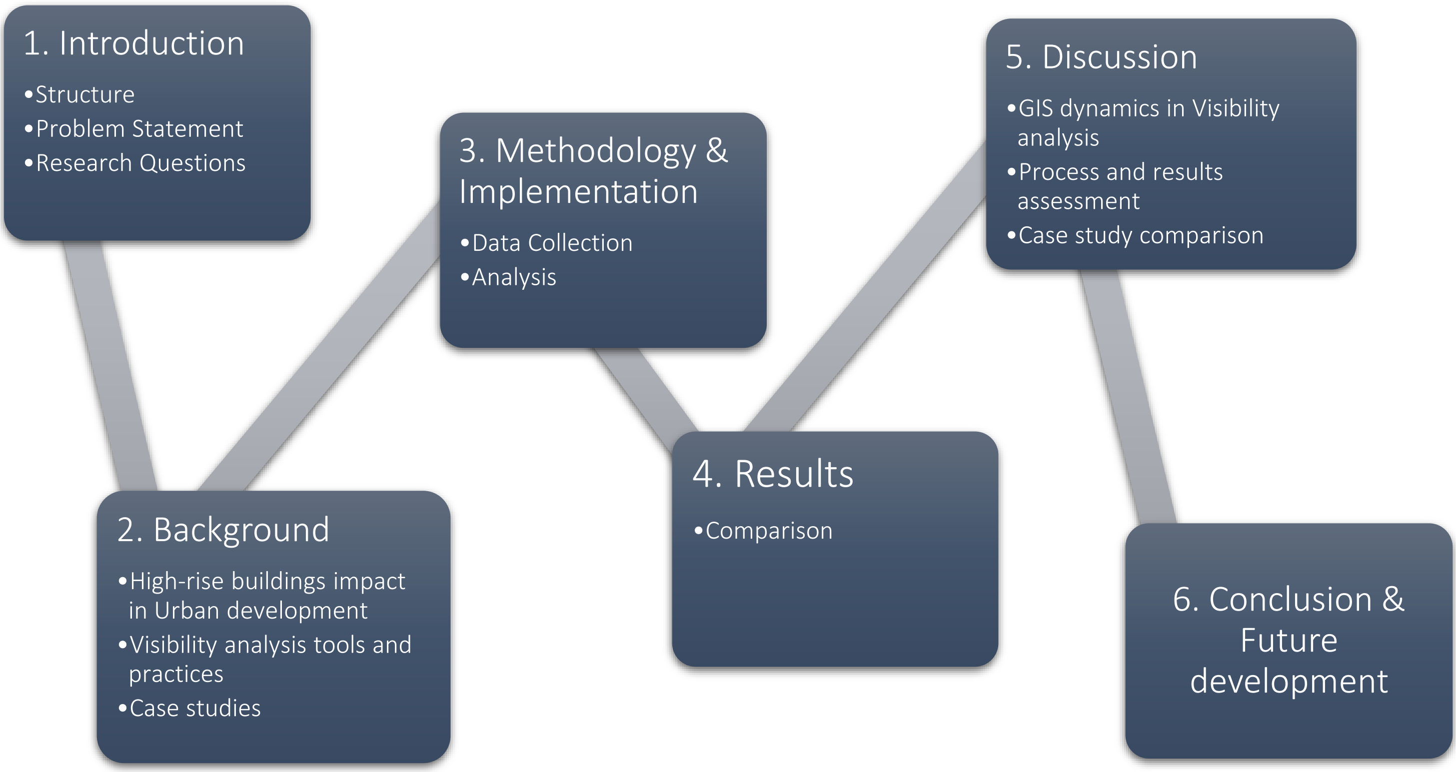


Figure 1:Thesis Structure

1.2. Problem Statement

Visibility analysis has been applied in various researches and practices in the last 30 years. In urban planning and landscape design, visual dimension is highly important since it can cause obstruction of the urban elements and consequently change the character of the city (Danese et al., 2009). Acknowledging that good analysis and monitoring of urban development is crucial for the management of the city structure, planners and researchers are gradually trying to include visibility analysis tools by extending the guidelines in the planning process (Saeidi et al., 2018).

The development of high-rise buildings, especially in European cities, threatens not only the urban core and the historic building stock but also its functionality. Particularly in these design cases, planners and decision-makers need to make more informed decisions at an early design stage and place greater emphasis on the relationship between human and physical environment. Over the past years, the development of geoinformatics and technologies has enhanced the ability to calculate views and therefore mitigate the negative impacts of new buildings. There have been presented numerous examples where visibility analysis methods and tools have applied in the field of urban planning. A great number of researches occurred by acknowledging high-density city growth issues and the need for quantitative integration of human visual perception with the visible landscape features (Koltsova et al. 2013).

3D visibility analysis has displayed a decisive role in urban studies and 3D city models, as the evaluation of the visible area in a 3D urban environment has provided more reliable results. However, the implementation of such an analysis in the planning sector has its drawbacks and limitations, as the collected spatial data related to landscape elements and features often obtain low resolution (Saeidi et al., 2018). Recognizing the effort of implementing visibility analysis and evaluate its use in the urban development, this thesis will attempt to apply a visibility assessment in two different city models with the use of GIS and the available methods.

1.3. Research Questions

The main research questions that this study will focus on, are the following:

1. How visibility analysis can be used as an assessment tool in urban planning and a high-rise building redevelopment?
2. Which visibility tools can interpret the visual assessment of the socio-physical factor in urban planning?
3. How different are the effects of high-rise building development between the two case studies?

The research focuses on the theoretical background and applies a visibility assessment using 5 Key Performance Indicators (KPIs) to better comprehend the results of the two case studies and therefore to compare them.

2. Background

2.1. Impact of high-rising buildings in Cityscape and Urban planning development

High-rise building architecture started in the United States at the end of the nineteenth century. Their development in Europe was relatively different in terms of design and scale size, with a smaller architectural height and quality (Pietrzak, 2014). In general, high-rise buildings represent the modernity attribute and economic growth for a city. For example, the development of a high-rise building cluster can aesthetically and economically upgrade the area. With this great effect on the city landscape and planning, they can reveal an urban typology or the sense of alienation (Czyńska, 2014).

In that direction, landscape cohesion and integrity may experience immense impacts. Therefore, planners and architects need to investigate all the different consequences high-rise buildings can cause in the cityscape. As Garnero (2015) noted, in a city-scale analysis, it is studied the variation of the skyline, the visibility of the buildings from the streets and the compatibility with the surrounded architecture. Additionally, he specified that is essential to protect old city skylines and historical heritage of European cities by applying deeper analysis for a high-rise building spatial development.

Other studies mentioned further issues, like air pollution, sunshine, wind flow and views and how those, along with the city density affect the social engagement with the building environment (Hawez and Khoshnaw, 2016). Studying unsuccessful and successful practices of existing high-rise models, cities and planners tried to apply regulations and policies in terms of the architectural height, land uses and development zones.

As Virtual 3D city models and geographical information systems facilitate the process of studying the city planning and development of high-rise buildings, this study is focusing on the analysis and the role of visibility. Visibility analysis has been used as a tool of cityscape and urban development assessment. Its analysis can vary in scale, including city, district and neighborhood level. In a city level, it has mostly been applied in the evaluation of the intensity. In other words, the visual impact of a new high-rise building in the urban environment. More specifically, to acknowledge from where someone can see a specific building and how much of it. This evaluation can prevent possible poor design of the urban landscape, protect the city's heritage and landmarks and therefore redesign the city skyline from some representative viewpoints (Garnero, 2015).

In the direction of urban development on a smaller scale, researchers reported the connection between the landscape and the visual experience of the environment. This connection of the spatial-social/psycho realm is commonly referred to as mental geography, meaning the geographical distribution of human mental perception, which focuses on the visual sense and human emotions caused by the built environment. In this context, visibility along with openness, enclosure, scale, density, and daylight perception has been studied. Focusing on visibility analysis and the geometrical characteristics of the spatial-social aspect of urban planning, various studies have explored two types of direction. The perception variables, which are describing the visual impact of the building environment, and the critical characteristics, which are shaping the cognition of the structure of the spatial form (Putra and Yang, 2015). Especially in the direction of 3D visibility analysis, where the views calculation includes spherical geometry, several studies have implemented such an analysis in order to evaluate the public perception of the landscape. In most of these studies, the analysis of those geometrical characteristics conducted with the use of geographical information systems and the results were evaluated through a public survey.

Further issues of high-rise buildings visibility have been noted in the economic value of a property that is affected by the views to the surroundings (Saeidi et al, 2018). Real estate is increasingly perceive that high-rise buildings influencing the prices as numerous studies have documented that both businesses and households are willing to pay more to be located on higher-level floors or in general to floors with access to a good quality of view (Yu et al., 2016). The visual aspect of natural features such as green areas, water elements as well as public spaces in the living environment determines the influence of housing prices (Bishop et al, 2004). In this direction, Bishop et al. (2004), explored the impact of views from high-rise buildings to the soundings, integrated with a public survey and property prices. They estimated the fluctuation of property prices through a statistical regression analysis. Hence, high-rise building redevelopment in an urban living environment considers view, highly important for real estate development as well as for the continuing link between place of residence and environment (Bishop et al, 2004).

2.2. Visibility analysis tools and practices

There are different terms used to describe visibility in relation to the practice of the study. As Putra and Yang (2015) mentioned, visibility in the context of the city landscape is conserved as the 'visible' or 'invisible' status of a point or location from a vantage point. A supplementary definition describes visibility as a quantitative term, questioning "how much of the built-up area people can see".

The idea of visibility analysis occurred from Gibson's psychological theory, implying the idea of human perception in the context of measuring the urban environment. The theory describes the spatial properties of the visible space that can be determined and measured by the collective amount of geometrical Cartesian space (**Figure 2**) occupied by photon rays or optical envelopes of natural surfaces visually perceived by an observation point (Putra and Yang, 2015).

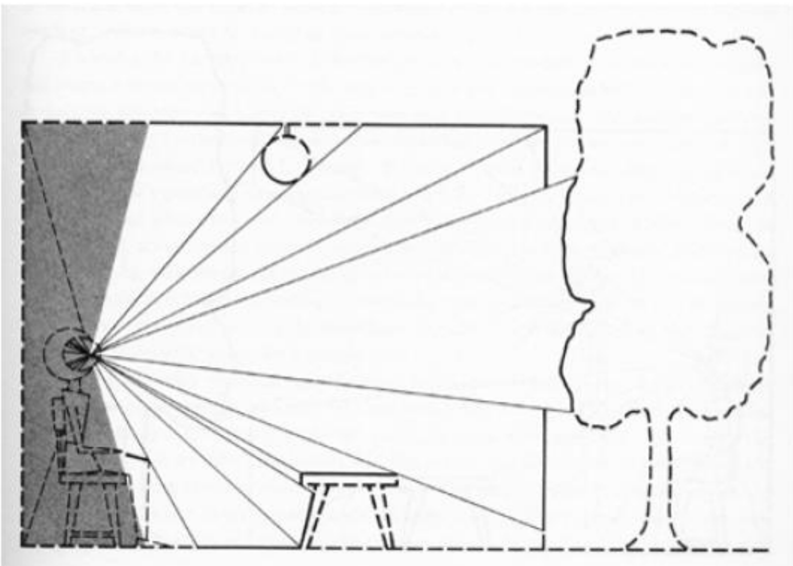


Figure 2: Ambient optic array of the human eye, Source: Putra and Yang, 2015

2.2.1. 2D visibility analysis

Since 1970s visibility analysis has been tried to be applied in the urban environment and landscape. Following the analysis in a 2D environment, Isovist analysis has been mainly implemented in architecture and urban planning and viewshed analysis in terrain and landscape. Isovist is defined as a set of points visible from an observation point in space, while viewshed analysis (Figure 3) has been defined as terrain visible from a major viewpoint (Yung et al., 2011). Both analyses have frequently used through ArcGIS software, so to visualize spatial and statistical properties in maps. In the implementation of those tools, the analysis is determining visibility sight of lines from a certain viewpoint in a raster surface (Czyńska, 2014).

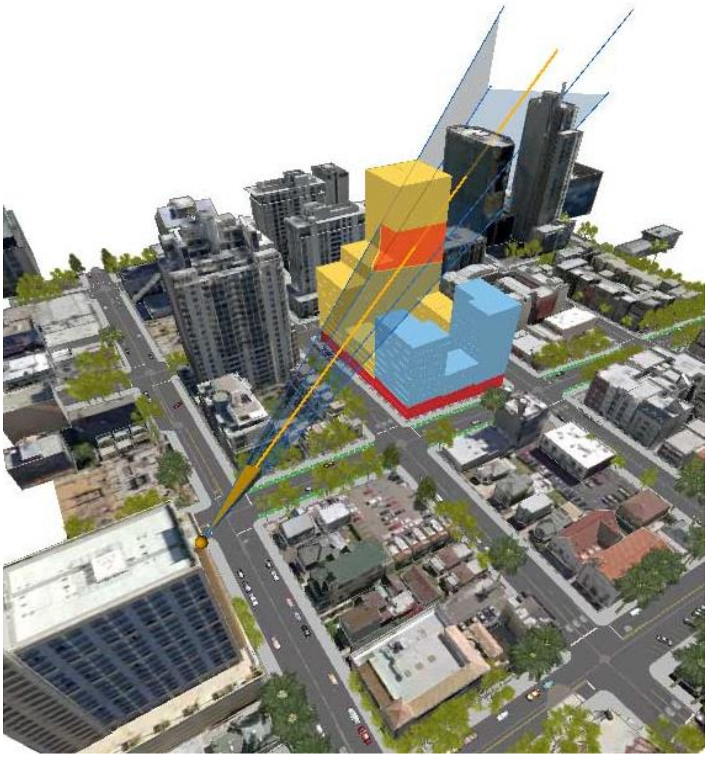


Figure 3: Viewshed analysis in Cityengine, Source: ESRI, 2020

Additionally, numerous researchers used viewshed analysis in urban planning for decision making and design purposes. In this context, the necessity of applying such analysis for numerous points of view instead of one led to the development of a multiple viewshed approach. This process produces a binary grid where 0 indicates targets that are not visible, while 1 shows which target is visible from the union of single viewshed raster. An alternative approach used in the evaluation of the visual impact of newly built areas, so-called cumulative viewshed analysis, identifies the visible targets by a certain cell (Danese et al., 2009). Another example mentioned by Hoeven and Nijhuis (2011) implements GIS viewshed and cumulative viewshed analysis to measure the visual coverage and intensity of high-rise buildings in the city landscape of Rotterdam in order to understand the visibility impact in the cityscape and identify building zones. High-rise building intensity determines the visibility value of high-rise buildings in the area. In other words, the location and quantity of high-rise buildings in the area.

2.2.2. 3D visibility analysis

Although the viewshed analysis has been practiced in numerous spatial analyses, the need for focusing on direct spatial experience through physical senses led to 3D analysis and the introduction of spherical-based analysis. This method has been developed as a GIS visibility tool, including the function of the automatic delineation of visible sky and obstacles (Yung et al., 2015). Concerning both 2D and 3D analysis related to the theory of Gibson's perception, it has been claimed that 3D's graph spatial representation is closer to the theory than 2D. This derived since viewsphere analysis can facilitate 3D spatial properties of the envelope which is closer to a 3D spherical field than a 2D flat surface (Putra and Yang, 2015).

Viewsphere analysis calculates the sight of visible `volume' that is filled with the ambient optic array from a specific observation point to the surrounding environmental obstruction points (**Figure 4**). The tool has been extensively practiced in landscape and urban development as well as for terrain landscape modelling in raster data (Putra and Yung, 2015). Facilitating 3D visibility tools in the city environment, most studies attempted to evaluate the human factor in the analysis. In the exploration of that direction, Spatial Openness Index (SOI) was introduced by Fisher-Gewirtzman in 2003. Compared with Viewsphere analysis, SOI is functioning as a 3D Isovist, highlighting the computation of the volumetric space and functions (Yung et al., 2015). A lot of studies have applied SOI in small spatial scale aiming to identify the visual enclosure, exposure and openness of the urban fabric.

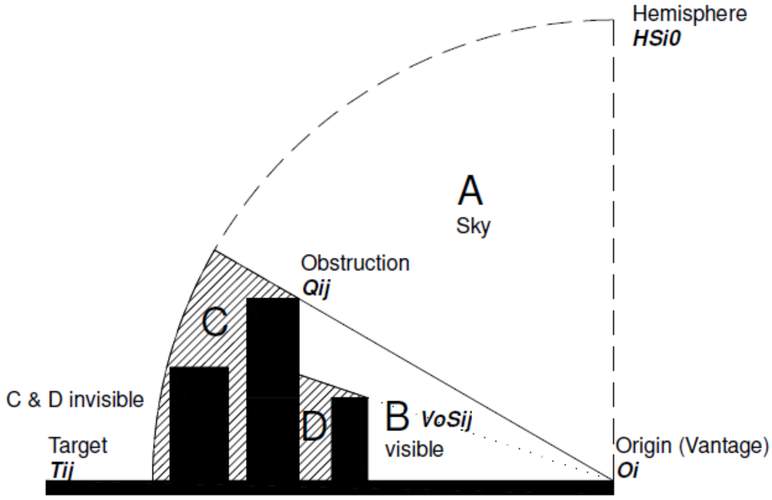


Figure 4: Viewsphere analysis: Ambient optic array of visible and invisible parts, Source: Putra et al. 2020)

Visual exposure illustrates the visual penetration of private built environment from outdoor spaces, for example, public areas. In contrast, visual openness defines the measured landscape that is visible from public areas or the building environment (Fisher-Gewirtzman, 2012). In the direction of the enclosure, the most common spatial perceptions are density and scale. In the exploration of understanding mental geography in the urban environment, several quantitative spatial indicators are defined, named as Euclidean indicators. Those indicators were either fixed distance-based either proportional. Well studied as Euclidean fixed distance-based indicators are visibility and scale (Purta and Yang, 2020). Scale measures the ratio of local/ aerial distance from the building area, more specifically, how enclosure the area is from a human's perspective. Density, on the other hand, is an indicator that measures the building footprint coverage divided by land area, defining how built an area is. The percentage of building density in an area can determine the cityscape as well as the land prices. Additionally, in the connection with the visibility and mental geography density is translated as the visual apparatus of the perceived built environment from a user's specific point, defined as perceived density. (Peiser R., 2015).

In the context of high-rise buildings and their influence on the urban landscape, the importance of using visual openness and enclosure has been widely noted. As mentioned in section 2.1, the exploration of mental perception in the urban environment is strongly linked to visibility analysis. For this reason, the resident's satisfaction in views can recognize strengths or weaknesses in different aspects of urban planning. There are various studies visual openness analysis has been applied. Openness measures how much the built environment obstructs the visibility to the natural landscape. It is also strongly linked to the resident's satisfaction with apartments' views. Especially in case areas with a dense high-rise building development, it is highlighted that residents appreciate openness in public spaces as well as in apartments' views (Shach-Pinsly et al. 2011). Additionally, other researches performed visual openness for safety reasons, such as property crime and surveillance in public spaces (Pinsly and Fisher-Gewirtzman, 2011).

2.3. Research's case studies

In the direction of studying visibility analysis impact in a high-rise building development area, it was decided to study two areas on a local scale (neighborhood level). Therefore, a research on European cities with high-rise building areas and similar urban planning development has been conducted. Among the investigated cases and based on the criteria of the present research, the mix-use urban planning development model was selected to be studied. The chosen case studies were Carlsberg in Copenhagen and Wijnhaven in Rotterdam. The common element of those studies is that both were office/industrial areas that are redeveloped into a high-rise mixed-use residential model. Even though both neighborhoods are located close to the city center and present similar redevelopment, they are very different in terms of landscape and city structure.

Carlsberg district, in Copenhagen, is built on a small heel, containing 9 high-rise buildings mostly spread in the newly redeveloped area that is still under construction. In the west and north border is located the remained area and on the south part near the train station, exists the main park of the neighbohood. The district is part of Copenhagen, a city crossed by a port in the south part with mostly low-rise buildings and a lot of green areas. Wijnhaven (Rotterdam), on the other hand, is built in the port area of the city, containing a lot of water in its main part and mainly connected with bridges. It contains 14 high-rise buildings of which 5, are forming a cluster in the center of the area, while the rest of them are located in the north, east and south borderlines of the area. Rotterdam is a high-rise city mode,l also crossed by a port and being covered by a lot of water and green areas. As the aim of this thesis is to study visibility analysis in the socio-spatial context of urban planning development, those areas were selected, in order to explore how different or similar visibility results can be shown in two similar in terms of urban development but a lot different in landscape, high-rise building neighborhoods.

2.4. Software and Technologies

In this chapter will be presented the software used to accomplish the research. The main analysis was performed through two of ESRI products, ArcGIS Pro and CityEngine. Another software used for a smaller part of the analysis was FME. Bellow, it is presented, the use and capabilities of those software. It should be mentioned that all licenses and software were provided by Ramboll A/S.

2.4.1. ArcGIS Pro

ArcGIS Pro is a geographic information professional desktop application system developed by ESRI. In ArcGIS Pro environment the user is able to explore, visualize, and analyse data in maps. Additionally, it can compute and manage data both in 2D and 3D environments, use different toolboxes and analyse models depending on the available bought licenses (ESRI, 2020). As a tool, it has been extensively used from different fields, for example, civil engineer, architecture, planning and so on. In this research, ArcGIS Pro was the main software used in the analysis. The main applied toolboxes were Spatial analyst and 3D analyst.

2.4.2. CityEngine

CityEngine (CE) is an advanced three-dimensional modelling software, developed as well by Esri R&D Center in Zurich (ESRI, 2019). The software uses Computer Generated Architecture (CGA) shape grammar, a programming language developed for procedural modelling to generate 3D content. The 3D content is generated through rule files that are applied in the ground surface of the model. The produced city model can also be exported and imported to a variety of software applications for further analysis, simulation and visualization of the scene (Ribeiro et al., 2014). Having the ability to create 3D interactive urban environments in less time than traditional modelling techniques, has enhanced its use in urban planning and city management. For this research CityEngine was used for the calculation of the apartments' Views, by applying the Viewshed tool.

2.4.3. FME

Feature Manipulation Engine (FME) is a data integration platform, especially used for spatial data. It is a software that assists in data integration and transformation, as well as in building workflows without coding. It supports more than 450 data formats and few programming languages such as Python and R. It is a useful tool frequently used for commercial, emergency services, architecture and many more industries (FME,2020). In this study, FME was used for small data transformation processes. Either for data format transformation either for spatial transformation of the data.

3. Methodology & Implementation

This chapter describes the methodology used to fulfil the assessment of visibility analysis. As **Figure 5** obtains, the methodology of the project, deployed into four main phases starting with data collection and preparation. In the phase of the analysis, the two case studies are presented. In addition, the selection of the Key Performance Indicators (KPIs) is obtained (Density, Scale, Openness, Intensity, Views) along with the GIS tools used to accomplish the process. Next in the process are shown the KPIs results and the comparison of the two case studies.

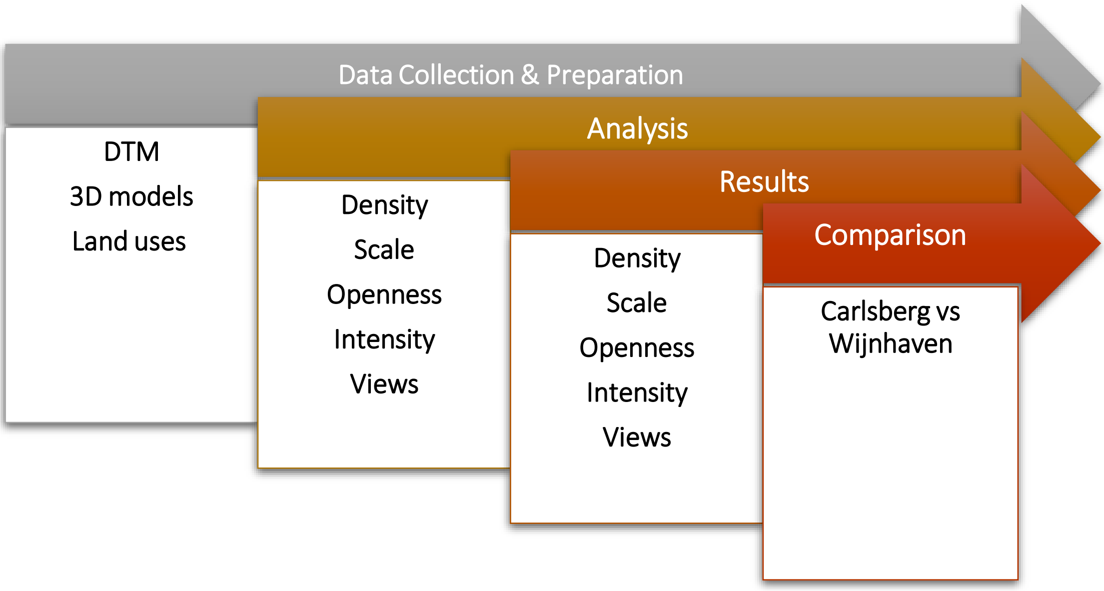


Figure 5: Methodology workflow

3.1. Data Collection & Preparation

3.1.1. Digital Terrain Model (DTM)

One of the datasets required in the analysis was a surface model. Thus, the Digital Terrain Model (DTM) of the two areas was collected. A digital terrain model is a raster surface illustrating the terrain's topography or the elevation above sea level excluding objects such as trees, buildings, cars and so on. It should be noted that for such type of analysis a Digital Surface Model (DSM) should be more suitable, as an elevation model is including objects like trees, and in general infrastructure elements that may have a greater impact on visibility assessment. However, in the case of Carlsberg, DSM was collected between 2014 and 2015 where the area hadn't developed yet and therefore the results wouldn't be accurate. Carlsberg's DTM has an accuracy of 40cm and it was collected the period 2014-2015 and published in 2016, from the Danish Agency for Data Supply and Efficiency, Kortforsyningen. As the below maps demonstrate, Carlsberg's elevation values fluctuating between 2,4 to 31,6 meters while Wijnhaven between -2,8 to 6,8 meters (**Figure 6**). In the case of Rotterdam, the latest DSM and DTM models were acquired in 2014 with 5cm accuracy, by a government organization Actuel Hoogtebestan Nederland. As the area had slightly changed since 2014, DTM model considered more appropriate for the analysis.

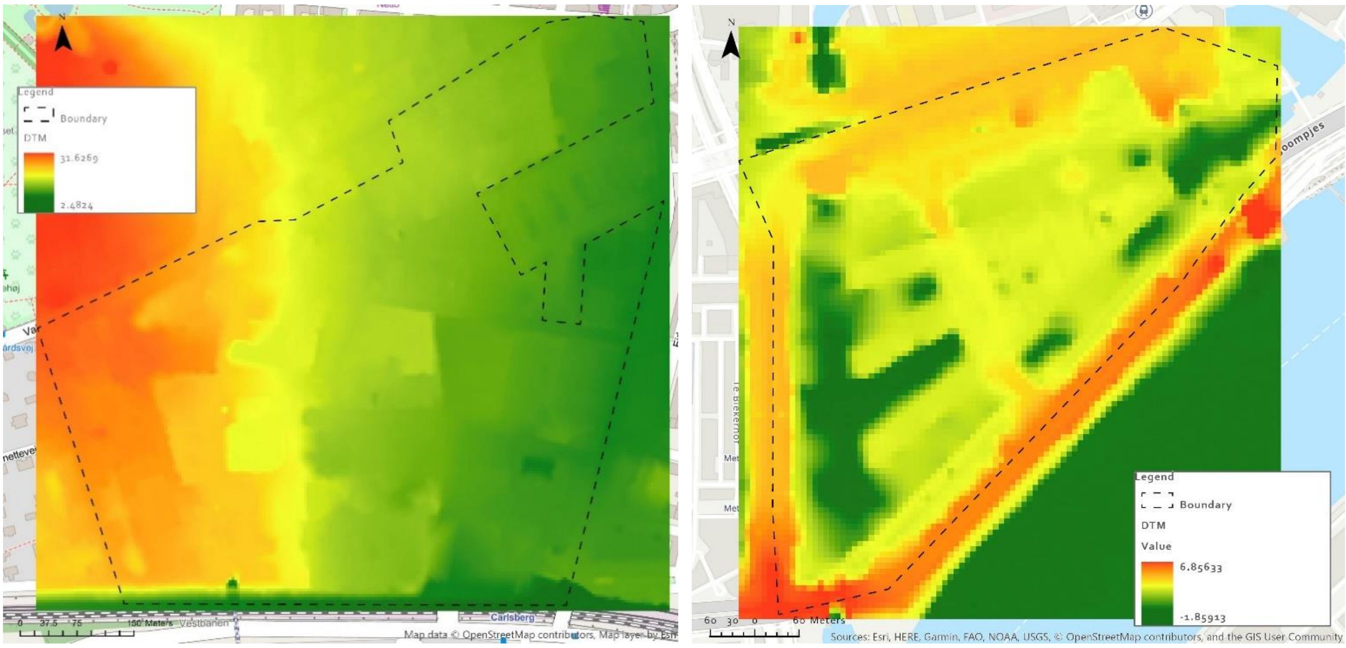


Figure 6: DTM Carlsberg (left), DTM Wijnhaven (right)

3.1.2. 3D models

The 3D models consist only of building information. Carlsberg's 3D model was provided by Ramboll with the production year of 2014. Since the year of the model did not include the redevelopment, the newly developed area was designed based on the local plan. First, the local plan of the area was collected from Erhvervsstyrelsen (Efficiency Agency for Data Supply, 2020). The procedure followed the extraction of the local plan and the transformation into a DWG file. The DWG file was imported into ArcGIS Pro and therefore scaled and cleaned properly. The new buildings and streets of the area created as polygon features. Hence, the attribute of the building heights was assigned to generate the 3D context. Once the shapefile of the area was prepared it was imported in CityEngine where a CGA rule was applied to generate the 3D buildings. The used CGA rule can be found in the Appendix.

Rotterdam case was simpler to process, as the 3D model requested and provided by the municipality of Rotterdam (Rotterdam in 3D, 2020). The model's creation year is 2019 and it was received in a Sketchup format. In order to process the 3D model, the dataset transformed into a multipatch format through FME. Before the analysis of the 3D models, two processes have been conducted. The first was to define the residential buildings of the areas for views KPI analysis and the second was to convert the 3D model into a raster model in order to include the building values in the surface models which will be described in the analysis part of the next chapter 3.2.

3.1.3. Land uses

Land uses dataset was required for the views KPI, so to measuring residential buildings views in nature and building environment. For this reason, Land uses of Urban Atlas developed by Copernicus Land Monitoring Service were selected as the most suitable dataset for the project's purposes. The version year of the data is 2012 as version 2018 of Rotterdam and Copenhagen cities has not published yet.

The land use datasets include 21 land uses. Since the purpose of the model was to measure building and nature environment, it was decided to simplify the datasets by merging the categories of uses in the first level of categorization based on the Urban Atlas Mapping Guide (European Commission, 2012). Hence, the new categorization had a result of 12 uses (Figure 7).

Figure 7: Urban Atlas first level categorisation

It should also be noted that in the case study of Carlsberg urban atlas uses was redesigned based on the new redevelopment of the local plan.

Figure 8 and Figure 9 below illustrate the land coverage of the two cities as well as of the two case studies. It can easily be observed that in both areas, are mainly appear uses of Urban fabric, Road, rail network and associated land. The main difference is that Carlsberg indicates areas with Artificial non-agricultural vegetated areas while Rotterdam indicates Water areas.

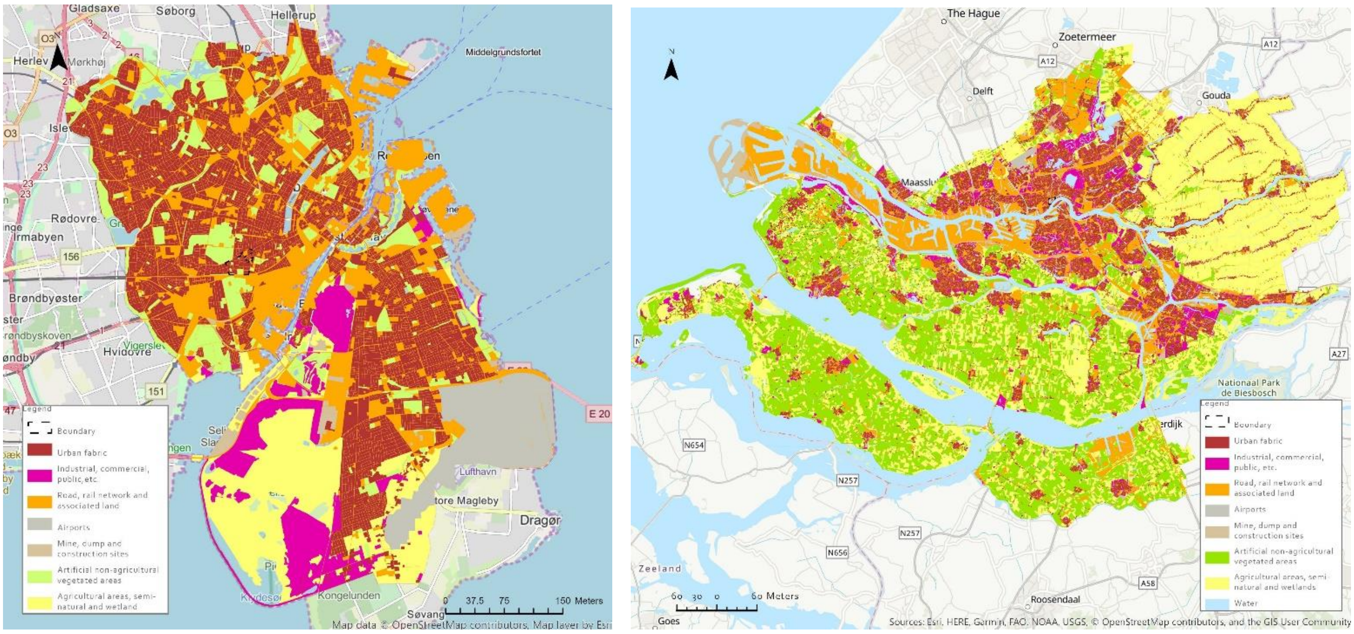


Figure 8: Urban Atlas Copenhagen (left), Urban Atlas Rotterdam (right)

Figure 9: Urban Atlas Carlsberg (left), Urban Atlas Wijnhaven (right)

3.2. Analysis

A well-planned neighborhood as stated in the previous chapter is characterized by good geographic and human relations. This thesis aims to study visibility analysis in the socio-physical context of urban planning development. Even though the two case studies are part of different city models in terms of urban development and landscape, they were chosen for two main reasons. Both neighborhoods are located close to the city center and are forming an urban redevelopment oriented to a residential and mix-use model including high-rise buildings. Additionally, it was desired to explore how visibility analysis tools can be involved in such development and compare the results between the two cities. In this chapter, the visibility analysis of two case studies is presented, along with the concept of the comparative analysis.

3.2.1. Case studies

As aforementioned, the selected case studies have a common relatively similar local plan, the transformation of a former office or industrial area to a residential, mix-use area. At this point, the definition of urban planning should be mentioned. Urban planning can be described as professional work of guiding urban development through plans and regulation to a dynamic social, economic, sustainable, and constructive environment with a better, healthier, and a more just place to live, work and get around (Zhang, 2015). Additionally, the local plan is one of the assisting tools, to apply urban planning guidelines in an area.

3.2.1.1. Carlsberg (Copenhagen)

Carlsberg case area is located close to the city center of Copenhagen and borders with Valby and Vesterbro districts. The area covers 40 hectares, is still under construction and is expected to be finished in 2024. Regarding the urban development, the area's master plan guidelines by Danish architects 'Entasis', followed a brownfield redevelopment, transforming the former industrial area into a residential mixed-use model. Furthermore, the district is represented by good accessibility for public transportation including train, metro and buses, as well as for cars and bikes. In **Figure 10**, the overview plan of the newly developed area is shown, while in **Figure 11** is observed the before and after the redevelopment of the area. Main nature characteristics of the area are the two parks, the existed park located near the train station (**Figure 10, number 1**) and the newly created one, in the north-west boundary (**Figure 10, number 2**). In terms of the building structure, the remained low-rise buildings (1-2 floors) located lengthwise the west boundary present an interesting contrast with the new high-rise building redevelopment of the area(**Figure 10, number 3**). In the current study, the 3D city model used for the visibility analysis contains the new construction of the area based on the local plan and the given guidelines of the area (CarlsbergByen, 2020).

Figure 10: Carlsberg's Overview plan - newly redeveloped areas, Source: Kobenhavn kommune, 2016

Figure 11: Carlsberg district before and after redevelopment, Source: Kobenhavn kommune, 2016 (1st), Carlsbergbyen, 2020 (2nd)

3.2.1.2. Wijnhaven or Wijnhaveneiland (Rotterdam)

Wijnhaven case area is covering 35 hectares including the water area. It is situated in the port of Rotterdam and borders with the city center. Historically most of the buildings of the area were lost in 1940 after the bombing of the city. The area started to redevelop after 1996 and is still under development. The master plan was applied by KCAP Architects & Planners and aimed to transform a monofunctional office area to a dynamic transformation model, including a residential mix-used area with high-rise buildings followed by specific rules of freehold boundaries, daylight penetration, sunlight, views, setbacks and wind nuisance (KCAP, 2017). The next **Figure 12** illustrates the before and after the redevelopment of the area. As observed, the location of high-rise buildings along with the great water presence in the area, may indicate interesting visibility results.

Figure 12:Wijnhaven before and after redevelopment, Source: KCAP, 2017)

3.2.2. KPIs Selection & Tools

Considering the theoretical part of this study as well as the available ArcGIS visibility tools, this study is focusing on visibility analysis and the geometrical characteristics of the spatial-social aspect of urban planning. Therefore, 5 visibility analysis aspects or Key Performance indicators KPIs was selected to be explored. By its definition, a KPI is a measurable value, used to evaluate different processes. Hence, it was considered suitable for the measurement and visual comparison of such analysis.

In chapter 2.2., was stated that intensity of high-rise buildings, openness, density and scale are four key factors that influence the socio-spatial context in an urban area. Additionally, the last year, another measurement that is gradually explored and studied, is housing views to surroundings and especially to the natural landscape. Declaring the correlations between those urban attributes and human spatial perceptions, these five indicators (Density, Scale, Openness, Intensity, Views) were chosen to be studied, so as to better comprehend their influence and connection to the urban development of the specific case studies. Thus, the process of the KPIs GIS analysis for the two cases is obtained bellow.

3.2.2.1. Density

Density, as mentioned in chapter 2.2, is a factor that has been used in the exploration of visibility analysis influence in urban planning along with the human perception of space. Building density is an indicator that measures the building footprint coverage divided by land area, in other words, how built an area is.

For this KPI analysis *Point Density* in ArcGIS Pro environment was selected. *Point density* measures the density of point features and produces a raster cell output (ArcGIS Pro, 2020). The process as shown in **Figure 13** was based on a point feature shape file. In this case, the point feature represents the buildings of the area. The procedure was based on the raster image of the area with the building's representation. With the tool *Multipatch to Raster* in ArcGIS Pro, all buildings transformed into a raster file. Next step was to transform the raster into point values to run the *Point density* analysis. The process accomplished with the tool *Raster to Points*.

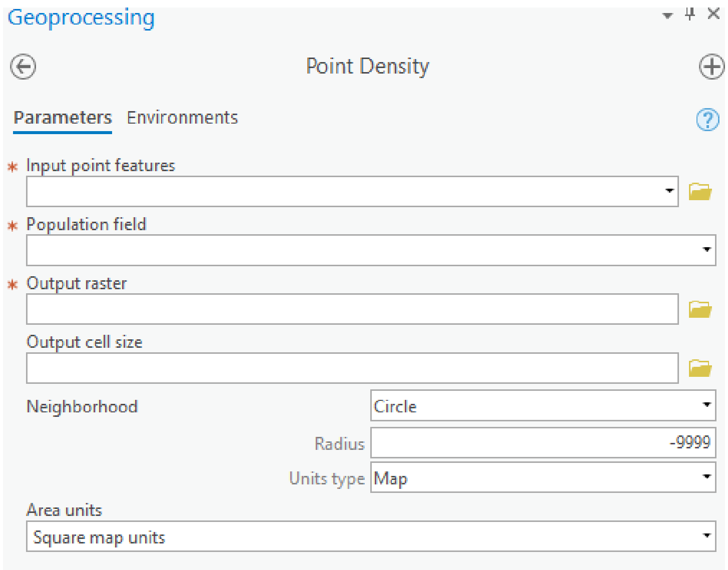


Figure 13: Point density tool ArcGIS Pro

As shown in **Figure 13,** other parameters addressed for this analysis. The *population field* indicates the number of times the point should be count. Since the building height needed to be included in the process, a few calculations were performed. In the point dataset a new field was created, where the building area was calculated in square meters multiplied by the height of the building.

In the field of the *Output cell size*, it was decided the default number. The *Output cell size* is defined by a numeric value or a raster dataset, in this case where nothing is specified, the default option, measures the shorter of the width or height of the area extent divided by 250. As far as concerns the *Radius* of the neighborhood field, by default, it calculates an appropriate search distance for determining neighborhood size and classify the output as Equal Interval with 10 classes. Since the increase of the *Radius* will not greatly change the calculated density values in a more generalized output raster, it was decided to use the default values (ArcGIS Pro, 2020).

3.2.2.2. Scale

Another indicator considered valuable for visibility analysis influence in the socio-spatial context was scale. Scale as stated in chapter 2.2, describes the perception between local and aerial space. In other words, how the distance from the building environment is perceived by the users or how enclosure the area is. To examine this aspect, it was chosen to be applied the *Inverse Distance Weighted (IDW)* tool in ArcGIS Pro.

As a tool, it has been widely used in various spatial researches to display qualitative sampling data of different phenomena like spatial perceptions and reveal spatial distributions of mental geography (Putra and Yung, 2020). Moreover, IDW tool is an interpolation method that predicts cell values by averaging the values of the input data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more influence on the predicted value than those farther away (ArcGIS Pro, 2020).

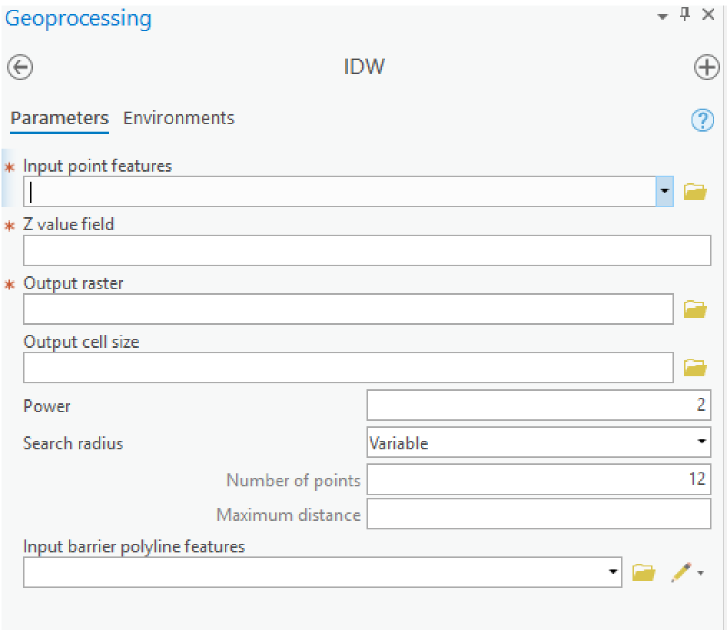


Figure 14: IDW tool ArcGIS Pro

As the above **Figure 14** indicates, building heights was used as an input, the same one used for the density analysis. Using the new point feature as an input, height values were assigned in the *Z value field*. The Output cell size along with the rest of the parameters was selected as the given default values. *Power* controls the significance of surrounding points on the interpolated value it should be between 0-3, as default the used value was 2. As for the *Search radius*, the variable and 12 for the number of the nearest input sample points to interpolate, was selected. The default *Maximum distance* specifies the length of the area's extent diagonal (ArcGIS Pro, 2020).

3.2.2.3. Openness

Openness is another influencing factor studied for evaluating the socio-spatial context of urban planning, and thereby, was selected as a KPI. Spatial openness as mentioned in chapter 2.2 is a tool for a comprehensive understanding of mental geography. The analysis has been applied in the streets of the two neighborhoods so to identify how open in terms of visibility the area is from a user's perspective.

The process as shown in **Figure 15** was implemented in ArcGIS Pro with the tool *Viewshed 2*. Viewshed analysis is a tool that identifies the cells in an input raster that can be seen from one or more observation locations using geodesic methods. In the output raster image, every cell obtains a value with the number of the observer points can be seen from each location (ArcGIS Pro, 2020).

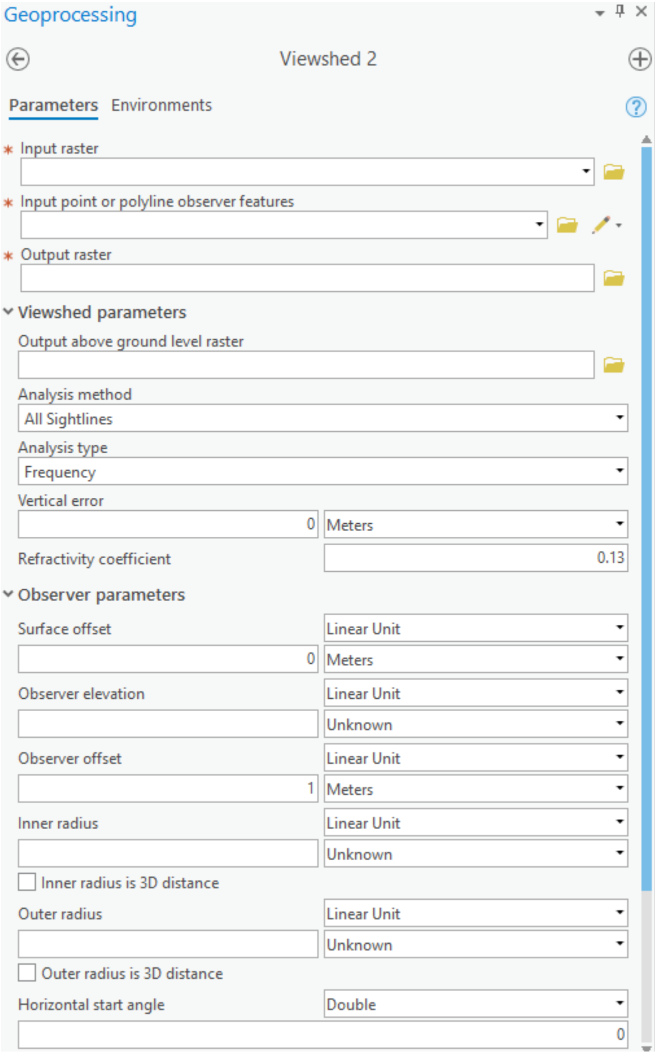


Figure 15: Viewshed 2 tool ArcGIS Pro

In this case, the input data is a raster image and a point or polyline feature layer. Since it was needed a raster file indicating all height values of the area, it was created a raster image including the DTM and the building values. As for the observation features, since the analysis was selected to be applied in the public areas and specifically in the streets, a small process followed to create a dataset of point features. Initially, the street layer of Urban atlas was extracted. In the case of Carlsberg, the network based on the current local plan was redesigned. After this process completed, the street file was converted into points through FME software.

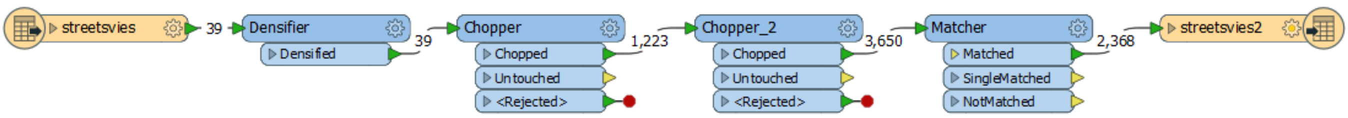


Figure 16: FME Polylines to point workflow

As shown in **Figure 16**, *Densifier* tool was used to densify the line with a chosen distance of 5 meters, to show the points where the line needs to be split. The *Chopper* tool was used two times, first to chop the line in segments of 1 meter and then chop the segments in points. Lastly, *Matcher* tool used to remove the duplicate points in cases where the start point of one segment is the endpoint of a second segment (ArcGIS Pro, 2020). In the case of Carlsberg, the observation points were 2.562 (**Figure 17**) and in Wijnhaven case were 2.368 (**Figure 18**).

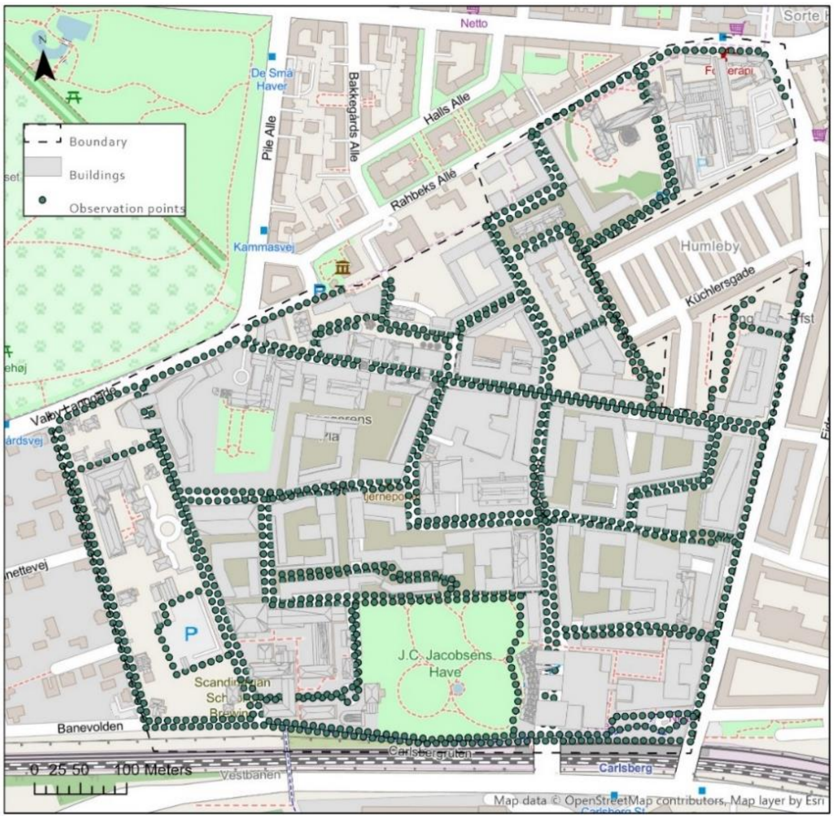


Figure 17: Carlsberg street observations viewpoints

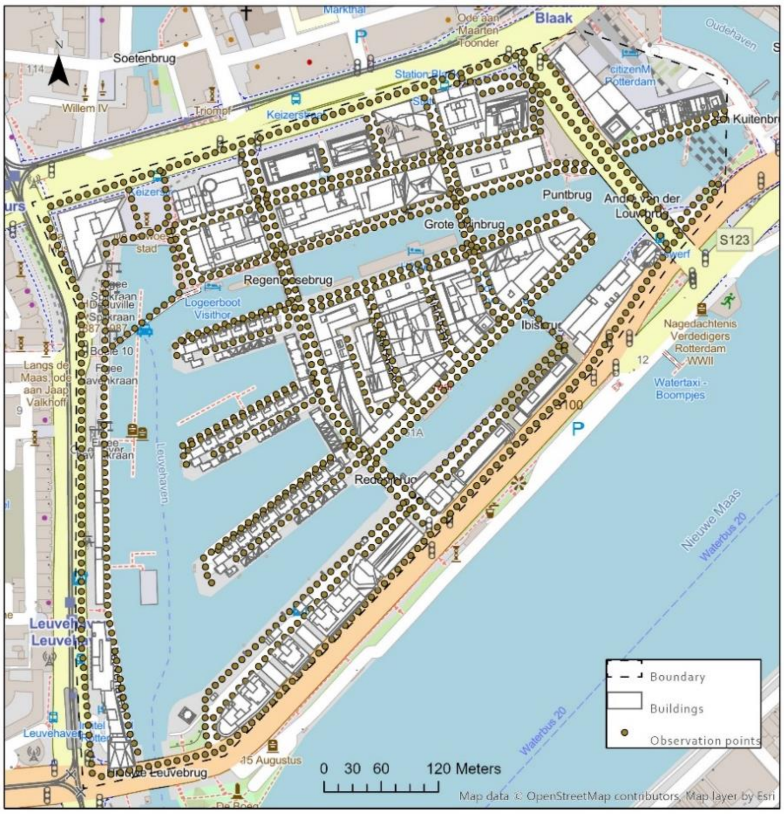


Figure 18: Wijnhaven streets observation viewpoints

For the raster file was used the elevation model of the area (DTM), where it was merged with the building raster image (*Mosaic tool*) (**Figure 19, Figure 20**).

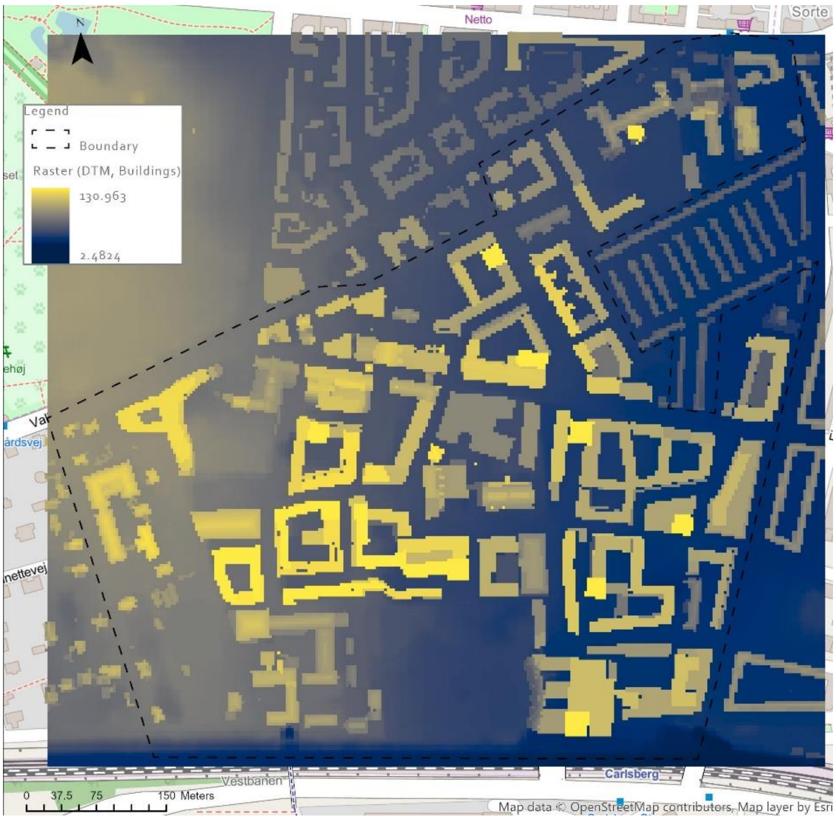


Figure 19: Carlsberg's Raster (DTM & Buildings)

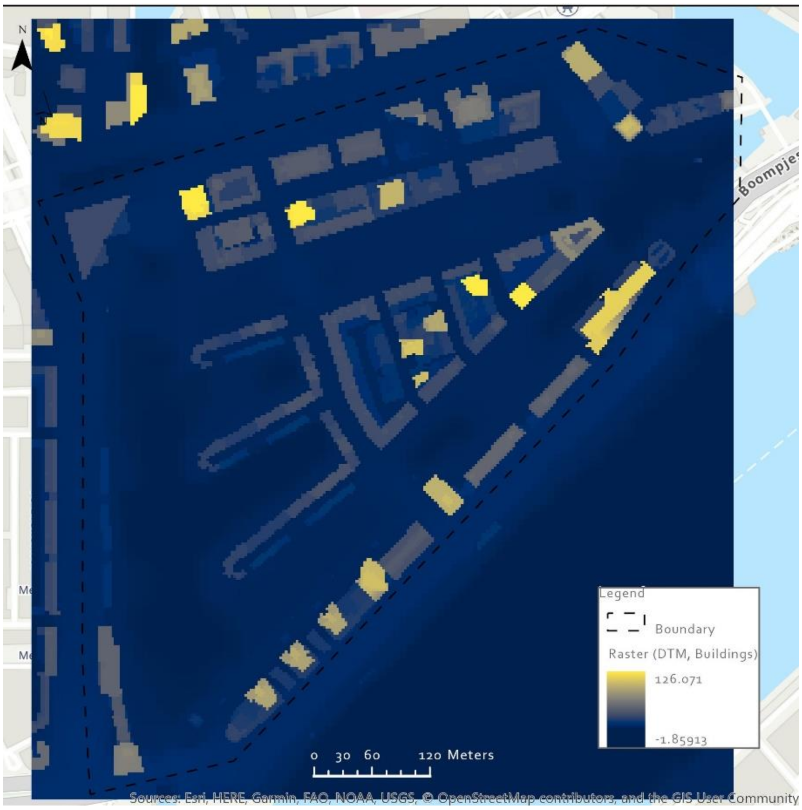


Figure 20: WIjnhaven's Raster (DTM & Buildings)

This tool (**Figure 15**) has two *Analysis methods, All sightlines* and *Perimeter sightlines*. *All sightlines* perform visibility analysis for all the raster cells of the area, while *Perimeter sightlines* only for the perimeter of the visible areas. For this case, it was selected the *Perimeter sightlines* as the top of the buildings should be excluded from the process as it can't be visible from the streets. Next step was to decide the *Analysis type,* between *Frequency* and *Observers*. *Frequency* identifies which raster surface is visible from the observation points, while *Observers* shows which observers are visible from each raster cell. Since it was desired to measure the visibility of the observation points, the *Frequency* method was selected.

One last parameter taken into consideration for this analysis was the *Observer offset*. As the analysis concerns the human perception, the observation points should be based on the people's average height per country. Based on the World Population Review for 2020, the height average is 183cm for Netherlands and 182cm for Denmark (World Population Review, 2020). Thus, both analyses performed by setting the *Observer offset* to the human eye level and set 8cm lower than the relevant population height for each case (ArcGIS Pro, 2020).

3.2.2.4. Intensity

Intensity, as aforementioned in chapter 2.2, is another important key indicator for this study, as it perceives the volume of visibility for a certain point or more observation points. As this study investigates the high-rise influence in the urban landscape, visibility of high-rise buildings has been applied. Moreover, to identify from where in the area high-rise buildings can be seen. The bellow **Figure 21** indicates, the process accomplished with the *Viewshed 2* tool in ArcGIS Pro.

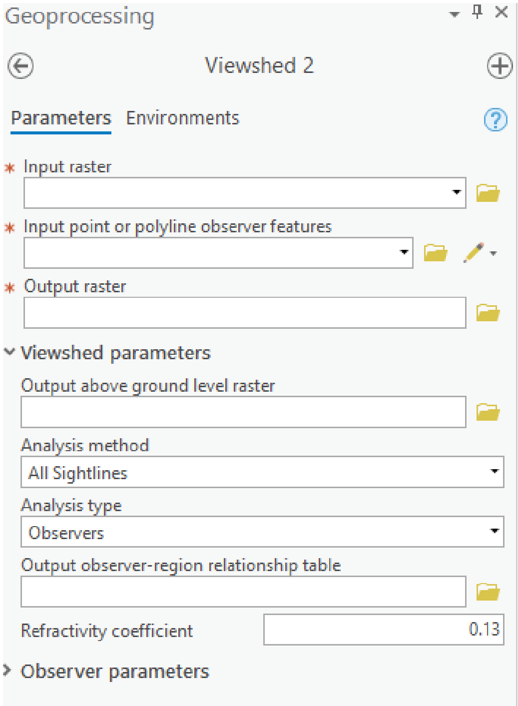


Figure 21: Viewshed 2 tool ArcGIS Pro (2)

As stated in openness analysis, *Viewshed 2,* determines the cells in an input raster that can be seen from one or more observation locations. The difference of this analysis is that the observation features are the high-rise buildings and the studying phenomenon examines in which locations of the area those features can be seen. Hence, the tool's parameters are slightly different. The input raster was the same as for the openness (DTM and Building heights). For the input observer features, a polyline shapefile was created in the perimeter of high-rise buildings (Figure 22, Figure 23).

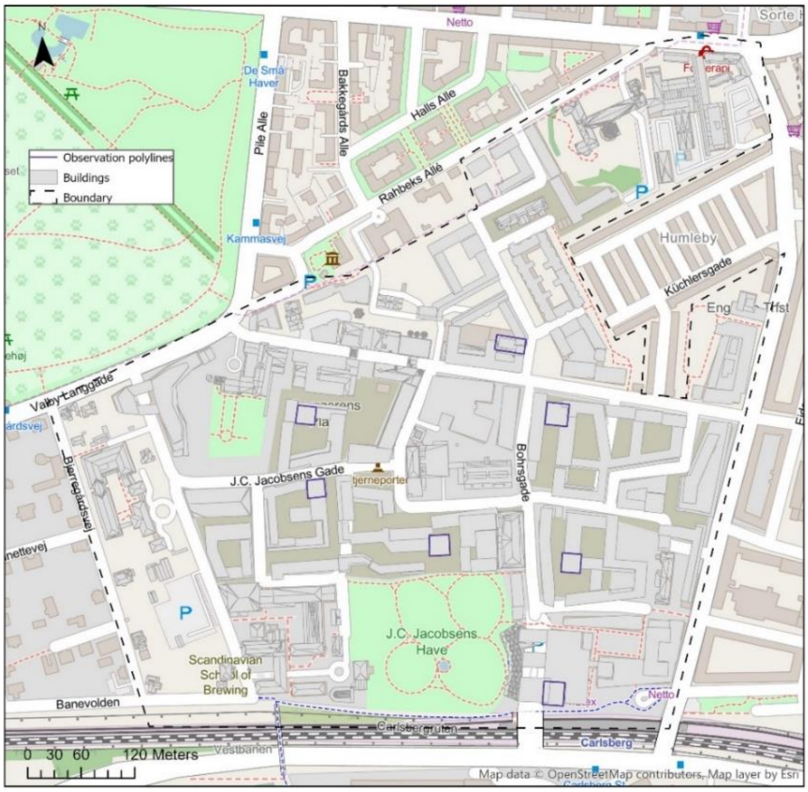


Figure 22: Carlsberg's building view lines observations

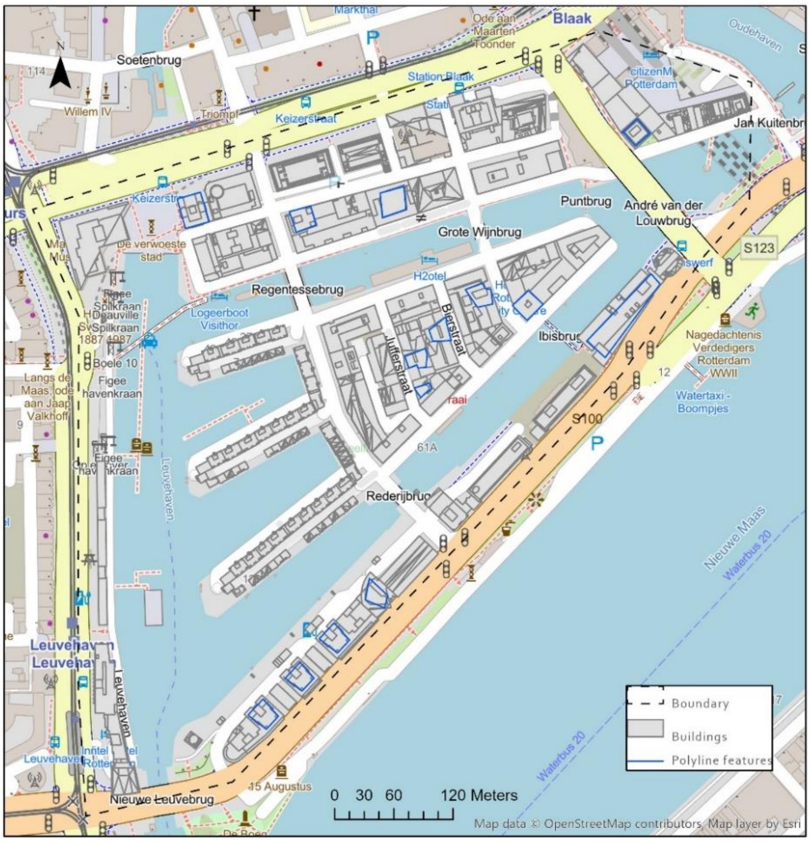


Figure 23: Wijnhaven's building view lines observations

Employing the *Analysis methods* (*All sightlines* and *Perimeter sightlines*), *All sightlines,* was selected*,* as the visibility analysis should be applied for all the raster cells of the area. In the direction of the *Analysis* *type* and the most important difference compared to openness, is the selection of the *Observers*. This process identifies which observers are visible from each raster cell and therefore, it was more suitable, for the analysis of high-rise buildings Intensity (ArcGIS Pro, 2020). All the rest parameters were the same as openness.

3.2.2.5. Views

Another aspect that influences the planning development is housing prices. As stated in chapter 2.2, the willingness to pay more to be located on higher-level floors and access to a good quality of the view, meaning nature environment, is increasing more and more the last years. In that context, viewshed analysis has been applied to the residential buildings for the two cases, through CityEngine environment. This KPI measures the land uses percentages of views and identifies whereas the area views in nature elements are high or low.

The procedure held in both ArcGIS Pro and CityEngine. The datasets used for this process was land uses from Urban Atlas, the open street map elevation model and the 3D city models of the two cases. Originally, urban atlas uses were categorized to the first level, mention in chapter 3.1.3. Next step was to import all data in CityEngine and adjust all layers to the elevation model. The process followed with the *Add map data* to download the terrain from Open street map and *Import tool* to load the data. Hence, the *Align to terrain* process was used, so both 3D models and land-use adjust based on the elevation. In order to run the process based on the residential buildings, a CGA rule has been applied to color and show the floors of the residential buildings (**Figure 24, Figure 25**). The applied CGA rule is part of the Building standard rules of the Tutorial Example Essential Context 2016 with the name BuindingShell. The rule was modified to illustrate residential buildings of the areas as a yellow color and with a level of detail 1 (LOD1) including floor level of 3 meters. The code can be found in the Appendix. The information of the residential buildings collected by the local plan of Carlsberg (Kobenhavns kommune, 2016) and by PDOK, an open government geodata platform for Winjhaven (PDOK, 2020). The floor height was set to 3 meters height based on measured average building height for the two areas.

Figure 24: Residential buildings (Carlsberg)

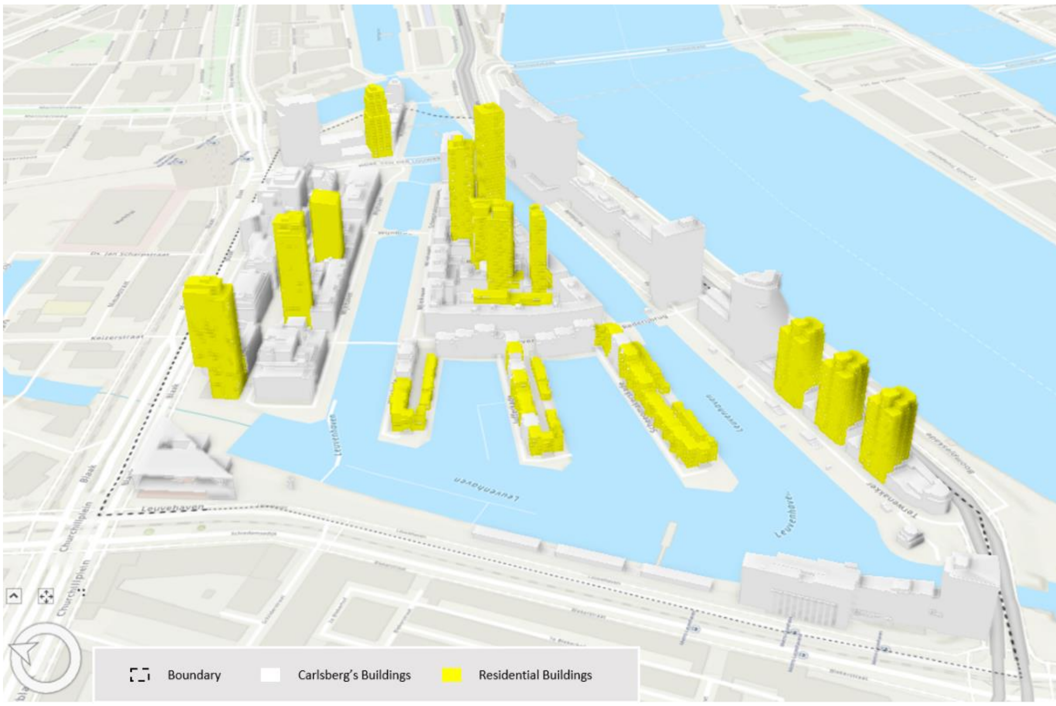


Figure 25: Residential buildings (Wijnhaven)

Once all datasets were set up in the environment Viewshed analysis tool was performed. In the next **Figure 26**, is illustrated the scene and the properties of the analysis.

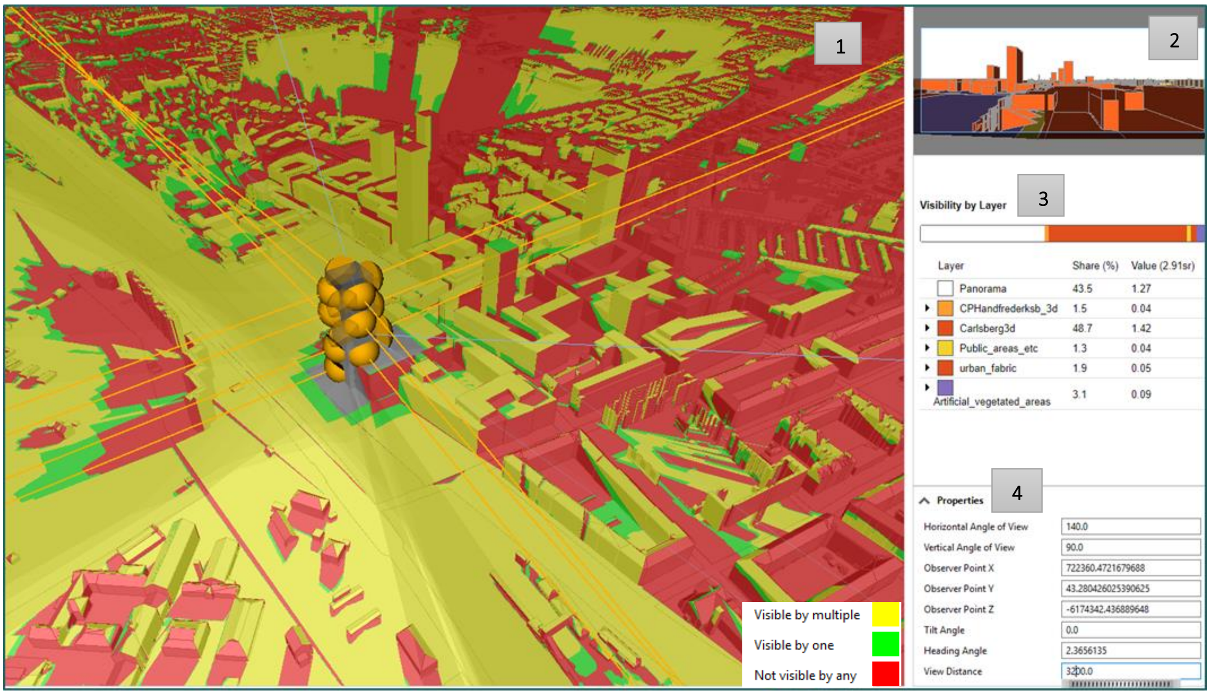
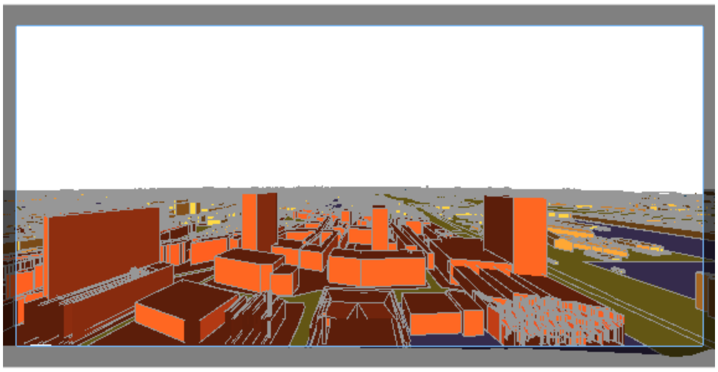


Figure 26: CityEngine Viewshed tool scenery

The main image of the scene (**Figure 26, number 1**) shows the 3D model of the Carlsberg case with all the viewpoints of one residential high-rise building. In the right upper side of the scene (**Figure 26, number 2**), the panorama view from one selected viewpoint of the buildings is illustrated. The panorama image changes with the selection of a different viewpoint. In the middle right side (**Figure 26, Number 3**), is indicated the view results of the selected viewpoint to the surrounding land uses in percentages. Lastly, in the downright side (**Figure 26, number 4**) of the scene, is included the camera's properties of the selected viewpoint.

Having tested the different observation points in the building and camera properties, it was selected to set observation points, every four floors and on each side of the building with a view angle of 140 horizontal and 90 vertical. The results as shown in **Figure 27** are percentages of views to surrounding land-uses, buildings and sky (Panorama).



Visibility by Layer

Layer	Share (%)	Value (3.96sr)
Panorama	49.8	1.97
CPHandfrederksb_3d	9.6	0.38
Carlsberg3d	30.3	1.20
Natural_semi_natural	0.2	0.01
Public_areas_etc	4.0	0.16
urban_fabric	2.4	0.09
Artificial_vegetated_areas	0.9	0.03
Water_elements	0.1	0.00

Figure 27: Example of Panorama and Views percentages to land uses

For the estimation of nature - building environment of residential high-rise buildings, all viewpoints were classified into three building levels, low-level floors, middle-level floors and high-level floors. In the case of the low-rise residential buildings of the area, two levels have been selected. Low level and high levels and only for buildings higher than 8 floors. Buildings lower than 8 floors were set as low level. Hence, the view distance was set up for each point through camera properties. For low-rise buildings, the view distance was around 500 – 1000 meters depending on the floor height and the surrounding buildings, and for high-rise buildings around 700 – 7000 meters. All view percentages results per viewpoint were extracted and summarized in an Excel sheet. The next **Figure 28** shows the computation process of the views in an area level.

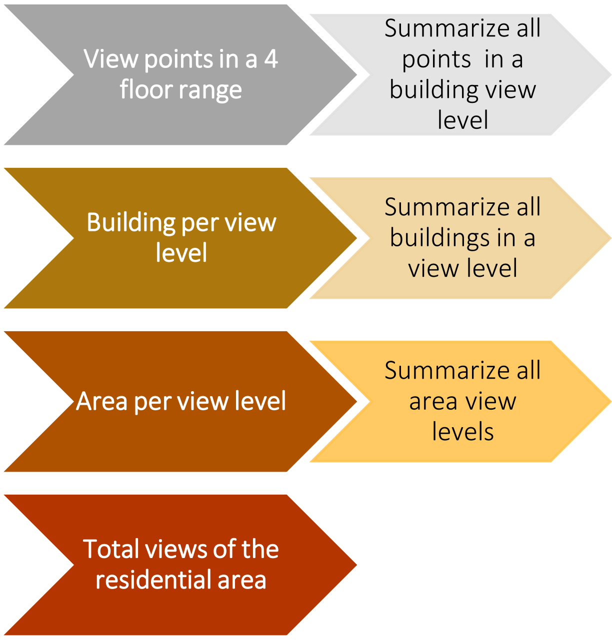


Figure 28: Workflow calculation of views

4. Results

This chapter explains the results of each KPI analysis as described in the previous chapter. At this point, it should be noted that the results obtained below, are explaining the prediction of the selected KPIs based on the mathematical calculation running in the backend of each GIS tool. As the literature review acknowledged, when such an analysis has been applied in other studies, the results were evaluated through a public survey comparison. However, the time this thesis had to be accomplished, did not allow the ability to include a public survey and thereby evaluate the results against the simulated data. Hence, it was applied a comparative assessment between the two case studies, exploring how the GIS analysis resulted in each case study.

In this section, the results emerged from the analysis are presented in maps. The visualisation of the maps is conducted with an equal interval method and a range of 5 classes, which later, was interpreted into a low(small)-high(big) classification, a similar method used in the research of Putra and Yung (2020). All KPIs will be described in relation to the urban environment and urban attributes of the two cases. For example, nature elements (water and parks), wide streets, narrow streets, open spaces, building perimeter surface, space between buildings nearby and building block.

4.1. Density

Density, as stated, is describing how dense an area is. For this KPI the density analysis was conducted only for the building elements of the two cases. Regarding the density measurement in Carlsberg's case, most of the area show low density, while medium to high is presented in the newly developed area. Furthermore, the higher density (more to most) is found in the open space of the building perimeter surface in 2 building blocks (**Figure 29, number 1 and 2**) and on the inside space of the nearby buildings of the building block **Figure 29, number 3**. The least dense areas are located to large open spaces, parks (**Figure 29, number 4 and 5**) and at the west boundary of the area where low-rise buildings (1-2 floors) are mostly located (**Figure 29, number 6**).

Figure 29: Density map (Carlsberg)

Figure 30: Density map (Wijnhaven)

In the case of Wijnhaven density, the area mainly shows low density which seems reasonable, as the half part of the area is covered by water. Generally, the area obtains low to medium density within the building core and higher density values around the high-rise building cluster. Moreover, few denser areas (medium to more) are found around 1 building block (**Figure 30 number 1**) and in the space between building block **Figure 30**, **number 1 and 2,** where 5 out of the 14 high-rise buildings are located there. Additional denser areas are spotted around 2 high-rise buildings (**Figure 30, number 3,4**). The lowest values of density in Wijnhaven's building core are situated in the low-rise residential area (**Figure 30, number 5**).

By examining density results for both cases, Carlsberg's newly built area, holds slightly higher density, lengthwise the new building blogs and on narrow streets indicating that those areas may influence the mental perception of space as well as the visual sense. In Wijnhaven's case though, the water area seems to eliminate the perceived building density as the results present lower density, despite the great high-rise building existence.

4.2. Scale

In the context of scale results, in Carlsberg, most of the area showed small to smaller scale. As described in the previous chapter, the ranges of scale perceptions depend on the adjustment building height and the horizontal enclosure of the space. The closer distance to a narrow open space with high buildings the higher the scale as well as the perceived density. In general, the area presents small to medium scale. The lower scale is mostly located in the old buildings of the area while the medium in the newly developed area. There are spotted 9 high values of scale (large to larger), all found around high-rise buildings, which also corresponds to the KPI's definition.

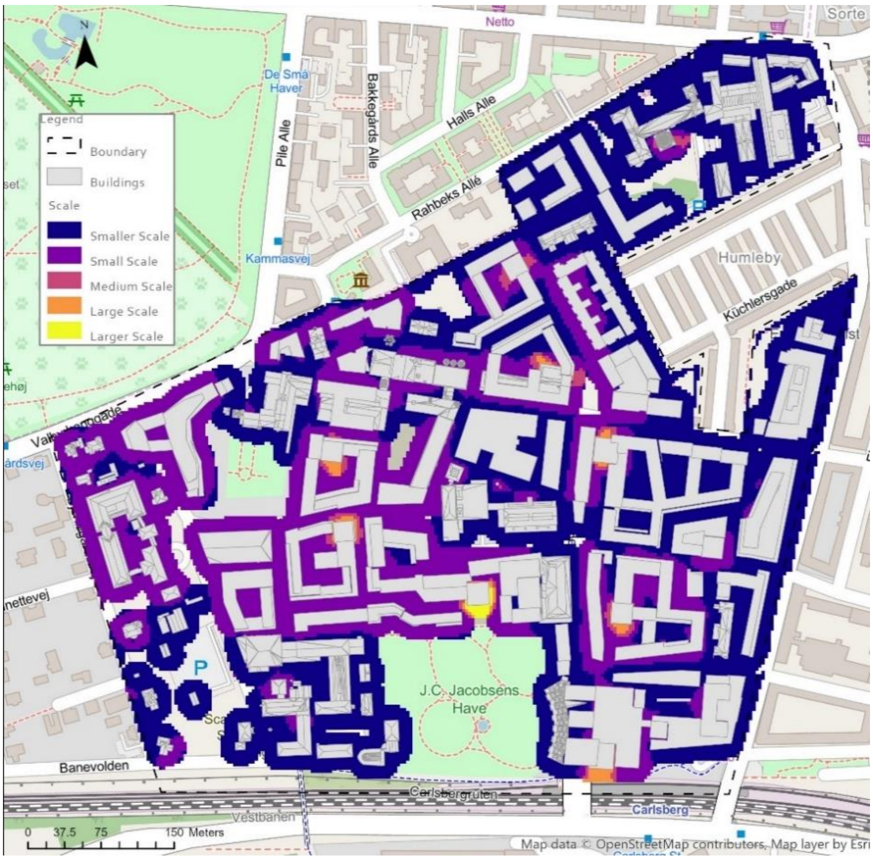


Figure 31: Scale map (Carlsberg)

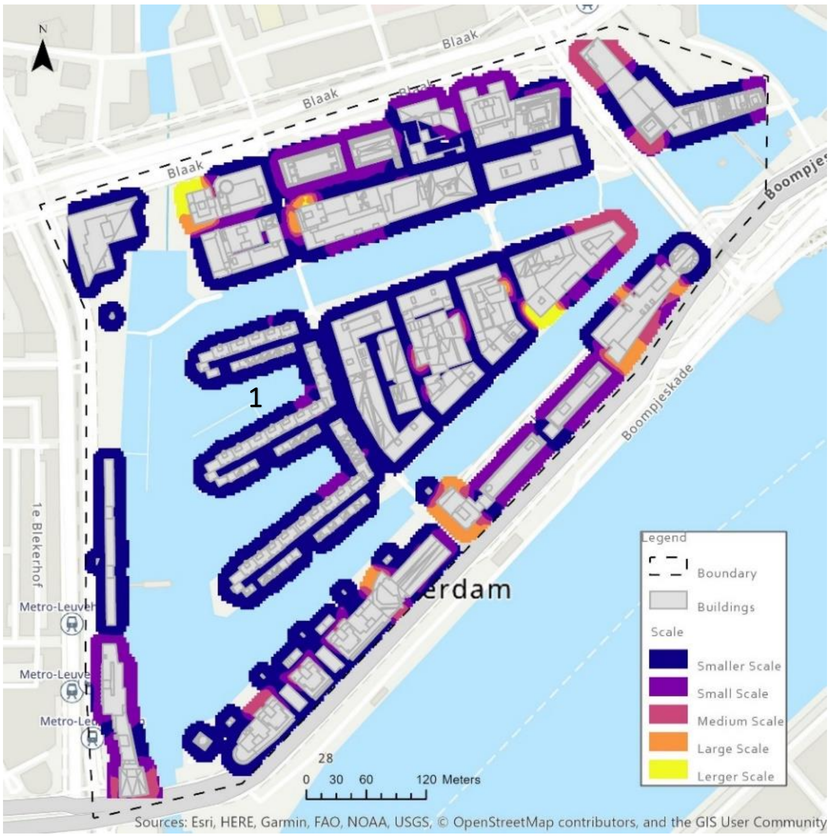


Figure 32: Scale map (Wijnhaven)

In Wijnhaven case, the area ranges mostly between small to medium scale following a similar pattern with the density results. The lower scale values are mostly positioned in the low-rise residential area (Figure 32, number 1), while the higher values of scale (large to larger) are located around high-rise buildings.

Scale, in general, seems to follow similar spatial perception to that of density, displaying a greater weight in the visual sense of the building height. Thus, comparing the results between density and scale it is concluded that the higher building surfaces and the more enclosed the urban space or narrow streets, the more will increase the perceived density and scale of the adjacent urban core.

4.3. Openness

In the direction of openness, meaning how open an area is perceived. In Carlsberg case, most of the area shows medium openness. Moreover, medium to more openness is located mostly in wide streets, large open areas and parks, which is reasonable as those areas have higher distance from the buildings and thereby better visibility. As for the less to low open areas, the indications displayed in narrow streets or the between of nearby buildings, and in open areas surrounded by building blocks (Figure 33, numbers 1,2,3).

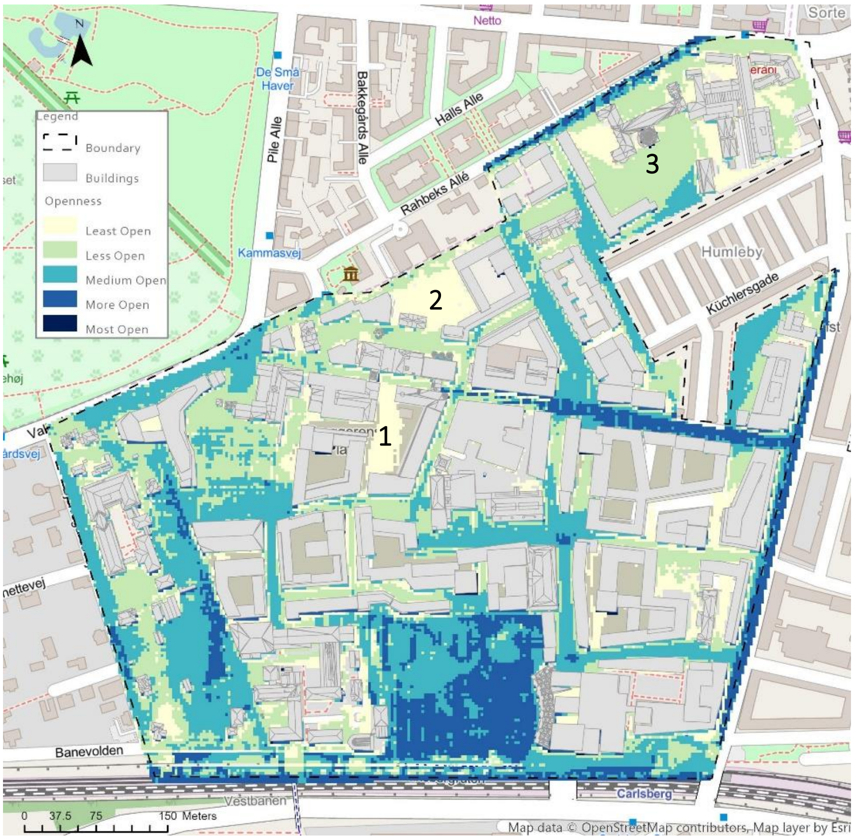


Figure 33: Openness map (Carlsberg)

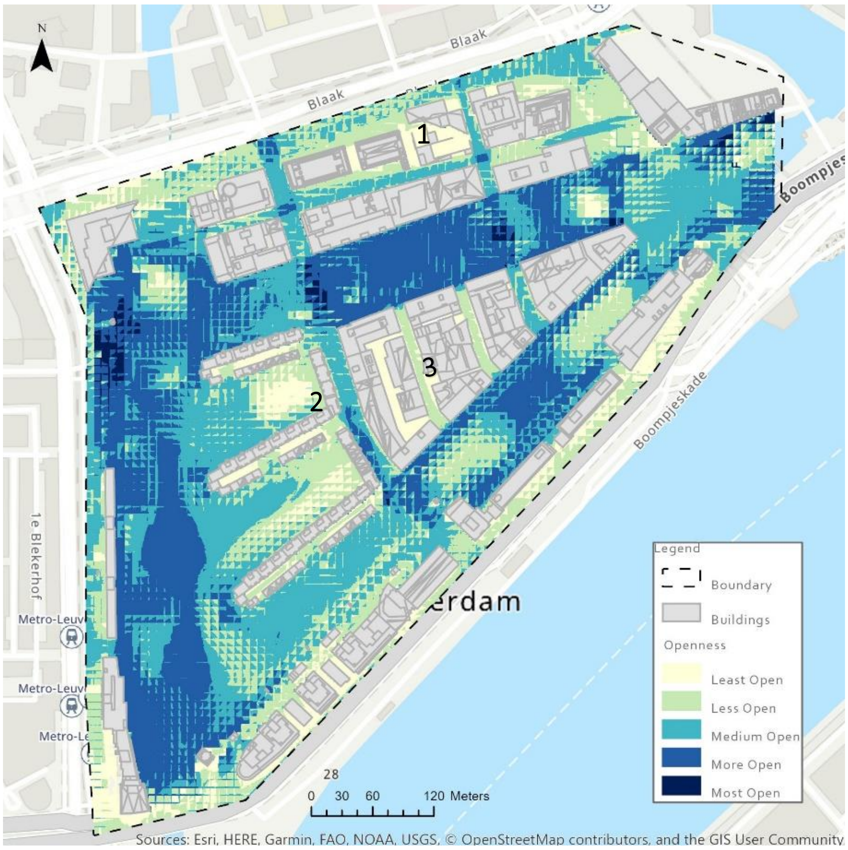


Figure 34: Openness map (Wijnhaven)

In the Wijnhaven case, the area shows mostly medium to more openness. This result is also expected as the area is surrounded by water and wide main streets, creating decent values of visibility. The least open spaces of the area (less to least), are mostly spotted in narrow streets or open areas surrounding by buildings (**Figure 34**, **numbers 1,2,3**).

In both cases, the results of openness imply that wide-open spaces and great distance from building surface shows significant openness, indicating that spatial perceptions of visibility, openness and scale are highly connected. For instance, the closer the distance to buildings, the smaller the scale and the less openness, residents will perceive. Additionally, the closer the spaces between the nearby buildings or building blocks and the narrow the streets, the less openness and the smaller scale the area contains.

4.4. Intensity

In Carlsberg case, intensity of high-rise buildings results shows partly more and partly less visibility. As stated, this KPI measures from where in the area high-rise buildings area visible. Hence, the areas show greater fluctuations with some areas having more or less visibility. For example, areas where high-rise buildings are more visible, are wide streets (**Figure 35, numbers 1, 2,3**), few open areas (**Figure 35, number 4,5**) and the half part of the park (**Figure 35, number 6**). The areas where high-rise building intensity is lower (less to least), is situated at the street of the southern border, in narrow streets and on the inside of building blocks. These results are reasonable, given the high-rise buildings location and other buildings presence in the area, as obstacles in the visibility measurement.
This KPI explores the influence of high-rise buildings in the area. In connection with the rest of the KPIs, it is observed that intensity is also highly linked with the results of the aforementioned KPIs, indicating that the higher the high-rise buildings intensity, the smaller the density and scale, and the higher the openness.

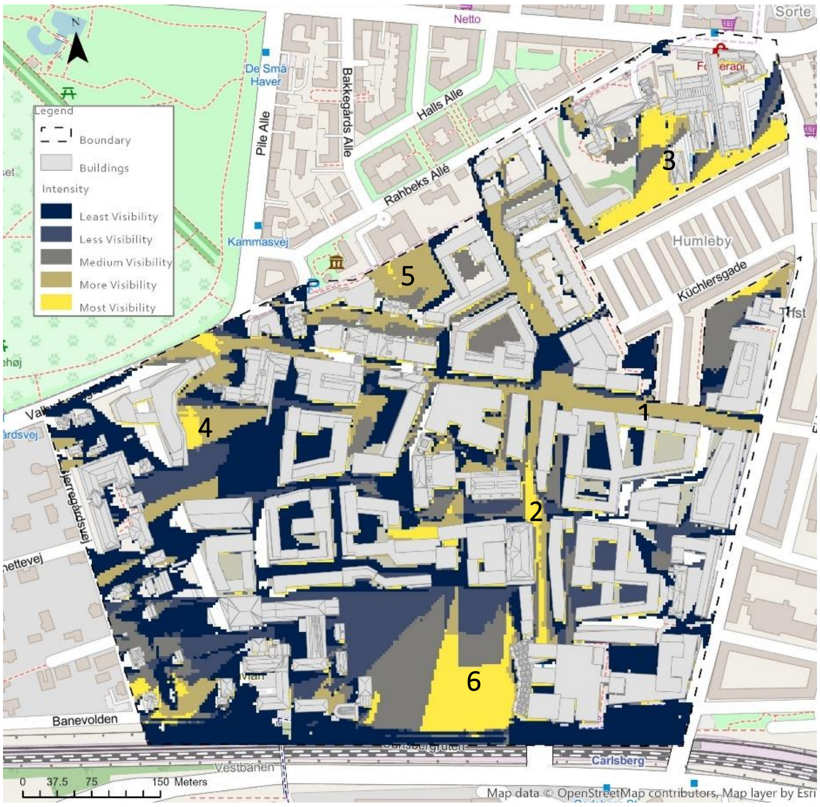


Figure 35: High-rise building Intensity map (Carlsberg)

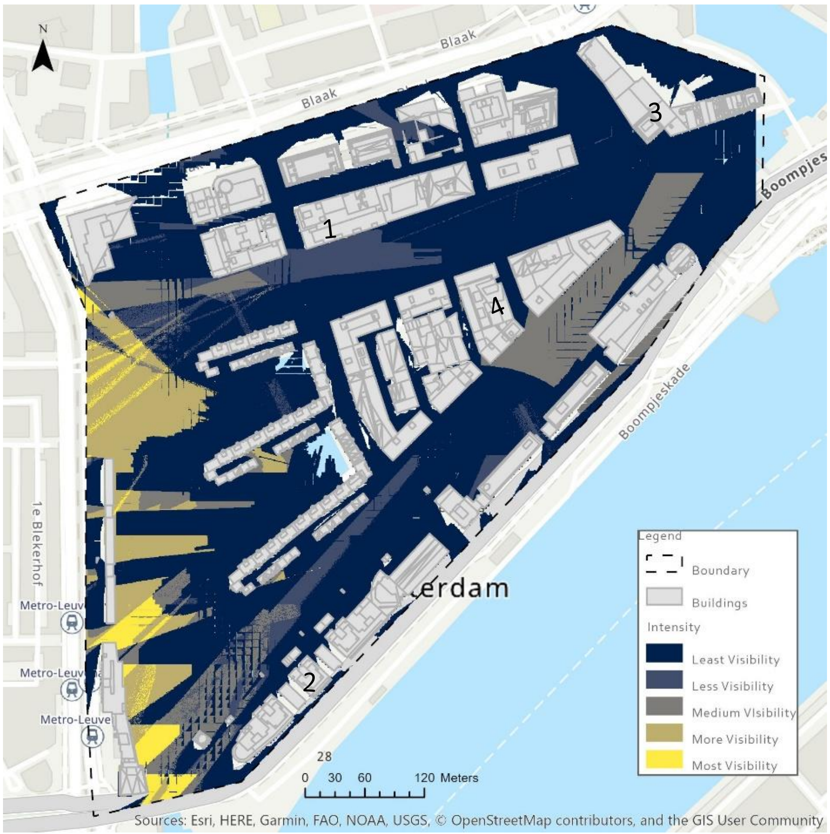


Figure 36: High-rise building Intensity map (Wijnhaven)

In Rotterdam case, high-rise buildings are least to less visible in the greatest part of the area. The area, in general, has spread high-rise buildings (**Figure 36, number 1,2,3**) and one cluster of high-rise buildings in the center (**Figure 36, number 4**). Thus, it is reasonable for the area that not all high-rise buildings are visible in most of its part. The area where high-rise buildings are mostly visible (more to most) is situated in the open public space and water areas of the west border. In connection with openness and scale, the urban area of the west border has significantly less density, more openness and larger scale, enabling the higher high-rise buildings visibility towards the entire area. It should be noted that the intensity results are also related to the high-rise buildings location within the area. For instance, in Carlsberg, high-rise buildings are spread in the area and mostly founded in the newly built part, setting the higher intensity values in the center of the case study and mostly in wide and open urban areas.

In conclusion, all four KPIs showed that there is a relationship between spatial perceptions and the surrounding space. For example, Carlsberg's case showed low openness, high density, scale and intensity, mostly in the newly built area and more particular, in narrow streets surrounded by buildings, around high-rise buildings and in the inside area of building blocks. However, all the results where fluctuated mostly from low to medium, meaning that visibility results were satisfying. In Wijnhaven case, the results had similar direction, as the highest density and scale and the least openness were spotted in the nearby building areas and mostly in narrow streets surrounded by buildings. As the case study was covered by water in its greater part, showed higher openness in its most part and high-rise building intensity on the west part of the area. Additionally, the results also ranged between low to medium displaying satisfying, in terms of visual sense results for this case study as well.

4.5. Views

In the analysis part of the views, the calculation steps of the views percentages in an area level were presented (**Figure 28**). In this section, all building viewpoints have been summarized in a building level in order to estimate residents' views satisfaction to nature areas. In the next figures, the views percentages of Nature areas, Public areas, Building areas and Sky, in a building height level (low, middle, high) per case area is illustrated. **Figure 37** indicates the results of high-rise residential building while **Figure 38** for low-rise buildings.

In high-rise buildings, is observed that views percentages of the resulted uses are range from low to high level of views. For example, building and public area percentages are being reduced from low to high level, while sky and nature are being increased. This is expected as it was stated in the theoretical part of the research, the higher the level of the floor the better the quality of view (nature element). In the direction of the two cases comparison, Wijnhaven shows higher level of views in natural elements for all height levels and slightly higher percentages in building areas. Carlsberg high-rise buildings, on the other hand, show higher percentage of views for the other two indicators, Sky and public areas.

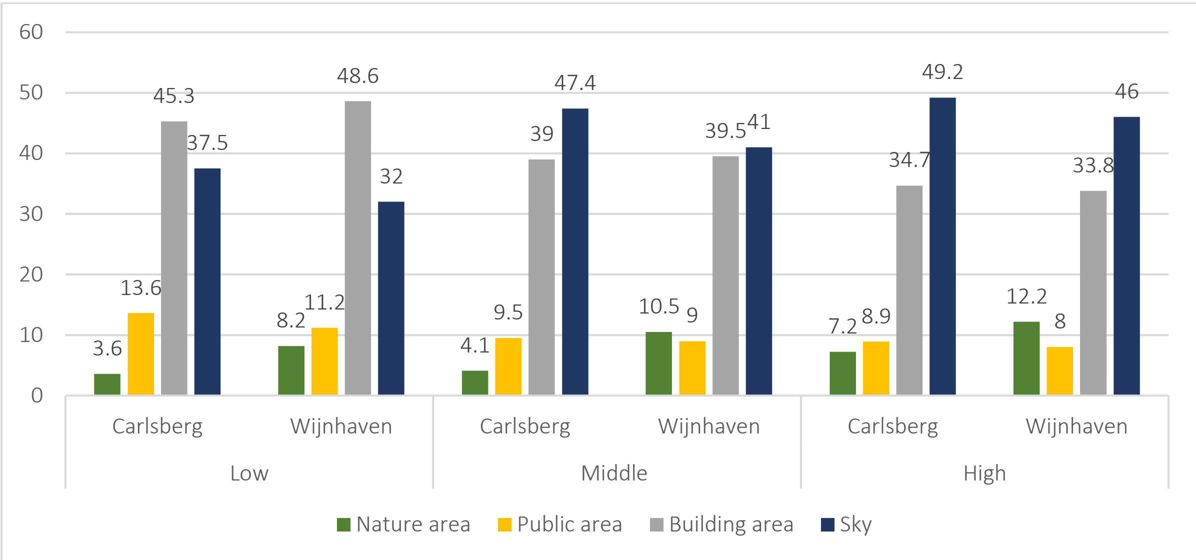


Figure 37: High-rise buildings height level results in %

In low-rise residential buildings (**Figure 38**), Carlsberg case has the same range of views from low to high level as emerged in high-rise buildings. Views to building and public areas are being reduced whereas sky and nature are increased. In Wijnhaven case the results are more interesting, as low to high level of views shows reduction for building, public areas and sky and increment for nature. The reduced percentage of sky, in this case, is explained by the location of the low-rise buildings (**Figure 25**). Low-level residential buildings (less than 8 floors) location has a great distance from other buildings and it is surrounded by water resulting into higher level of sky view. Additionally, the high-level low-rise buildings (more than 8 floors) are located closer to the building core of the area, resulting in less sky and more building area views.

In the comparison of the low-level views, Carlsberg presents higher percentages on buildings and public areas and slightly higher in nature areas, while Wijnhaven shows higher percentage in Sky views. In high-level views of low-rise buildings, Wijnhaven indicate higher level of view in all indicators beside sky which is lower.

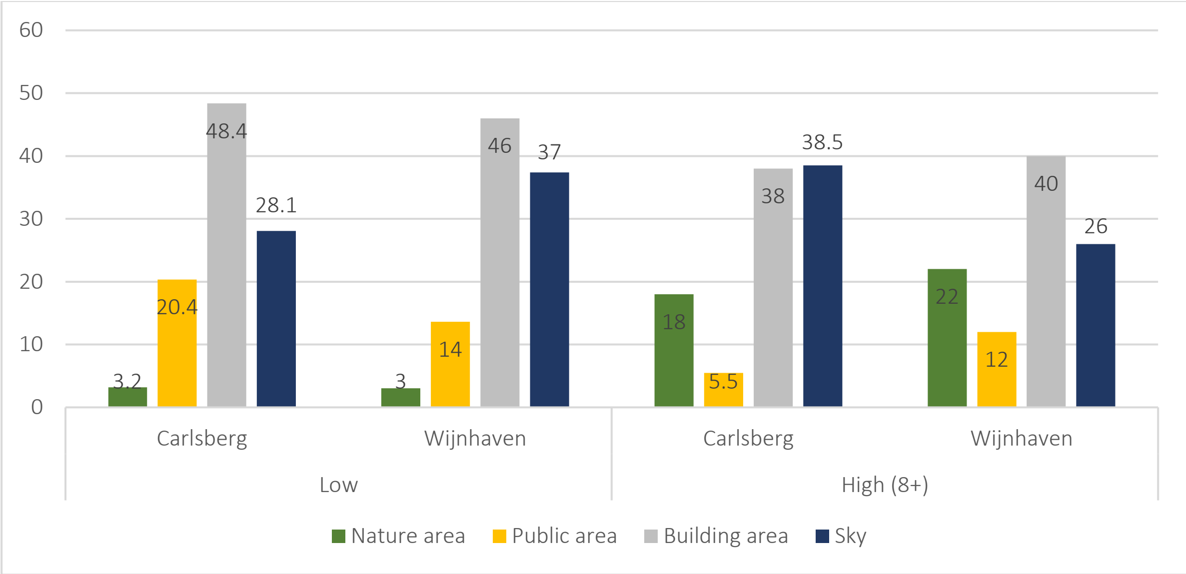


Figure 38: Low-rise buildings height level results

As the desirable results of the views required to show the percentages between Nature and Building environment, it was decided to summarise sky with nature areas into views to Nature environment and public areas with building areas to Building environment. Thus, the outcome for both cases in high-rise and low-rise buildings is illustrated in the next **Figure 39**. Wijnhaven low-rise buildings present slightly higher views to nature environment while Carlsberg's, a greater percentage of views in the building environment. In high-rise buildings views, both areas indicate almost equal percentage of views between nature-building environment with both reaching 50%.

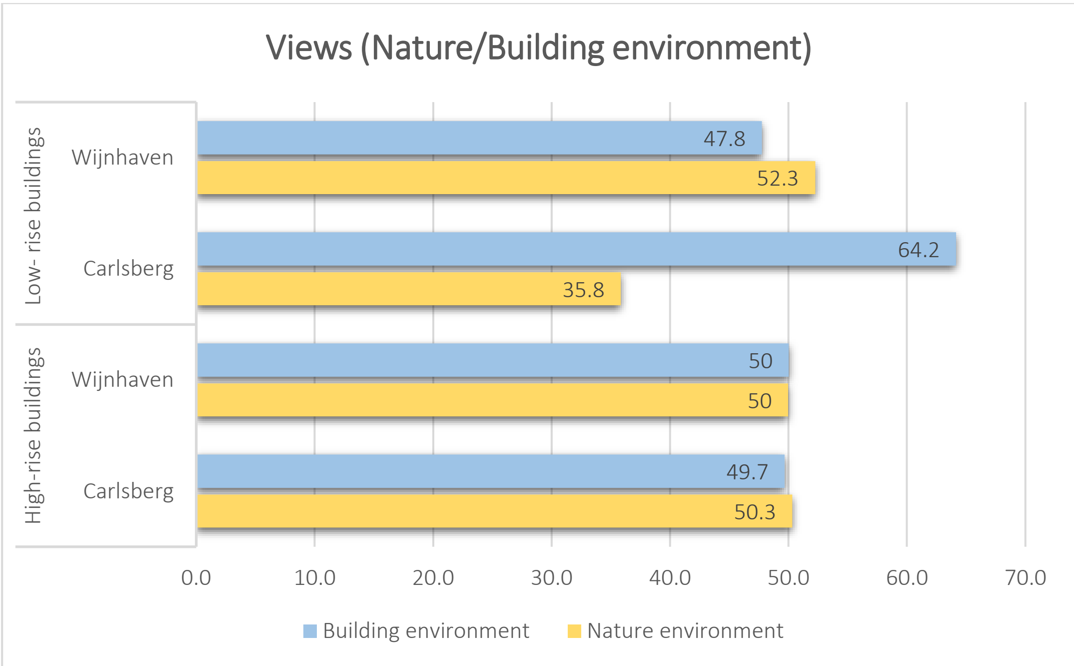


Figure 39: Views results to Nature - Building environment

4.6. Comparison of the case studies

Perceiving the results and the influence of visibility analysis in the socio-physical context of urban development in the two cases, a comparative analysis with the use of a spider webs graph was performed. The selection of this graph was made in order to create a comprehend visualization between the two case studies based on the KPIs results and understand the visual sense in the two planning approaches.

For the assessment of the KPIs in a spider webs chart, it was necessary to classify the results based on a scale system. The evaluation applied through a rating system as shown below (**Table 1**), the same one used to illustrate the results in the previous section 3.3. The rating system followed the KPIs classification as shown in the results: Least-Smaller, Less-Small, Medium, More-Large, Most-Larger.

Rating system	
Least, Smaller	1
Less, Small	2
Medium	3
More, Large	4
Most, Larger	5

Table 1: Rating system of the comparison

The process required first to get the classification numbers of influence from KPIs results and then select the highest number of influences to create the spider webs-graph. Thus, the first part of the procedure accomplished with the use of the reclassification tool in ArcGIS Pro. The reclassification tool was set in a range of 1 to 5 and with the equal interval classification method. The same classification method was used to present the maps of KPIs results obtained in the previous chapter 3.2.2.

Since views KPI has not attained with a classification process as the other KPIs did, it was required to classify it as well. As stated in the literature review chapter 2.2, housing prices are influenced when apartments have access to a good quality of view, meaning view of the natural landscape. Thus, the classification of the views KPI was set with a range of 5 and equal interval method in a scale of 100, taking into consideration only the views to nature environment. The below tables present the results of the reclassification **Table 2,**

Table 3.

Table 2: Carlsberg's KPIs classification results

KPIs	Density	Scale	Openness	Intensity	Views (nature)	
					High-rise	Low-rise
1	25570	8178	7031	**10959**		
2	**31605**	**17518**	**12200**	5867		**35.8**
3	27562	12652	10785	4618	**49.7**	
4	11029	659	5455	6176		
5	3172	512	243	9499		

Table 3: Wijnhaven's KPIs classification results

KPIs	Density	Scale	Openness	Intensity	Views (nature)	
					High-rise	Low-rise
1	**23241**	7018	304276	**675109**		
2	15122	**12118**	250811	357107		
3	5242	2913	**354826**	205952	50	52.3
4	346	1739	280604	141559		
5	67	701	10209	17223		

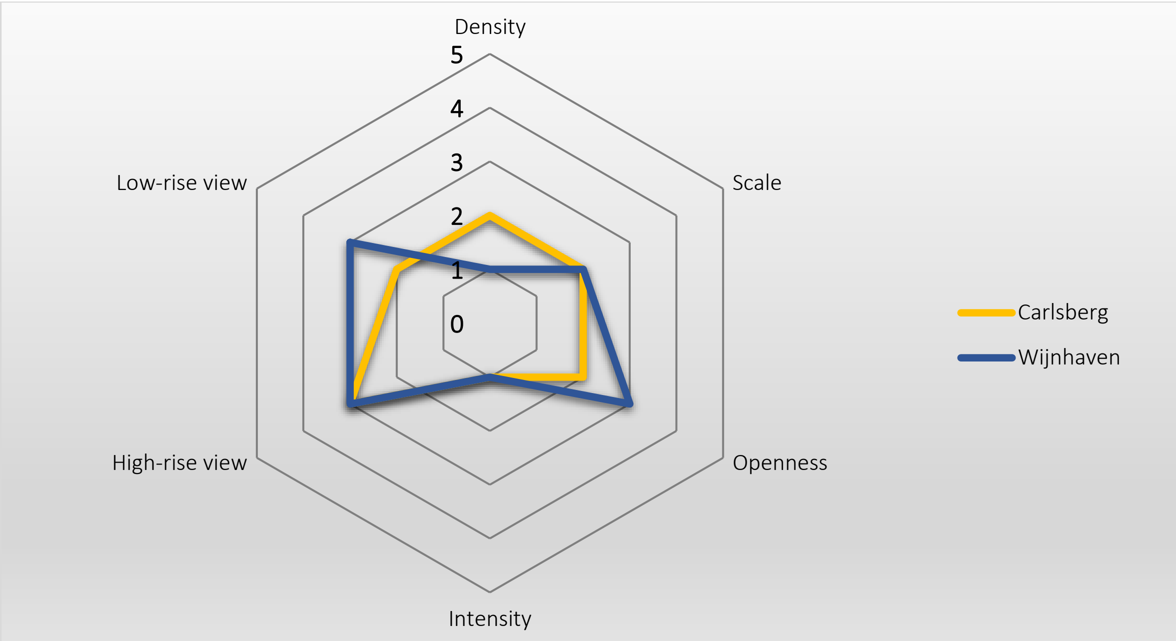


Figure 40: Comparison of KPIs results

Based on classification results, the highest number for each KPI have been selected to illustrate the spider webs chart, as Figure 40 shows. A good planning development in the context of visual sense should score the lowest for density, scale and intensity, and highest for openness and views in the natural environment. As the graph demonstrates, both cases are successful in the direction of visual sense impact in urban planning. However, assessing the comparison of the two cases, Wijnhaven has slightly better visibility analysis results than Carlsberg. This outcome was expected, as the half part of Wijnhaven area is covered by water and mostly containing wide streets, creating a well visible and pleasant environment for users, even though the great number of high-rise buildings existence. It is also observed that, buildings' location had a greater impact on the accuracy of analysis than building heights, as any building in close proximity to the viewer, will block his view.

It should be mentioned that Carlsberg's high-rise building redevelopment is also a successful case. Even though the area is denser and less open in some parts, it has managed to create a balanced environment for residents and users with a decent visibility result. Lastly, in terms of views, both area's residential buildings showed satisfying numbers of views percentages in nature environment, expecting higher property prices in the real estate market. Additionally, it was observed that locations of buildings had more influence on the KPIs results than building heights, concluding that in urban planning development of a high-rise building area, building location is more crucial than the building's height.

5. Discussion

This chapter provides a discussion of the study and evaluates the potential strengths and weaknesses of the implementation methods in relation to the research objectives.

5.1. Visibility analysis as an assessment tool in urban planning and a high-rise building redevelopment

This study applied a visibility assessment in two different high-rise building redeveloped areas and explored its impact on the socio-spatial context of urban planning. The results of this research show that the structure of a landscape is an important criterion for determining sustainable guidelines and parameters based on the different analyses. Landscape layout can immensely affect the visual experience, and therefore the use of geometrical methods for visibility and landscape analysis seems crucial. The constant development and use of GIS tools in such studies have been valuable for urban planning. As the study showed, several tools can measure and analyse the urban landscape in the direction of visibility. However, it has been argued that the visibility of high-rise buildings in the socio-spatial context is more complex and only the use of GIS tools cannot produce objective and qualitative results. Hence, the incorporation of those results in the planning process can be used as a suggestion for improvements and corrections of the visual impact analysis. Additionally, it shows to planners and decision-makers, the level building structures can influence the perception of space (Garnero and Fabrizio, 2013).

The performance of such an analysis can be accomplished with limitations. One of the most significant limitations is the quality of the results, which depends on the accuracy of the input datasets. One of the most important datasets is the 3D city model. The temporal completeness of the model and the level of detail of buildings, can determine the accuracy of the results. In this case, the limitations presented in the temporal completeness of the data, especially for Carlsberg case, where the used 3D model was developed in 2014, indicating a chronological gap where a lot of development and redevelopment occurred in the city of Copenhagen. As stated, all physical and structure elements can pose an obstacle in views. Thus, an up-to-date and complete model including the higher possible level of detail is essential. In this study, the provided 3D models were of LOD2. Hence, the given level of detail and the size of the model processed in CityEngine, carried out with some technical struggles. For this reason, when the analysis is performed on a big size 3D model with a more detailed level of buildings, more computer power is required.

Another crucial factor that can further improve the analysis, is the surface raster model. In both cases, a DTM, collected in 2014, has been used. A DSM model though could be more accurate for such analysis as it contains all the structure and physical elements existing above the surface. In this case, this could not be applied because of the temporal incompleteness of the dataset. Eventually, the DTM model in integration with the building structure was used. Additional option, in order to further improve the accuracy of the raster, could be the use of other kinds of 3D elements that mostly influence visibility, such as trees, bridges and technical infrastructure (Czyńska, 2014), which were not found in the open-source data platforms. An additional limitation of the used datasets was land uses. The selection of this dataset decided, in order to measure the percentages of the land uses views from residential buildings in each case study. The two land use city datasets of Urban Atlas are part of 2012 version, which again temporally wise was incomplete, as both cities and particularly Carlsberg, have transformed within the last 8 years. The new urban atlas version of 2018 has not published yet so it could not be used for this analysis.

In most of the studies that applied visibility assessment, a public survey has been used for the evaluation of the results. Visibility analysis is an aspect that examines the human visual sense. When it comes to urban planning, planners are exploring how space is perceived by people's visual sense and emotions and therefore, investigate improvements and limitation of the planning guidelines. The evaluation of those results is mostly practiced through a public survey where people rate space, similarly with GIS visibility results, detecting if those results correspond to the human perception of space. Thus, the integration of the results with a public survey would be highly valuable for this study, as it could produce a more comprehensive research. However, the limited time and the circumstance under which this study was carried out, could not afford the implementation and integration of a public survey.

5.2. GIS tools in the visual assessment of the socio-physical factor in urban planning

As mentioned in the theoretical part of the research, the connection of mental geography and the spatial perception of the urban environment can be performed with 3D visibility analysis based on different GIS tools that can interpret factors such as enclosure, openness and intensity. In this study, 5 key performance indicators: density, scale, openness, intensity and views, selected to be studied. Openness, intensity and views were related to visibility analysis while density and scale to the geometrical character of the space. In the direction of visibility analysis, the Viewsphere 3D analyst was used. The Viewshere 3D analysis generates volumetric indices that measure the visible space, making it a tool, applicable to human spatial perceptions. As mentioned, scale and density are the two most common spatial perceptions of the enclosure. Thereby, point density and inverse distance weighted interpolation (IDW) are two methods commonly performed to show spatial distributions of mental geography (Putra and Perry, 2020).

In general, all KPIs' input data had limitations explained in 5.1. section. In the case of views indicator, which was practiced in a 3D environment with manual input points, arose limitations in the accuracy of the results emerged from the quality of the 3D model. Moreover, the level of detail in the buildings, for example, floors and structural elements like windows or balconies, will acquire better decision on the input viewpoints and thereby, in the results. In several studies, the views percentages measurement has been accomplished in connection with other factors that affect housing prices. As stated, housing prices impact the development of an area as well as, urban design. Furthermore, the view is a significant factor that influences the property pricing, and so, it was selected to be studied as a part of the visibility assessment. In most studies where views influence has been explored, a statistical regression analysis along with other influencing factors such as property quality, accessibility, amenities and a lot more, has been conducted. In the current research, this kind of analysis could not be applied as the relevant data information was not publicly available. Another evaluating process that has been deployed in the exploration of the ''willingness to pay more for a better view'' (Bishop et al., 2004) was a public survey, where people were questioned about property prices based on the floor level and the quality of the view. Such an evaluation could not be accomplished in this research due to the lack of data, along with the timeline of the study.

All results were presented with the use of a classification system, a method similar to the one applied from Putra and Perry (2020). A method, useful for describing urban spaces based on these perceptual classes. This study assessed the results based on common urban attributes such as street layout, building blocks, natural elements and others. In the direction of studying the socio-spatial context of urban planning with the given GIS tools, the results could be also correlated with urban typologies (Putra and Yung, 2020), so to identify specific urban patterns of visibility. For example, typologies based on the building use and streets, translated into residential, mix-use area or office area, that could show, how visibility is performed in a more detailed level for each case. However, the results of the two areas were described in a building block level, evaluating visibility with common urban attributes and then in a local scale (neighborhood level), as it was not found any relevant building datasets regarding local plans for Wijnhaven and building usage for Carlsberg's case.

5.3. Comparison assessment of the results between the two case studies

Generally, both cases indicated satisfying results for all KPIs. As it has been defined both cases are forming a residential, mix-use redevelopment with high-rise buildings. In the direction of the visibility assessment, building and physical landscape can influence the results. It has highly noted that views to the physical environment and especially to water and green areas increase the resident's satisfaction in the socio-spatial context. In that framework, Wijnhaven case was expected to handle better results than Carlsberg as the half part of the area is covered by water. Another aspect that impacts the results was the location of high-rise buildings and residential buildings in general. Carlsberg's high-rise building was more spread throughout the area while Wijnhaven's more clustered.

In the observation of KPIs results, both areas show similarities. Moreover, scale and high-rise buildings intensity had the same score, while Carlsberg showed one level denser than Wijnhaven and Wijnhaven one level higher openness. Views to the natural landscape of residential high-rise buildings ranged in the same level as Carlsberg's, while low-rise buildings of Wijnhaven scored a level higher than Carlsberg's, which was expected given the building's location. This small differences on openness, density and low-rise residential buildings views, fulfilled the assumption that Winjhaven was anticipated to hold slightly better results. In spite that, both cases presented good visibility results in a local scale, observing that locations of buildings rather than building heights had a greater impact on the accuracy of analysis and thereby, in the urban planning process.

This research applied GIS tools that correspond to the analysis of the spatial-mental context. However, the analysis carried out with limitations discussed in sections 5.1 and 5.2. Based on that fact, it is observed that even though the results correspond to a certain point with the planning information, they are not accurate enough and require further improvement so to be used as a part of the urban planning process.

6. Conclusion

This study attempted to explore the visibility impact of high-rise buildings in the socio-spatial context of urban planning development. Aiming to further strengthen the urban planning guidelines by enhancing the involvement of the human factor in the planning process and create even more livable and well-designed urban environment. In addition, it investigates different geoinformatics tools that can describe and analyze different aspects of human visual sensation in the spatial planning process. In this context, the analysis of five selected indicators that affect the visibility of an area's skyline was performed based on the literature review. Observing the results, it concludes that such tools can in fact benefit and be an assessment tool for urban planning. However, it recognises the necessity of using good quality and temporal complete datasets in order to receive reliable results.

Finally, the research is applying this analysis in two case studies, so to perceive the visibility evaluation of high-rise buildings in two different urban city environments. Thus, it concludes that the used tools correspond to both theory and reality of the visual sense of the socio-spatial relationship, observing limitations in the quality of the input data, as well as in the evaluation of the results.

6.1. Future development

Taking into account what was mentioned in this paper, as well as from other researchers that dealt with this topic, this chapter will introduce the possible future development of this study.

6.1.1. Evaluation of the results through a public survey

As noted, this thesis studied the visual sense of the socio-spatial context in urban planning. Such a study widely involves the mentality or psychology of the human factor and how it is affected by the built environment around it. In the effort of studying this phenomenon, geoinformatics tools and techniques have been developed and increasingly being used for this purpose. Although, the use of these tools should be evaluated, both for their improvement and for the accuracy of the results. In this context, many studies have integrated and compared the GIS results with identical results derived from a public research. In this way, they will be able to determine whether the results of geoinformatics tools were capable of successfully perform and predict such a process. Hence, as a follow-up of this applied research, it would be prudent to perform a public survey so to strengthen and improve the quality of the results.

6.1.2. Views influence on housing prices through Statistical analysis

Real estate has been a factor that influences the economic development of a city or neighborhood and thereby the urban planning development and guidelines. For this reason, one of the key performance indicators attempted to be explored in this study, was the view of houses in the natural environment. In recent years, the housing views has been increasingly affecting real estate prices as people are willing to spend more money to access a better-quality of view. Thus, plenty of researches applied statistical regression methods to measure that influence and predict housing prices. This research requires data such as current property prices, as well as other features that may affect the price such as building quality, date, parking, land use, accessibility, distance from the city center and many more. Due to the lack of time and access to the relevant data, it was impossible to conduct this type of research and for this reason, this KPI focused on the measurement of a physical and structured environment. However, such an analysis could be part of the future development of this KPI as well as of the entire research.

6.1.3. Visibility analysis in a city level

Another possible future development of such study is referred to as the scale of the study. Due to the limited time, this thesis had to be accomplished, the exploration of visibility influence of high-rise buildings conducted on a local scale. Applying such research to a neighborhood level has helped to comprehend the visibility effects of high-rise buildings on a district/neighborhood redevelopment and in a more detail sense. In various researches, the influence of visibility of high-rise buildings has been studied in a city level to protect the cultural heritage of the city and identify contradictions in order to avoid poor planning development. This process could be practiced in this project and investigate possible impact in the cultural heritage skyline as well as on the landmarks of the two cities. In addition, it would be interesting to study in what extent, a high-rise neighborhood-level redevelopment is capable of affecting two different city models, as is Copenhagen, a city model with low-rise buildings and Rotterdam a high-rise city model, and thereby compare the differences of the urban planning guidelines.

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Appendix

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@Hidden
import Three_Part_Texturing: "Referenced/Three_Part_Texturing.cga"
import BuildingReference:"Referenced/Building_Reference.cga"
import Color_Names:"/ESRI.lib/rules/General/Color_Names.cga"
####################################################
# CONSTANT PATHS

const facadeDirectory =
  case typologyRemoveBlanks == "Unknown":
          "Buildings_Standard/BuildingTextures/Facades/Unknown/"
  else:
          "Buildings_Standard/BuildingTextures/Facades/"
const roofDirectory = "Buildings_Standard/BuildingTextures/Roofs/Flat/"
const modelFilePath = "" #TODO, I think this is a remnant from Building.cga. Verify later.

typologyRemoveBlanks = case isBlank(typology): "Unknown" else: typology

####################################################
# ATTR: Building Form

@Description("The style of the building that determines which library of textures to use. It also pre-sets several attributes across the rule, include Floor_Height, Roof_Type, and the Usage Profile.")
@Group("Building Form",10) @Order(10)
@Range("Residential", "Others")
attr typology = "Unknown"

#@Description("Total in meters.")
#@Range(0.1,10.1)
#@Group("Building Form") @Order(20)
#attr totalHeight = -1

/*
@Description("The number of stories in each building (above ground).")
@Range(1,60)
@Group("Building Form") @Order(30)
attr Floor_Count =
  case levelsAboveGround > 0: levelsAboveGround
  else: 1
#???XX?
attr levelsAboveGround = 0

@Description("The number of stories in each building (above ground).")
@Range(1,6)
@Group("Building Form") @Order(31)
attr levelsBelowGround = -1
*/

@Description("Floor-to-floor height in meters.")
@Range(0.1,10.1)
@Group("Building Form") @Order(40)
attr levelHeight = 3
@Hiden

#const eaveHeight = Floor_Count * levelHeight
```

```
const totalHeight = scope.sy
const levelsAboveGround = totalHeight / levelHeight

###############################################
# ATTR: Display

@Group("Display",20) @Order(10)
@Description("Visual display of building colors or textures.")
@Range("Textured", "Others", "Residential")
# We don't need now:  "Raster color sample")
# "Textured" option doesn't make sense on a drawn MP shape.

attr representation = "Usage"
/*
@Group("Display") @Order(20)
@Description("LOD gives lowest or highest detail based on start shape.")
@Range("Low LOD", "High LOD")
attr levelOfDetail = "High LOD"
*/
###############################################
# ATTR: For Models
/*
@Description("Name of the geospecific model in the assets/Building_Models folder.")
@Group("For Models",25) @Order(60)
@File
attr modelFile = ""
*/
@Description("GFA for geospecific model. User must supply value. If value is <=0 then it will not calculate
metrics.")
@Group("For Models") @Order(70)
@Range(0,100000)
attr modelGFA = 0

/*
@Description("Name of the geospecific model in the assets/Building_Models folder.")
@Group("For Models") @Order(80)
@Range("From Original Model", "From Typology")
attr textureSource = "From Original Model"
*/
###############################################
# ATTR: Texturing

@Group("Texturing",30) @Order(20)
@Decription("Randomly selected path in the correct Typology Folder, or user specified.")
@File
attr facadeTexture = Three_Part_Texturing.getFacadeTexture( levelsAboveGround , facadeDirectory)

@Group("Texturing") @Order(30)
@Description("Manual X offset to help align textures.")
@Range(-10.1,10.1)
attr facadeHorizontalOffset = 0

@Hidden @Group("Texturing") @Order(40)
@Decription("Randomly selected path in the Roofs folder, or user specified.")
@File
attr roofTexture = fileRandom(roofDirectory + "*.jpg")
/*
```

```
#@Handle("shape=ColoredBuilding type=selector align=left extensionLines=scope")
@Description("Form of roof.")
@Group("Texturing") @Order(50)
@Range("Standard", "Standard, High LOD")
attr roofType = "Standard"
*/

##############################################
# ATTR: Reporting

@Group("Reporting", 100) @Order(10)
@Description("User defined unique ID. May be pre-existing on a footprint, or set on newly created buildings. Used so that buildings are represented in Reports/Dashboards.")
attr buildingFID = ""

@Group("Reporting") @Order(20)
@Description("Unique ID for parcel containing building. May be layer mapped to existing GIS features.")
attr parcelFID = ""

@Group("Reporting") @Order(40)
@Description("For mapping to a raster layer.")
@Range(0,1)
attr Residential = 0

@Group("Reporting") @Order(50)
@Description("Mapping to an object attribute, or a layer map to another layer.")
@Range(1,2,3,4,5,6,7,8,9)
attr Others = 1

####################################################
# RULES

# Start Rule Note: Footprints with multiple faces are not compatible with this rule.

@StartRule
BuildingShell -->
	# This is a multipatch.
	cleanupGeometry(edges, 0.1)
	alignScopeToAxes(y)
	# For dashboard:
	report("Building_FID", buildingFID )
	report("Parcel_FID", parcelFID )
	#report("Demand_FID", _Demand_FID )
	#USAGE_PROFILE.ReportUsages(Total_GFA, 1)

	BuildingReference.Usage_Typology.ReportUsages(modelGFA, 1)
	#UsageVisual
	BuildingShellDispatch

_multipatchFloorCount = rint(scope.sy / levelHeight )
_multipatchFloorHeight = scope.sy / _multipatchFloorCount


BuildingShellDispatch -->
	case representation == "Textured":
		# Using the texture of the original model.
		X.
```

```
        else:
                # This multipatch is de-textured and sent to colored building rule.
                deleteUV(0)
                BuildingReference.ColoredBuilding


##################################################
# Reference function

# Tests if a value is any number of spaces or is empty string.
isBlank(someString) = removeSpaces(someString) == ""

# Recursive function calls itself, removing first space it finds, till it finds none.
removeSpaces(someString) =
        case find(someString," ",0) == -1:
                # There are no spaces. Just return the current value.
                someString
        else:
                case find(someString," ",0) == 0:
                # It is the first character, just use rest of string.
                        removeSpaces(substring(someString,1,len(someString)))
                case find(someString," ",0) == len(someString)-2:
                        # It is the last char.
                        removeSpaces(substring(someString,0,len(someString)-1))
                else:
                        #str(find(someString," ",0))
                        # It is in the middle.
                        removeSpaces(
                                substring(someString,0,find(someString," ",0)) +
                                substring(someString,find(someString," ",0) + 1,len(someString)))
```