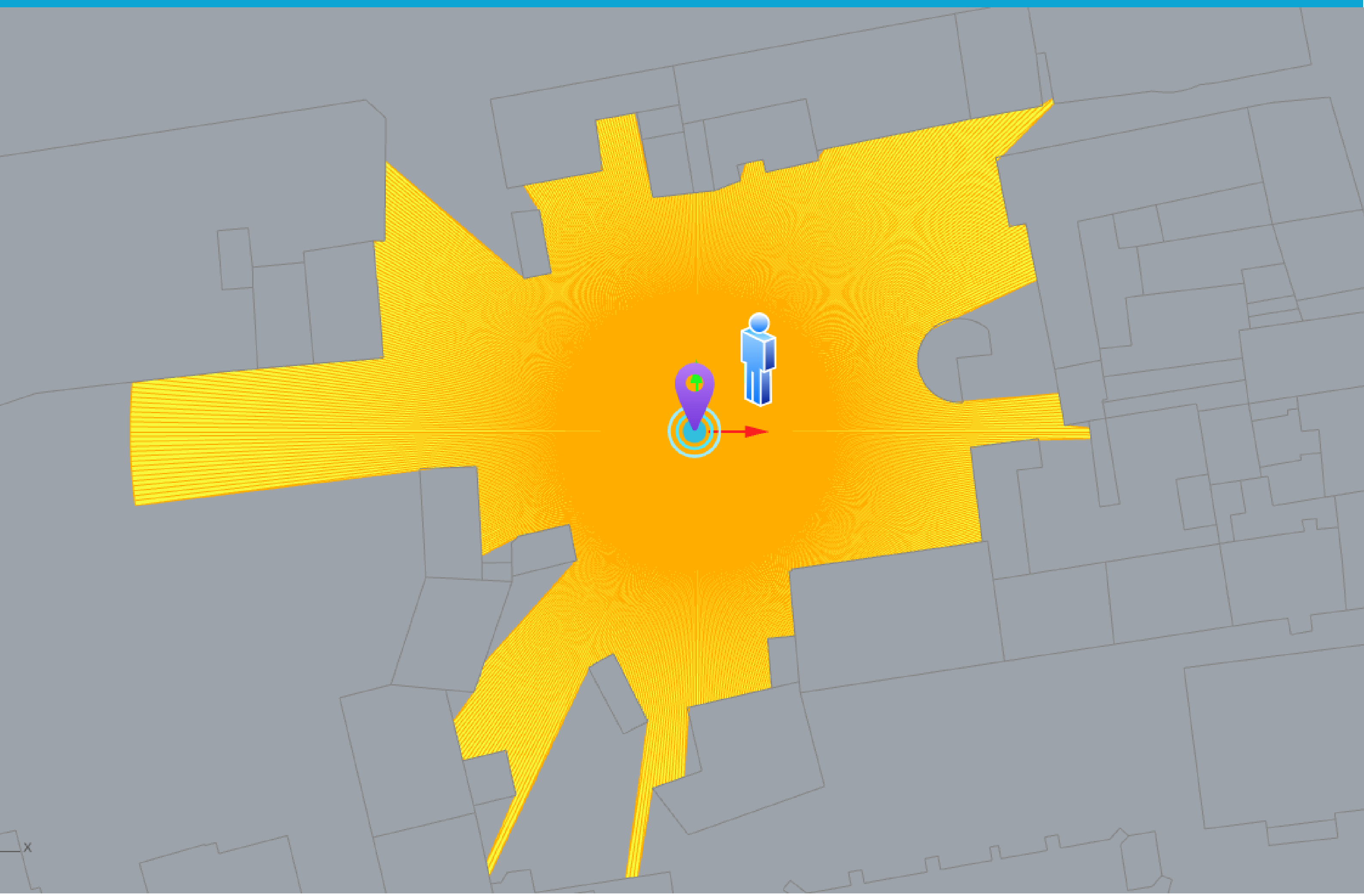
MSc thesis in Geomatics

Isovist Fingerprinting as new way of Indoor Localisation

Georgios
Triantafyllou

2022



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Isovist Fingerprinting as new way of Indoor Localisation

Georgios Triantafyllou

June 2022

A thesis submitted to the Delft University of Technology in partial fulfillment of the requirements for the degree of Master of Science in Geomatics

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Geo-Database Management Center
Faculty of Architecture and the Built Environment
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Supervisors:	Ir. Edward Verbree
	Dr. Azarakhsh Rafiee
Co-reader:	Dr. Lucía Díaz Vilariño

Abstract

Nowadays, humans rely in technology more and more when it comes to navigation and localisation and in many aspects of life as well. While most concepts related to localisation and navigation of outdoors environments are already well derived from various researches and softwares, the indoor environment remains a significantly unexplored area. Nevertheless, lately there have been increased interest on Location Based Services (LBS) and Indoor Positioning Systems (IPS). There are already several methods available for indoor localisation such as Wi-Fi Fingerprinting and Bluetooth Beacons, but none of them is fully functional yet. It remains a field that requires more and further research and investigation in order to reach a satisfactory and complete Indoor Localisation-Navigation method.

Therefore, this thesis main objective is to investigate and explore a new method for Indoor Localisation based on Isovists. The exploration and evaluation of Isovist-Fingerprinting approach for Indoor Localisation can extend the fields of LBS and Geomatics. The main research question is *"To what extent can isovist support Indoor Localisation"* and through this and a series of sub-questions to analyse the Isovist concept in relation with the Indoor Localisation. This is achieved by forming a proof of concept and a methodology that investigates how the Isovists would benefit a LBS.

To succeed that the methodology is divided in 4 main sections. The *Data Acquisition* for which the newly supported from smartphones Light Detection And Ranging (LiDAR) technology were used. The *Space Syntax and Isovist Analysis Measures*, where all the concepts related such as the Isovist Parameters were analysed in depth for better understanding of their effect. Then the *Matching and Localisation Algorithms*, where the possibilities and options on how to reach the localisation were investigated and analysed. And finally, the *Tests and Experiments* took place in order to evaluate all the prior stages of the methodology.

The main conclusion of this research is that a method for Indoor Localisation based on Isovists is feasible and can indeed support an LBS. The analysis and evaluation of all related components has be done and if putting all the parts in the right order they can be of high value for LBS applications. Since is a new method of Indoor Localisation, there is plenty of future work to be done which mainly focuses on how to connect it with existing techniques and integrate all together into a user application.

Acknowledgements

This section is dedicated for expressing my gratitude to all the people who directly or indirectly were part of this journey till the completion of the master and thesis specifically.
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Acronyms

BIM Building Information Modeling 58
CRS Coordinate Reference System 7
GNSS Global Navigation Satellite System 1
IPS Indoor Positioning Systems v
LBS Location Based Services v
LiDAR Light Detection And Ranging v
NFC Near Field Communication 5
PCA Principal Component Analysis 38

1. Introduction

This MSc thesis consists part of the Master's program Geomatics at the Faculty of Architecture and the Built Environment of TU Delft. It is the final phase of the program after one year of core courses and two quarters of electives. During this thesis, the knowledge acquired from the past quarters is put into practise to deep into new methods, improve existing and propose future ones. More specific the thesis is focusing on Indoor Localisation Methods.

1.1. Problem Statement

Nowadays, technological advances appear to do dramatically big steps forward. In all aspects of life, there are already or in progress, various technologies with one main goal, to make living in this planet better and better. One of these aspects of technology is anything related to localisation, positioning or navigation systems. However, due to the increasing popularity of smartphones, people are starting to rely on these tools more when they need to know their location or to navigate towards a specific destination point. This is making them eventually to lose their orientation skills or the ability to use traditional navigation techniques. [McKinlay, 2016]

The need for orientation and localisation has existed in the minds of people since ancient times. For a variety of reasons it was of great importance especially for sailors while sailing in open seas where the loss of orientation and location could lead to catastrophic consequences. So way before Global Navigation Satellite System (GNSS), sailors used their relative position to the stars to determine their position in the sea, as well as everyday people used their relative position to what it was visible to them to determine their location and position in space and eventually be able to guide themselves to the right destination. [Sobel, 1998]

While most of these concepts of localisation and navigation in outdoors environments are already pretty well derived from various researches, mechanisms and softwares, unfortunately, relying on these services for localisation and navigation in the indoor environment can be challenging due to the lack of reliable GNSS signals [Torres-Sospedra et al., 2019].As Roberts concludes, people spend most of their time indoors and as he states in the title this amount of time reaches the 90% of time. This obviously results in high importance field of research and as already mentioned, it consists a gap at the moment. Therefore, the need of indoor localisation and navigation arises in recent years and many studies have been conducted already.

When a human being enters a room or a building, it takes a few seconds to check around and understand the obstacles and the geometry of the room according to the visibility from the point he stands. Additionally, a human can easily understand the semantic details of the room such as the doors, windows, furniture etc, but when it comes to the geometric ones it becomes more complicated. People in general can express the approximate size and perimeter of a room but not accurately and not everyone have the same ability on understanding geometric details of a room. Therefore these are meaning, that a person can easily understand where exactly stands in a room and navigate towards the door or any other part of the room following the best path according to his preference. All these although appear to be a really hard issue for machines to tackle. There are already several works which mainly focus on the navigation part by finding for example the shortest or less risky to get lost paths to a destination [Wang and Zlatanova, 2013], [Vanclooster et al., 2013]. Furthermore, there are works as Grasso et al. [2017] where check the least complex paths according to the visibility, and this is where the focus it turns to.

Before the navigation it is important for everyone firstly to know where exactly or approximately they are. Therefore, in this thesis is explored the possibility to get the location based only on the visibility from a specific point in space. And this is actually the concept of Isovist as Benedikt defines "the set of all points visible from a specific vantage point in space and with respect to the environment" [Benedikt, 1979]. Additionally, the thesis will be focused to create a sufficient methodology to evaluate if it is possible or not to be localised by using Isovists. Several different methods and combinations of using the concepts of Isovist, Space Syntax and visibility graphs will be checked and evaluated.The further methodology will be explained later in the Chapter 3.4.

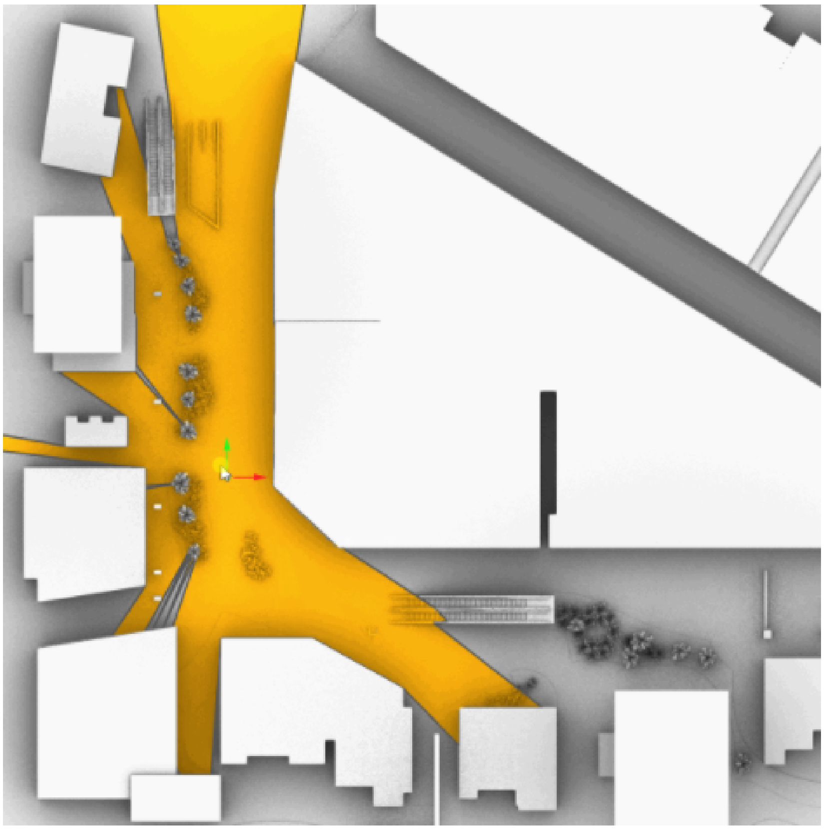


Figure 1.1.: A single Isovist produced in Grasshopper with DeCodingSpaces. Source: toolbox.decodingspaces.net

1.2. Objectives and Research Questions

The main objective of this MSc Thesis is to explore the relatively new field of Indoor Localisation by forming a proof of concept for a new method with the use of Isovist Fingerprinting. Specifically to provide an initial investigation on how the general Space Syntax theory as long as the Isovist and visibility analysis concepts can work together to deliver a new method and solution for localisation on indoor environments. Following, several more sub-objectives were formed during the process. These are for example how to use Isovist analysis measures in a right way to produce valid formats of data capable for localisation purposes. In fact, find a way to create a useful database of Isovist measures which with the right comparison of user's data could estimate a location in a indoor environment. Or to find and prove the best and most useful choice of Isovist parameters and distance algorithms for the final matching and estimation of the location.

Therefore, the general main research question of the thesis is:

To what extent can isovist support Indoor Localisation?

Of course next to the main question there are several other ones which immediately arise and form the secondary objectives:

- *How to create/formalize a database with the Space Syntax measures (Isovist analysis, visibility analysis/graph) of the sample area?*
- *How to get accurately the visibility of the user from the point he stands with real life data and get the correct location?*
- *Which and how many parameters should be used from Space Syntax measures (Isovist parameters) to determine the location?*
- *How the final comparison and matching of data will be take place in order to estimate the location of a user?*
- *Which distance/matching algorithm to perform according to the form of the data?*
- *Is it possible to make it usable as a user app?*

1.3. Research Scope

In order to better understand and establish the goals for the final result and what this will or won't include, a clarification of the research scope had to be structured. As it was mentioned previously, the main goal of this thesis topic is to examine and explore a new technique of localisation and more specific Indoor. This topic consists part and the initial step of a broader topic, the LBS. LBS as it's name reveals, it is a wide field of services based on the information retrieved from the location and furthermore the information and capabilities which come from that, such as navigation, management of space, transportation and other [Junglas and Watson, 2008].

Therefore the present research thesis is divided into two basic phases where in the first the part is the part of the creation of the database whereas the other one is for the artificial user's side at this initial point of this research topic. This study focuses on analysing and developing a proof of concept for indoor localisation based on Isovist and Visibility analysis as long as checking it's capabilities for other future purposes such as routing and navigation.

As mentioned, the goals and the limits of the research must be clarified. Therefore, first step of this research that is going to contain all the necessary Space Syntax measures, meaning the 2D Isovist and Visibility analysis of the sample area. Additionally, several artificial tests as well tests with real life data were made regarding the Isovist analysis measures in order to reach satisfactory conclusions on what extent indeed the 2D Isovists can help on indoor localisation. In this research although, there will be no 3D Isovists calculations nor use of them in any form just (maybe a future recommendation). Also the research is not gonna create a solid and fully integrated final product such as web or mobile application, although an analytic pipeline of the whole process of reaching the location from Isovists will be given as long as proposals for future real time application. The focus of this research will also be on how the connection of user's produced data will be compared with the constructed database in order to reach it's location. Through that process several softwares will be used for the data acquisition and data manipulation and process as well as different algorithms for the comparison and matching of data for the final localisation results.

1.4. Scientific Relevance

The topic of this research could be divided into two main scientific fields as the title even points. One is the localisation and the other is the Isovists or more generic the Space Syntax theory. Regarding the field of localisation and positioning of outdoors environments are already pretty well derived from various researches, mechanisms and softwares / Applications with even high precision systems such as GNSS. Even though for outdoors this field have been thrived the past even centuries the indoor environments relatively recently started to attract the interest of scientific community. Many researchers have been trying and developed several techniques for indoor localisation and navigation like Wi-Fi Fingerprinting, Bluetooth beacons or Near Field Communication (NFC). The reason why the indoor lacks of solid solutions instead of outdoors is because the indoor environment have it's own extra challenges with the biggest one that anything related to Satellites that is used for outdoors cannot be used indoors due to insufficient use of signal.
The second main field of this research is the Isovists, which consists part of the wider field of Space Syntax theory. Space Syntax is a theory firstly developed by Hillier et al. [1976] which examines and analyses the spatial configurations as long the social impact of space in cities and the interaction of it with the humans. It is a theory that have been used in various fields but mainly in Architecture and Urban planning. This theory is broken down in more concepts, one of them is Isovist "father" of it is Benedikt and which is actually the space visible from a

specific point in space.
Although the pre-mention fields and researches are different and unique, in combination, they can lead to a promising result even though there have been extremely limited studies with similar ideas of using Isovists for the indoor localisation purposes.

applications that use triangulation, trilateration of users based on Bluetooth, Wi-Fi, or other sensor beacon approaches (comparable to the GPS) but on a more local level, Chowaw- Liebman et al. [2010]), the fingerprinting of the (static) indoor environment based on signal strengths of (Wi-Fi) beacons (Xiao et al. [2011] and Chan and Sohn [2012]), or cameras and image (QR-codes) recognition to localise users within the indoor environment (Vo and De [2016]).

1.5. Thesis Overview - Outline

The structure of this thesis and the outline is organised as followed:

- In Chapter 2 the theoretical background is provided in order to introduce in short all the concepts necessary to follow this research topic. As well several related works on all the different topics and fields that are combined during this research.
- Chapter 3 is giving a detailed explanation of the methodology which were followed, meaning all the planning the and the pipelines and experiments necessary to answer the research questions and eventually reach a satisfactory result.
- Then Chapter 4 dives into specific details of the technical implementation of all parts and phases of the research as well how and why the experiments were conducted
- Following Chapter 5 presents all the results and their analysis which lead to valuable answers.
- The final Chapter 6 is dedicated to maybe the most important part of the research. The conclusions and the final evaluation and discussion of the results. Additionally, refers to all the problems and limitations that were faced during the process as well the questions answered along with any future recommendations and work.

2. Theoretical background and related work

This Chapter is divided as the title reveals into two main sections. Firstly, the Theoretical Background section provides all the relevant theoretical knowledge and prepare the reader for the following topics and therefore to be able to follow the more detailed analysis and discussion on the thesis document. Secondly, the Related work section aims to present the already available research work done in all the aforementioned fields of localisation, Isovist and specifically indoor localisation as long as in other topics more detailed under the umbrella of the main ones.

2.1. Theoretical Background

Therefore this section is organised as follow. Starts with explaining the most basic concepts of Localisation and Positioning in order to define and distinguish the differences between the two. Continues with the Space Syntax theory basics and afterwards with the Isovist definitions. Finally the section is closing with a introduction to LiDAR technology and 3D point-cloud basic knowledge.

2.1.1. Localisation vs Positioning

The first and probably most important concept of this research since it is actually at the same time the final goal to achieve, is localisation. One of the most basic separation and knowledge necessary for the rest of the thesis is Localisation versus Positioning or Location versus Position. Therefore, Localisation in general, is the the concept which focus is to give the location of a person or any agent in the space or a map. One first key here is distinguish the difference of it with the term positioning. Localisation is trying to determine where is someone or something on a map in a more generic idea (e.g. city, street, or room in a building), where positioning is trying to determine as much accurately as it can the exact position with coordinates in a Coordinate Reference System (CRS) of someone or something in space [Sithole and Zlatanova, 2016]. These concepts were taught and derived as well and quite accurately in the Positioning and Location Awareness (GEO1003) course of MSc Geomatics in TU Delft [Verbree, 2021].

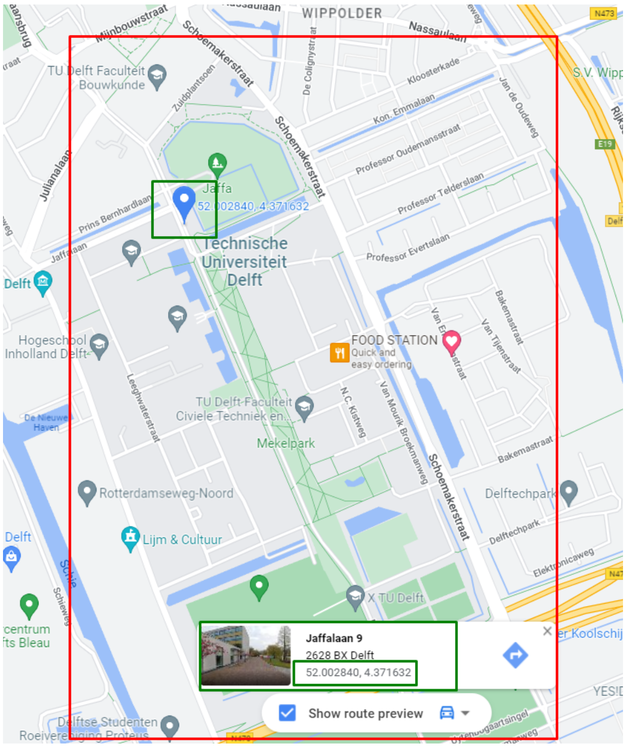


Figure 2.1.: Example of diference between Location and Positions.
Red box = Location : TU Delft Campus
Green Box = Position : Exact Coordinates
Source: https://www.google.com/maps

2.1.2. Space Syntax

The second core concept of the thesis is Isovist. But Isovist consists an element of the general Space Syntax theory. Therefore it is important to have an introduction to this great theory. Space Syntax which introduced by Bill Hillier, Julienne Hanson and colleagues at The Bartlett, University College London at around 1979 consist a really wide concept which applies in multiple topics and applications. In brief, Space syntax theory is trying to give insights and explain the relation between society and space. One of it's main uses is on architectural and urban space fields. A great book recently published, which introducing the whole Space Syntax theory has been written by Akkelies van Nes [2021] and it was a valuable help through this research in order to understand and get a pretty good idea of this theory.

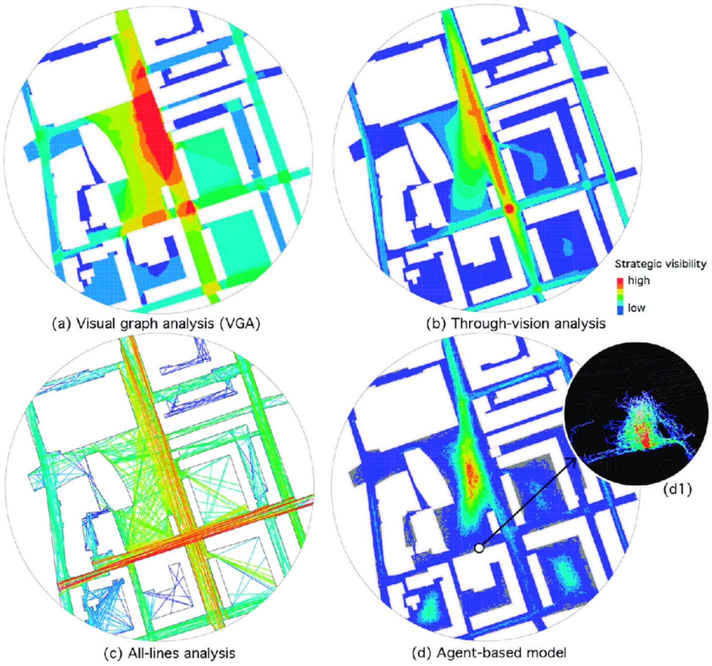


Figure 2.2.: Analysis of De Doelen and the Schouwburgplein in Rotterdam using (a) a visual graph analysis (VGA), (b) a through-vision analysis, (c) an all-lines analysis, (d) an agent-based model (ABM), and (d1) an agent-based model where the agents are released from a specific location. Yamu et al. [2021]

2.1.3. Isovist

According to Akkelies van Nes the general idea is that spaces can be split into different parts, so the analysis of choices can be made and then be able to represent these information into graphs and maps. Next to Space Syntax theory there are 3 more concepts which are the Isovist, Axial space and convex space. Benedikt who is commonly known as the father of Isovist, defines isovists as "the set of all points visible from a specific vantage point in space and with respect to the environment" [Benedikt, 1979]. Isovists can be represented in many ways, such us visibility graphs or polyhedral volumes for 3D and polygons for 2D [Dalton et al., 2015a],[Díaz Vilariño et al., 2018]. Finally, isovists are connected to 2,5D visibility analysis regarding orientation and path finding in indoors and outdoors [Dalton et al., 2015b].

When it comes to Isovists, it is important to present also the main parameters which are derived from the Isovist calculation and analysis as they are explained .

- **Area** : Expresses the area of all space visible from a vantage point in space.
- **Perimeter** : Expresses the length of the edge of all space visible from a location. In isovist terminology, it represents the geometric isovist perimeter at said location Benedikt [1979]
- **Compactness** : Expresses the shape property (relative to a circle) of all space visible from a location. In an isovist field, compactness identifies the regions of plan in which an observer's spatial experience is contiguously consistent. Meanining it identifies opportunities for the emergence of new surfaces in the visual field as a result of movement. Peponis et al. [1997]
- **Occlusivity** : Expresses the proportion of edges of an isovist that are not physically defined. It represents how previously unseen space may be revealed during movement Benedikt [1979]. Occlusivity fields reveal the intense visual change while a user passes between spaces. That means that if a user pass by a door the occlusivity is high but when the user is inside a convex room has zero occlusivity.
- **Average Radial** : Expresses the mean view length of all space visible from a location.
- **Drift** : Expresses the distance from a subject point to the centre of gravity of its isovist Dalton and Dalton [2001]. In an isovist field, drift identifies the inherent 'flow' within a series of spaces, or the 'pull' or 'push' one might feel from the volume of space itself `https://isovists.org/`. High Drift identifies regions from which space can be surveyed with a minimum of head turning.
- **Variance** : Expresses the mean of the square of deviation between all radial lengths and average radial length of an isovist Benedikt [1979].
- **Skewness** : Expresses the mean of the cube of deviation between all radial lengths and average radial length of an isovist Benedikt [1979].

In the following Figure 2.3 there is a visual representation of some typical Isovist parameters for further understanding of the concept.

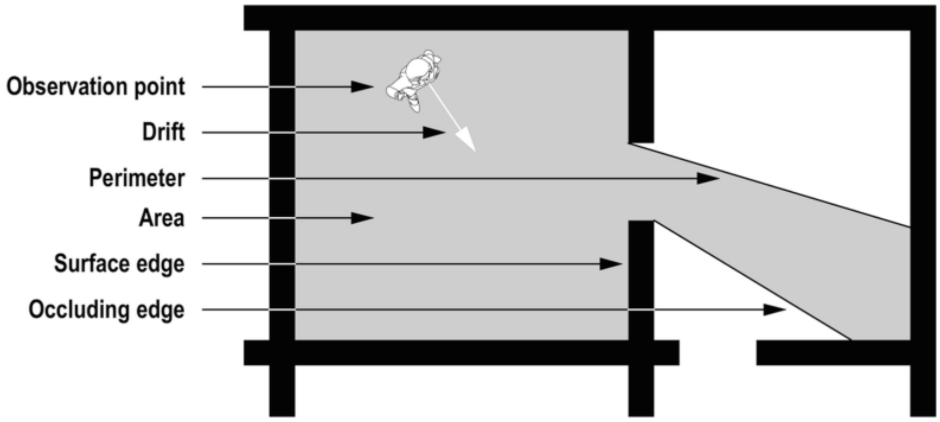


Figure 2.3.: Explanation with visual representation of some typical Isovist parameters. Source: Ostwald and Dawes [2018]

2.1.4. LiDAR point-clouds

LiDAR is one of the methods used for scanning the world in 3D. LiDAR uses laser beams in order to create a 3D representation of the environment [Mehendale and Neoge, 2020]. It is a technology used in many industries such as automotive, robotics, industrial, mapping etc. As the name reveals LiDAR produces its own light and that makes it easy to use in any occasion and lighting conditions. Lately Apple for first time introduced and adopt this technology in their smartphones, make it even more accessible to not only professionals but also everyday people. The data produced by LiDAR is a collection of numerous 3D points in space which all together shape a real object [Cao, 2021].

2.2. Related work

In order to reach a satisfactory result and succeed in a research topic it actually needs to complete a study of related research topics. Topics of various previous related work and studies which will help in understanding and forming this thesis. Therefore, this chapter is divided in few categories which consist parts/steps of the main research objective. In detail the subsection are as follows. Begins with mentioning and exploring works related to Indoor Localisation. Keeps going with referring to researches and works done related to LiDAR and 3D Isovists. Since related works about Space syntax have been mentioned previously in Section 2.1.

2.2.1. (Indoor) Localisation

Firstly, a real important step is to understand the first core concept of this research and its original goal. Which is not other from "Localisation" and more specifically "Indoor Localisation". As already mentioned in the introduction, it is a field of research which lacks of viable and easy to use solutions as it happens outdoors.

The recent years there have been several studies about methods for indoor localisation and positioning systems. Methods such as Wi-Fi fingerprinting and monitoring, Ultra-Wide band Positioning, Visible Light Communications and many others see [Huthaifa et al., 2021]. Another interesting approach though conducted by [Andreo et al., 2021], who created an indoor positioning system by using micro-controllers (arduino) with Wi-Fi sensors along with Wi-Fi fingerprinting and ArcGis Indoors in order to form a real-time application with location awareness and privacy preserving of its users.

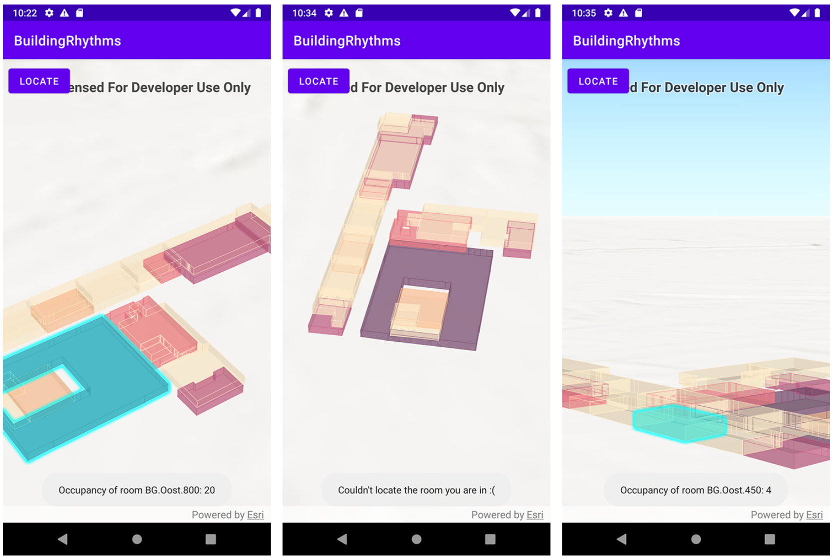


Figure 2.4.: The main screen of the Building Rhythms app, with the Oost Serre Room of Bouwkunde selected. Source: Andreo et al. [2021]

Most of the methods for indoor positioning systems, they use actually the technique of *fingerprinting*.According to Guan and Harle [2017], the typical fingerprinting systems consists of two stages. The first one, is the surveying stage, where the surveyor walks around the building and collects enough fingerprints in order to create a radio map which is actually a database containing all the necessary information from the indoor environment of the building connected with their location. And the second stage, the online positioning stage, where the building user captures a new fingerprint which after the comparison to the radio map it gives the estimate location. There is is where it stands the title to this thesis (Isovist-Fingerprinting), since it is going to be checked the possibility of this new way of fingerprinting.

What can easily summed up, is that the majority of the methods for indoor localisation need to use sensors and many hardware devices and softwares in order to determine the location. Even though in this thesis the goal is to investigate a new method of Indoor Localisation, all the preexisting methods provide great knowledge and understanding of the main objective which is to determine accurately and easily the location of any kind of user.

2.2.2. LiDAR scans to Isovist and 3D Visibility analysis

Literature and studies where there is direct conversion of point clouds from LiDAR scans into isovists is really rare and only research where they first transform the 3D data to at least 2,5D. Although, the idea of using LiDAR to produce isovist in order to quantify a location's spatial configuration [Schmid and von Stülpnagel, 2018]. Additionally, Díaz Vilariño et al. [2018] worked and created a really interesting methodology with the goal to create 3D Isovists directly from point cloud by following a voxel-based structure. Finally, Laure et al. [2021] conducted a research in order to create an adaptive mobile indoor route guidance system. Work which appears to have the most similarities since it uses most of the core concepts of the present thesis.

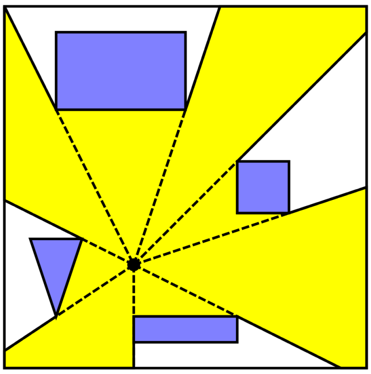


Figure 2.5.: An isovist with the visibility polygon and the obstacles around.

3. Methodology/Experimental design and development

This Chapter gives an overview of the chosen methodology as well as describes all the ideas and proposed pipeline of work in order to answer the research questions of the topic and create a complete framework for localisation by using Isovists. To present that efficiently the chapter is divided into 4 sections. The initial Data acquisition, the Space Syntax and Isovist measures, the Algorithms needed to implement as well the tests in order to prove or not the concept.

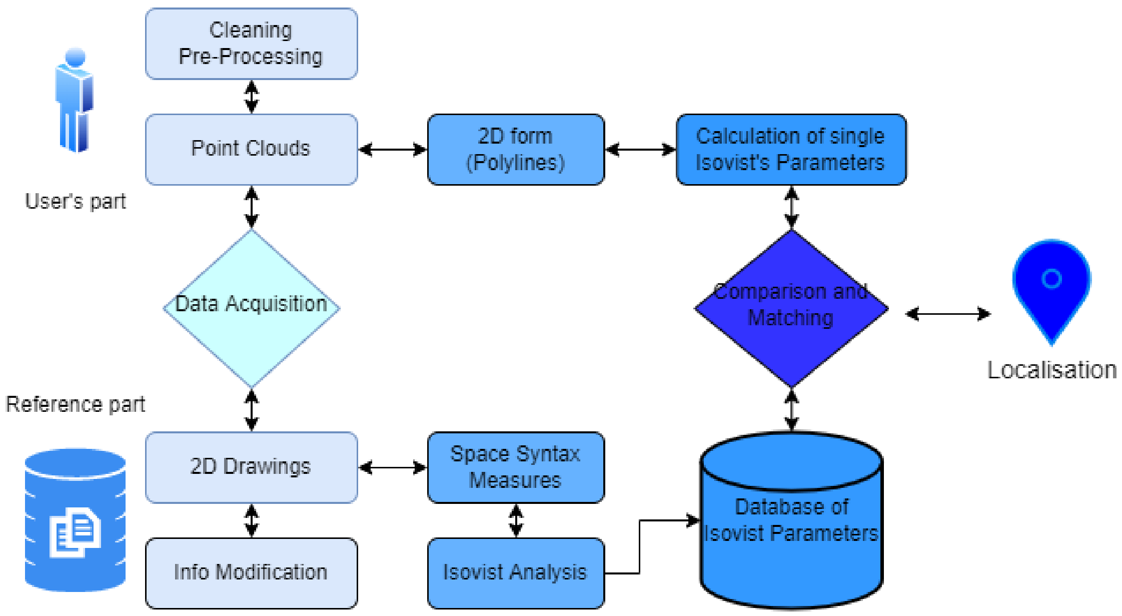
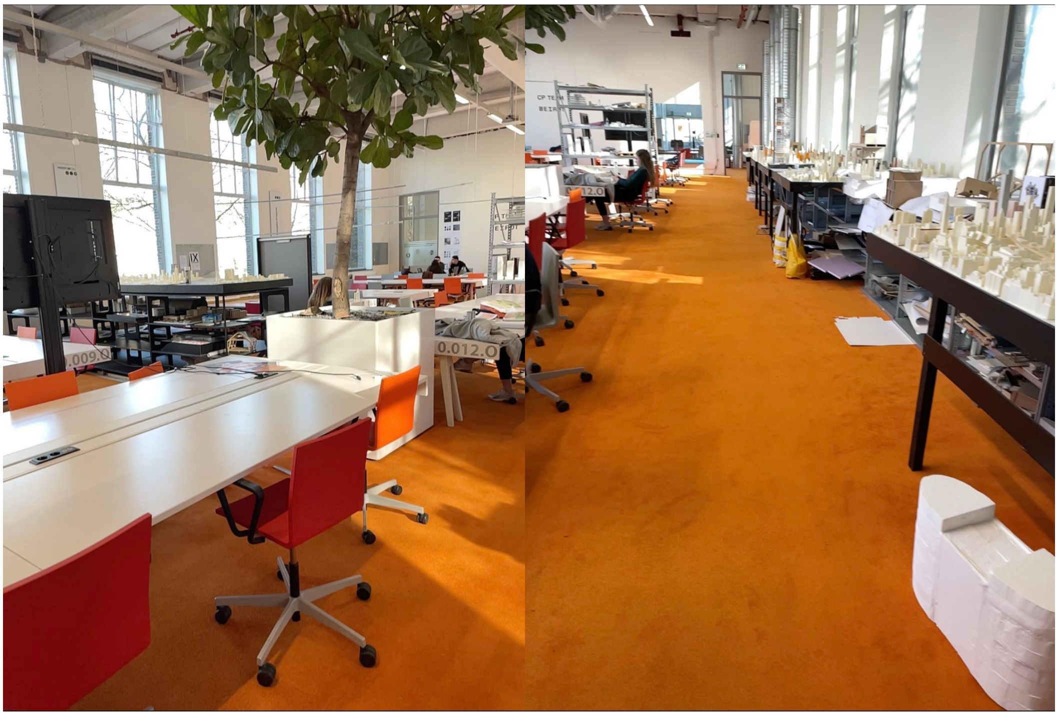


Figure 3.1.: Thesis Methodology in flowchart

When started to form and plan this research topic a good plan is to visualise in mind the whole process and how would that work in reality and in practice. To do that successfully, needs a really good break down of the topic in all possible smaller tasks and form a separate pipeline for each of them which combined at

the end can provide an initial proof of concept on Indoor Localisation with Isovists.
The main idea of the topic is to prove that a possible user who walks around in an indoor environment of a complex building it is possible to gets find its location in the building by using an Isovist fingerprinting method. A big challenge of the project was how to connect the data taken by the user/person who wants to know his location with the already produced data (Isovist fingerprints) into a radio map in order to do the matching and determine his location. Something else needs to be noted is that in order to form the wanted proof of concept the first thing that need to be decided is the indoor environment which will act as the sample and test area. For this project the chosen building is the the Faculty of Architecture of TU Delft, a unique, beautiful but quite complex building with many big and small rooms, stairs, hallways and commonly accepted as an easy to get lost building. With these in mind, the whole idea and methodology followed will be analysed in the following sections.



(a) View from closer to the center of room (b) View from the door/entrance of room

Figure 3.2.: View of one of the rooms of Faculty of Architecture that was captured

3.1. Data Acquisition

In every project, the very first action is to collect all the necessary data for it's completion. On this topic and after the thorough planning of it, the data needed consists of all the 2D floorplans of the decided sample area and also point-clouds for each room which will take part in the tests. The plan was that the 2D floorplans were going to be used for the calculation and storage of all the isovist parameters which will act as the database while the point-clouds consists the data produced from a theoretical user who searches for the right location.

The Isovist analysis will be done all in 2D therefore 2D data are going to be the input, and that is the reason of gathering the official 2D floorplans of the Bouwkunde (Faculty of Architecture TU Delft) which were actually already collected from the Geomatics Synthesis project [Andreo et al., 2021]. Regarding the user's side, the choice were to use point-clouds since they can provide great geometrical and spatial information. The main reason that point-clouds were chosen is that are easier to capture in 3D the environment and therefore derive more valuable information in contrast with other sensing techniques like Image Acquisition. With images is again possible to construct a 3D representation of the environment, but it needs tenths or even hundreds of images form different angles and heights, something that a simple user would definitely not be able to capture in a satisfactory level. The practical aspect of the project is the most important, since it has to be able to become user friendly. Nowadays, producing point-clouds have become quite easy since the smartphone industry advances rapidly and already there are mobiles with LiDAR technology (mention the chapter that describes it prior). To be noted, at the period of time that the research took place in the industry only the series 12 and 13 of iPhone Apple were supporting LiDAR technology, although it is highly believed that in short period of time more and more mobile brands will have products with this technology.

Figure 3.3.: iPhone 12 Pro LiDAR scan Sourse: Polycam Channel in Youtube

For the project's purpose and in order to have enough data sets to form the proof of concept and answer the research question, 6 rooms were chosen strategically in order to cover many different situations for the testing later on. The rooms must have door, windows, furniture and be separated with any other space of the building. The door is important since it will be the core element of the most measurements and tests later on in the implementation of the methodology, while the windows even though would not be necessary in most buildings, in this project's sample area the windows appear to create an extra gap or depth in the walls which makes the rooms even more unique than the rest in the building. At last, the furniture are the most important elements for this technique since are the ones which give the highest level of uniqueness between the rooms.

In order to capture the user's point clouds an iPhone 12 Pro were used and specifically the PIX4Dcatch app which is part of a broader applications from PIX4D, a Swiss company in the field of 3D Digital mapping, photogrammetry and computer vision. The iPhone 12 Pro even though is not a professional instrument for 3D scanning, appears to have great accuracy on indoor environments, since in a test case conducted by Díaz Vilariño et al. the Root mean square error of the apple device was 0.53 while a Terrestrial Laser Scanner had in the same case 0.28. During the planning of data acquisition, it was decided to capture point clouds from the entrance of its room and in 180 degrees view with direction on the interior of the rooms like it is explained in the following Figure 3.4.

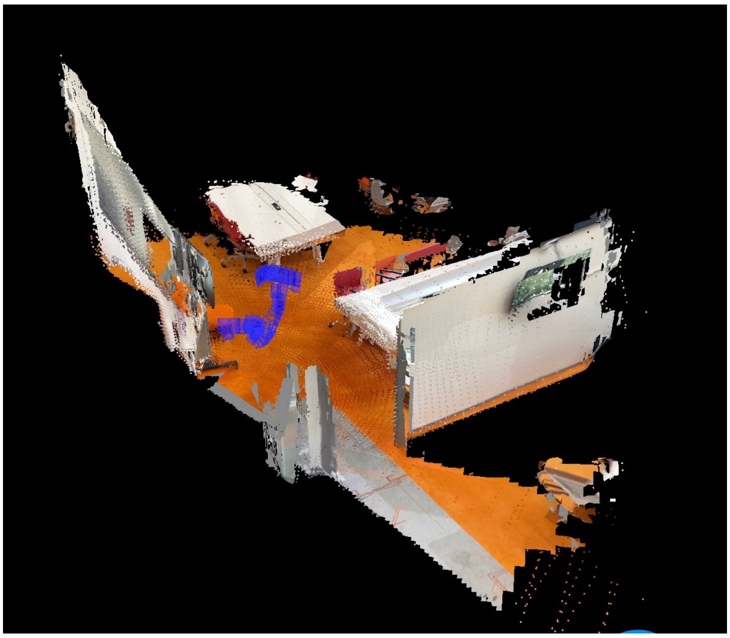


Figure 3.4.: Example of acquired point-cloud from room BG OOST 410 of BK, with the 180 degrees view and direction the interior of the room

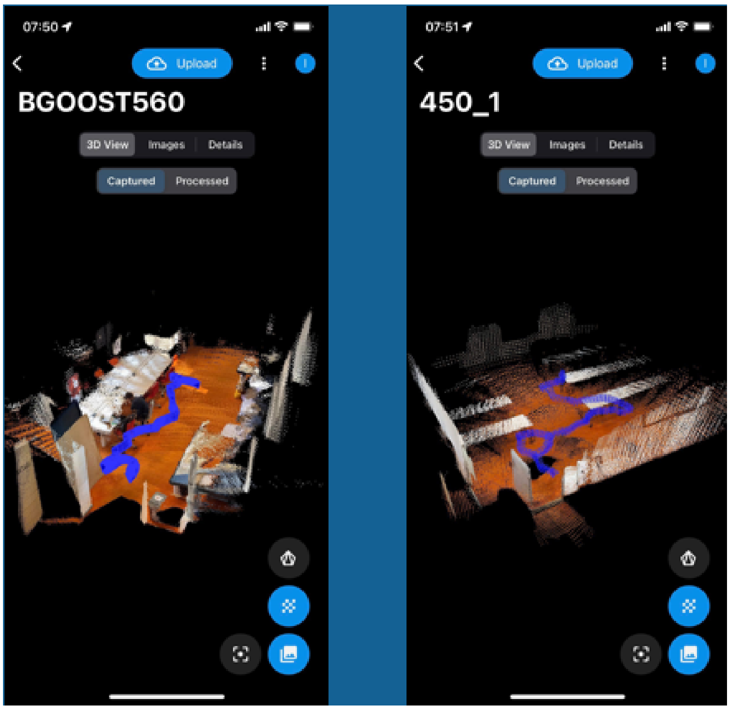


Figure 3.5.: Point Clouds of rooms BG OOST 560 and 450 acquired with the PIX4DCatch app using the iPhone 12 Pro

That was decided, so that it can be closer to reality, since any user will most likely want to know its location before enters the room, therefore the captures are from the entrance of each room. Additionally, from that position the calculation of isovist parameters is "easier" since also will be in an angle of 180 degrees and not 200 or 360 degrees for example like it is shown bellow. This difference of course can save time of process which is valuable when we talk for practical and real time applications.

3.1.1. Data preparation and pre-process

Next part of the whole process is of course the preparation as well the pre-process and process of the acquired data in order to be able to be used as an input for the next phase of Space Syntax - Isovist parameters calculation. For that purpose the manipulation of the data is split in two parts, one for the 2D floorplans of the sample area and another for the point clouds of the user's side.

The idea was to "clean" the 2D drawings from the hundreds of different layers they were consist of and make them more simple for next phase's calculations. Simple, meaning create clear polylines for all the rooms, spaces and objects (furniture) that are needed for this project. In order to proceed to this preparation of the floorplans the AutoCad software of AutoDesk were used while more details about this procedure will be given in the next Chapter 4. The second part of this process were more complicated since it's user's side and so ideally should be done automatically. Since the whole Isovist parameters calculations are done in 2D the user's side also should transformed in 2D from the initial 3D point clouds. For the scope of this research the transformation is not gonna happen automatically in first phase, although several steps and research have been made to prove that is possible and also provide how that could be done in future work. Therefore, the pipeline followed at this moment was partially manually with the use of Python, CloudCompare and AutoCad.

3.2. Space Syntax and Isovist Analysis Measures

Continuing, next step and really important one is calculating all necessary Space Syntax measures regarding the sample area. That means specifically calculating the Isovist and making the Isovist analysis of the area. These calculations were done by using a commercial software for which a free license is given by TU Delft, and it is called Rhinoceros 7. This software is mainly used by Architects,

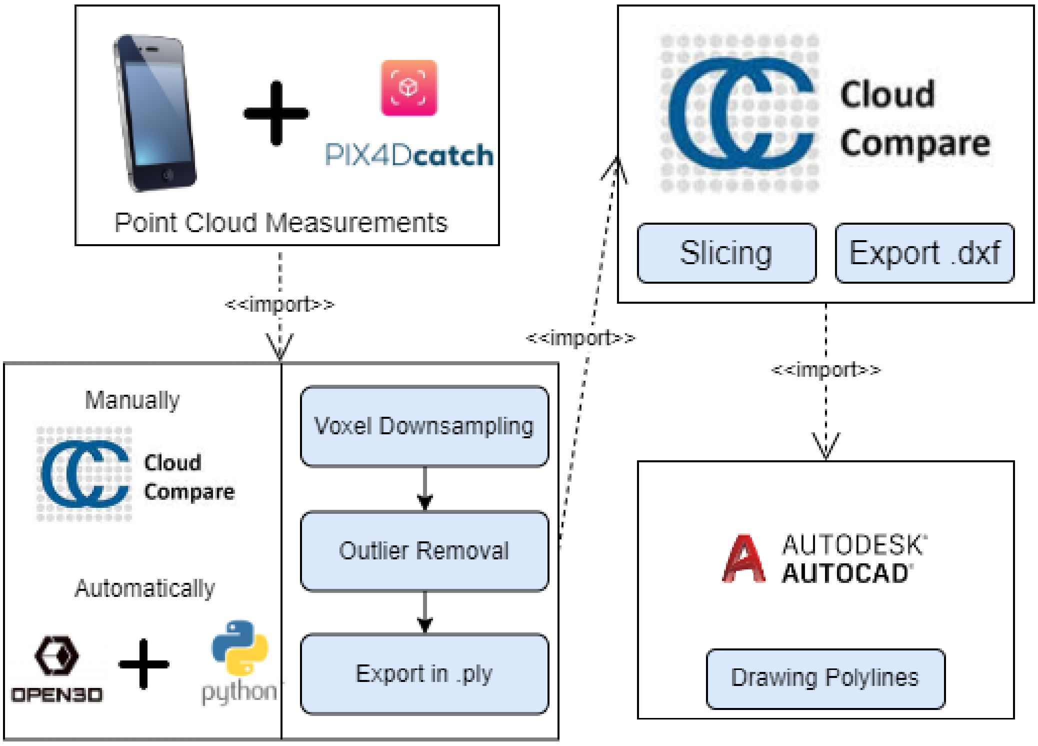


Figure 3.6.: Methodology for transforming 3D point-clouds to 2D form data (polylines)

Designers and Urban planners, although on this project is going to be used in different way. Rhino contains also several plugins, where one of them that is going to be used is the "Grasshopper" for which there is a special toolbox called DeCodingSpaces toolbox (`https://toolbox.decodingspaces.net/`) that provides a collection of analytical components for architecture and urban planning as well as huge capabilities for calculating isovists, visibility analysis graphs and many other parameters of isovist field Koenig et al. [2019]. In that way, it is possible to explore a great variety of Isovist parameters in order to experiment and answer the research question more successfully. The Grasshopper consists actually a virtual programming environment attached to Rhino so anything that is programmed in Grasshopper it can be visualised in Rhino. Therefore some experimental localisation were made through the DeCodingSpcaces toolbox in order to explore and understand better how the isovist parameters playing role in the matching/localisation process which is following in the next section.

Finally, an important assumption that even made previously, in order for the main idea to work in first place. All the calculations are going to happen approximately from the door of each room and space of the building. Therefore, the user will be advised to go in the entrance of the room and approximately 1-2 meters ahead in order to get the best estimation of his location.

3.3. Algorithms

This section of the methodology contains the ideas and algorithms were followed for the completion of the project. The algorithm part is divided into three sections and written mainly in Grasshopper in order to conduct more tests along with visualisations of the isovists as well as in Python.

The first one, is as mentioned some initial steps for transforming automatically the point-clouds from LiDAR scans into 2D format. This part of the project even though is done manually as was explained in 3.1.1, it was also attempted to be automated as much as possible. The idea behind that automation, is to manipulate the initial point-clouds with voxel down-sampling of the cloud to reduce the size of it and then to conduct a statistical outlier removal of the ”noise”. Afterwards, to create a virtual ”slide” in a particular height from the point cloud data and draw the borders with 3D vectors in order to eventually transform the data to 2D and get the final 2D data with lines and objects necessary for the isovist calculations. More details about the implementation in the next chapter.

The second section has to do with the algorithm created in Grasshopper and DeCodingSpaces regarding not only the calculations for Isovists Parameters and Analysis but also for the first try of getting virtual and artificial localisation of a vantage point (user) in the space. The idea was to find a method and workflow in order to explore the possibilities of Isovist Parameters and take advantage of the tremendous capabilities of Rhino and Grasshopper. For that reason the algorithm which was created is doing in short:

- The connection and loading of the 2D data from the floorplans and also from the 2D parts coming from the user's side point-clouds.
- Calculation of Isovists. For the database as well as single isovists for the user's side
- Matching the one single Isovist from the user with the database of Isovists and providing also visualisation of an artificial localisation in the environment of Rhino
- Export of all Isovists related data (User's Isovist values and database's Isovist values) into a .csv file

The final algorithm is actually doing the matching that happened in the software, although this time using purely Python. That is happening of course for a really important reason. The main idea for that is that in order to answer the research questions lots of research had to be done in order to find out what works and what not or in what extend something is better than the other. Therefore, on this phase the focus was to try different normalisation of the 17 Isovist parameters as well as distance algorithms for the matching.

3.4. Tests and Experiments Planning

This part of the methodology might consists the most important one since is the one that will eventually provide significantly important outputs and results that their analysis will eventually bring up the conclusions regarding the research questions of the thesis.

The tests and experiments made are multiple and their goals are diverse but the main purpose remains the same, Indoor Localisation. The plan is really specific and with the research questions in mind became even more.

The tests are divided into 3 main parts. First one is to examine and evaluate the Isovist Parameters that are calculated from the DeCodingSpaces Toolbox of Grasshopper. The second one has to do with the evaluation of Distance Algorithms for the matching process. And the final one is the localisation itself. In order to conduct these tests the environment of Grasshopper is used along with the use of Python Scripts.

4. Implementation and Experiments

This Chapter is the natural continue of the methodology. After the the ideas and methods to follow were stated and planned then it is time for action and implemented these. In the following sections is going to be presented step by step all the tasks and procedures done in order to reach the wanted results which will be shown in the next Chapter 5. In short on this Chapter will be explained in line the data acquisition step by step in practice especially for the point clouds, the detailed manipulation of all the data used for the project as well all the necessary algorithms for the calculations of Isovists and the matching for the localisation. Last but not least, all the experiments will be shown and explained in detail.

4.1. Data Acquisition in reality

Many people consider the data acquisition not so important part and many times the data is just there ready for analysis since someone else did it. Although, if the first step has been made correctly, half of the job is done, so it has to be done as good as possible this first step. As it was mentioned before, the data acquisition is split into 2 parts. The 2D floorplans is the one but the main part consists of capturing the rooms in 3D using LiDAR scans to create the point-clouds. Before explaining the whole process of scanning, the tools were used should be mentioned and introduced. As was previously mentioned this part is actually obtained by the author itself although is going to act as the "user" for this project.

For this thesis's purpose, the "tool" that was used is an Apple iPhone 12 Pro. The choice of this smartphone depends on two important factors. The first one has to do with the idea that the possible future indoor localisation application has to be in the hands of the user and easy to use in practical manners. That means that it should be ideally something that could be used just with an already owned electronic device such as a smartphone that is lately necessary for our even daily life. Thankfully, there are plenty already existed applications which can capture in 3D the surroundings for many models of smartphones of several brands. Applications such as "Polycam", "SiteScape", "EveryPoint" and "PIX4Dcatch". "Polycam" and "Pix4Dcatch" can be used either with Android or IOS smartphones

while ”Sitescape” and ”EveryPoint” use only LiDAR technology or hybrid with photogrammetry and therefore only few Apple iPhone devices are compatible with them. More details regrading these apps are available in the Table 4.1 As it was mentioned in Chapter 2 at the period of time that this project took place only the series 12 and 13 of Apple iPhone were supporting the LiDAR technology.
The second factor of using this particular mobile is that can support the LiDAR technology which can improve dramatically the results of 3D capture of space. As it was mentioned in Chapter 2 and section 2.1.4 LiDAR is not a new technology in general, although it is newly introduced into smartphones and alongside with photogrammetric techniques can reach incredibly accurate reconstructions of real environment.

	Polycam	SiteScape	EveryPoint	PIX4Dcatch
LiDAR	✓	✓	✓	✓
Photogrammetry	✓	X	✓	✓
LiDAR + Photogrammetry	X	X	✓	✓
Free	✓	✓	✓	X
Free Export .ply	X	✓	✓	X
Export with Free Trial	X	✓	X	✓
Android	✓	X	X	✓
iOS	✓	✓	✓	✓
In App Advanced settings for Scanning	X	X	X	✓
Visual Detection for Good Scanning	X	X	✓	✓

Table 4.1.: Characteristics comparison of 3D Scanning Mobile Apps

Besides the choice of the device, the next important decision to be made for the data acquisition was the application which will carry on the measurements. As mentioned there several of them with their disadvantages and advantages of course. In order to decide the best one for this topic few test measurements have been made and the choice was clear. PIX4Dcatch is the best option since it uses both Photogrammetry and LiDAR technology to reconstruct in 3D the surroundings. The big advantage of LiDAR technology here is the depth information of the surrounding during the image acquisition. The LiDAR points will compensate for the lack of 3D points over reflective and low texture surfaces. Another benefit of using LiDAR is real-time feedback generated by the LiDAR sensor which provides a visual on how good and if the area of interest is captured sufficiently.

Additionally, in the pre-processing the LiDAR data can be used to estimate more accurately the scale of the reconstruction as well to fill low texture areas that photogrammetry alone is not able to reconstruct `https://support.pix4d.com/hc/en-us/articles/360043331092-FAQ-PIX4Dcatch`. Finally, in comparison with other apps like ”SiteScape” which uses only LiDAR technology, the PIX4Dcatch as already mentioned it gives the possibility to use both technologies and also provides the user with many other side applications under the umbrella of PIX4D software.

Moving on to the last part of Data acquisition, is the field work. Before the real field measurements it was necessary to plan and scout the environment in order to cover the best areas and enough information in order to conduct later on sufficient tests and experiments. For that purpose, 5 rooms of the Ground East floor of the sample area were chosen with different furniture and obstacles, direction and even more than one entrance option.

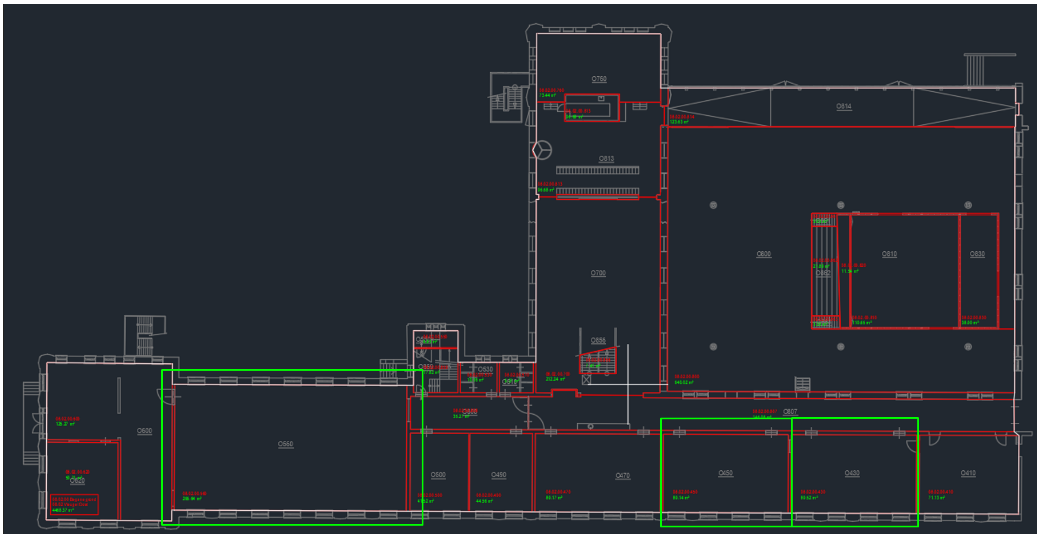


Figure 4.1.: Floorplan of Sample area. Inside the Green Boxes 3 of the tested rooms with their difference and similarities on size, number of entrances, windows

Finally, the measurements took place early morning so some rooms will have no people and also later one with some students to see also how the moving or not stable obstacles can create issues on the process of data and eventually on Localisation.

4.2. Data processing and manipulation

Following the acquisition, the data process and manipulation is next and this is what this section is talking about. This section has to do with all the procedure that were followed in order to process the acquired and not data in such way so they can be used properly and analysed later on.

First step was to evaluate and modify the 2D floorplans of the Faculty of Architecture accordingly so to be ready later on to use them as input into Rhino Grasshopper for the Isovist calculations. The original floorplans which were acquired from the TU Delft Real Estate as part of the Synthesis project of Geomatics 2021 Andreo et al. [2021] were not totally up to date and also they were quite complex. Since these floorplans were created few years ago, some rooms and spaces were different as in reality and therefore had to be changed before the use of them later. Additionally, the structure of the CAD files was really complex with tenths of layers and lines and polylines that were forgotten or with no particular information. So, the decision was to actually draw it all from scratch by using the original files. This decision were made since many layers were locked and therefore it was impossible to modify the files or even to copy some parts of it in another file because even with that many unwanted information were moving too. Therefore, a complete new file were created and only the necessary information were drawn, such as all the walls and doors of each rooms as well some artificial extra objects like tables. All these were drawn into one layer so the Isovist calculations later to be easier.
Second step of the process was the initial point cloud processing and transformation into 2D polylines. Regarding this procedure more details will be presented in the following Subsection 4.3.1. What can be mentioned here is that eventually the manipulation of the point clouds took place manually by using mainly the CloudCompare for the slicing and cleaning of the initial point-cloud and export in .dxf format file so it can be input on AutoCad for the drawing of the obstacles visible from the point-cloud.
The manual procedure started after exporting all the captured point-clouds from PIX4Dcatch on .ply data format. And then it is imported into CloudCompare as it is shown in the following image.

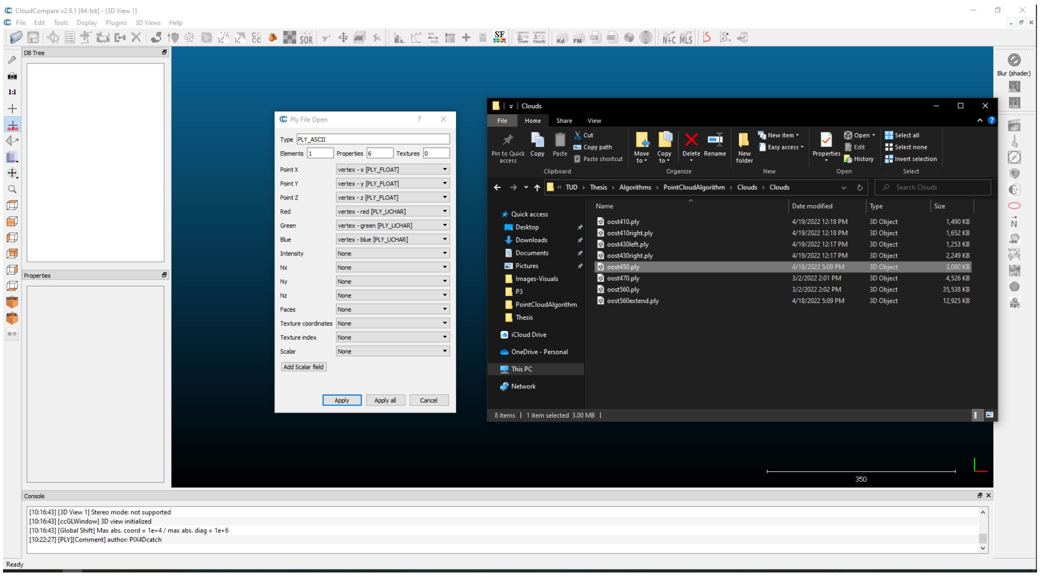


Figure 4.2.: Example of Importing a .ply file into CloudCompare

First important step on the process is to subsample the original point-cloud in order to reduce the size and complexity of the information given. For that purpose the command subsample of CloudCompare were used with the following sampling parameters. The method chosen was ”Space”, meaning to subsample the points regarding the minimun distance they have between them. This minimun distance was decided for 0.0388m or 3.88cm as it is shown also in the figure below.

Next step is the ”cleaning” of the point-cloud by discarding the outliers and the ”noise” of the point-cloud, meaning the unnecessary points that give no valuable information for the purpose of the project. As it is visible in the following figure, for this step the ”Statistical Outlier Removal” was used. This action requires two parameters, the number of points to use for the mean distance estimation and the Standard deviation multiplier threshold (nSigma). For this reason the first parameter were chosen to 6 points and the second as 1.00. Since the goal is to clean the data in the best way, the nSigma had to be small and therefore the standard deviation was low, so that the points will be clustered around the mean distance of the 6 points and finally more outliers will be removed. Results of this procedure are presented in the Chapter 5.

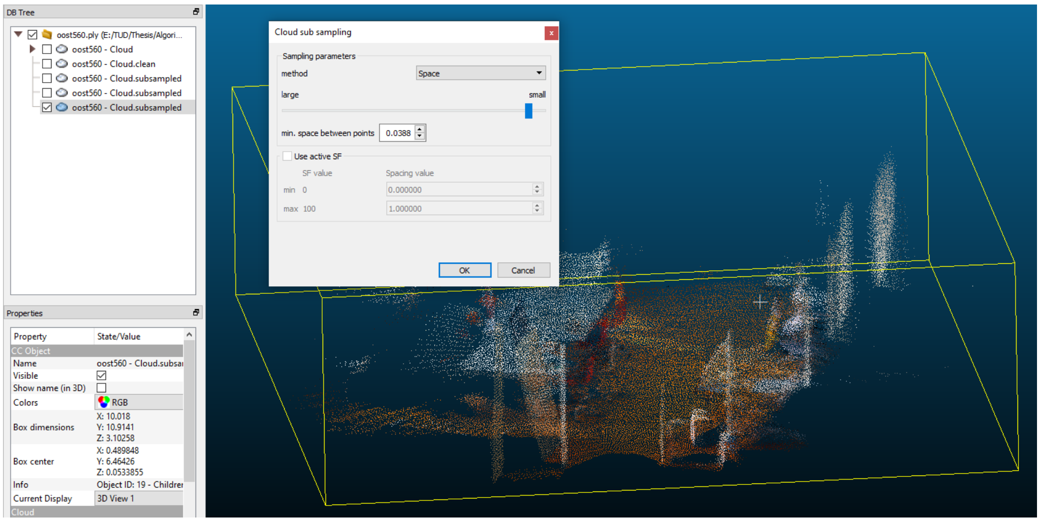


Figure 4.3.: Subsample of the point-cloud in CloudCompare

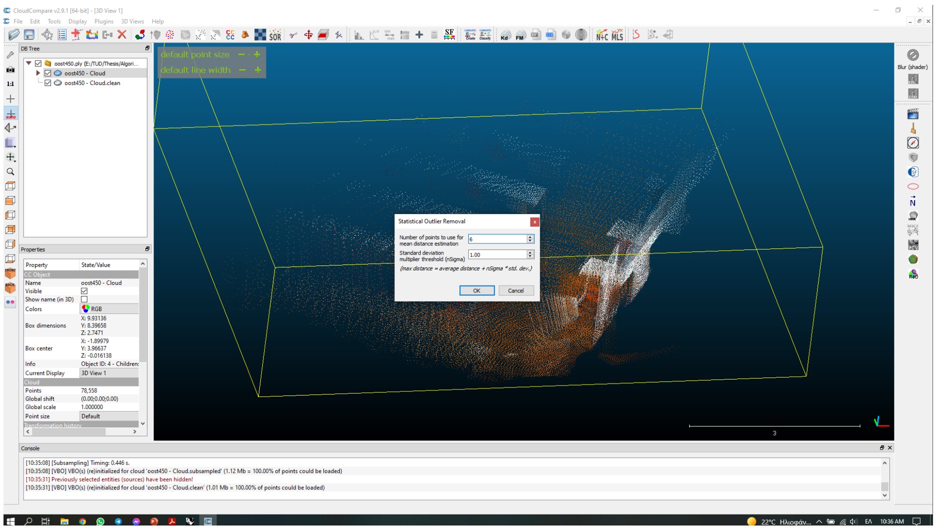


Figure 4.4.: Implementing Statistical removal of outliers in CloudCompare

Continuing, a cross section is creating in a height where the most obstacles can be still visible like in the example point-cloud in the following image. This height varies from room to room but was decided to be between 0.6m to 1.20m in order to include the most important information. Then after the point-cloud is clean and cut in the aforementioned range of height it is exported into .dxf format which is compatible with AutoCad where the final step of drawing the obstacles by using 2D polylines will be done.

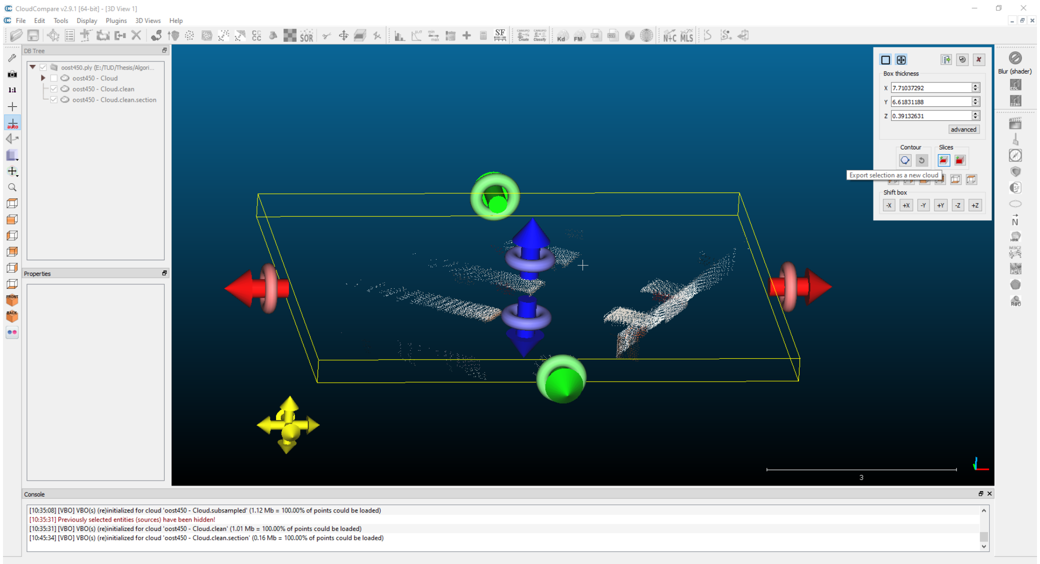


Figure 4.5.: Point cloud slicing into CloudCompare

Last step of the procedure is taken place in AutoCad where manually the borders of all the obstacles is drawn as it is shown in the next image. Of great importance action, was to ensure the unit system on which the work will be done in all stages of the implementation and keep the same standards when export and import the data into different softwares. In AutoCad the units were in meters as well as in the previous steps.
This pipeline were followed for all the point-clouds and eventually all the user's data were ready for the next step and the implementation of the Isovist calculation which will be explained in the next section.

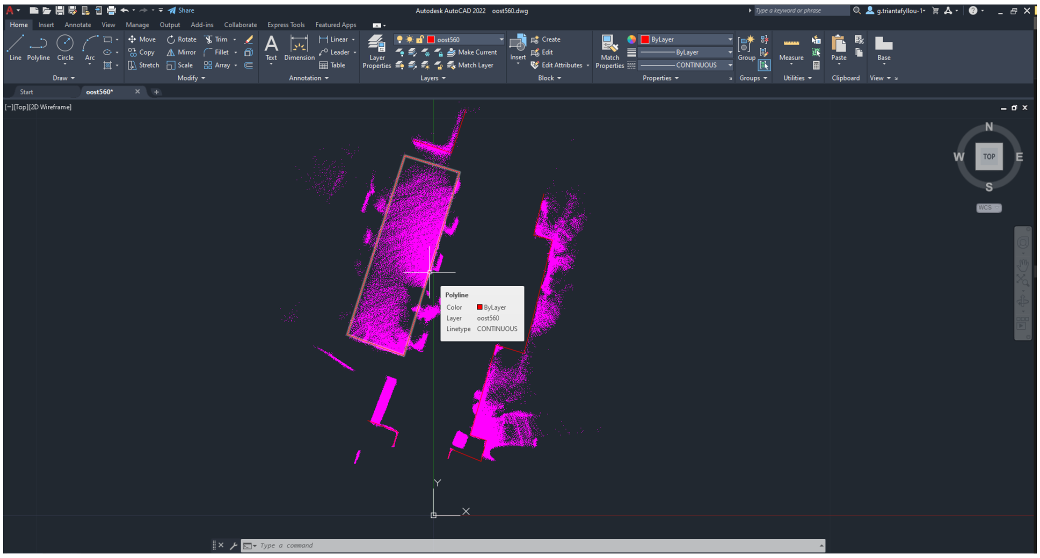


Figure 4.6.: Example of drawing the objects in AutoCad after the processing of point-clouds in CloudCompare

4.3. Algorithms

On this section is going to be presented step by step the implementation of all different algorithms conducted during this project. For that reason is additionally divided into 3 subsections in order to cover in more clear and better way all the necessary details.

4.3.1. LiDAR point-clouds to 2D polylines

Chronologically the first algorithm and pipeline needed to be created was the point-cloud process and transformation into 2D polylines. Since ideally the future end product targets to be a mobile application, the whole procedure should become automatically. Therefore the part of communicating what the user sees with the back end of the application and the algorithms calculating and estimating the location has to be automated.
This automation is not fully implemented on this thesis although some initial steps has be done along with some research and ideas for the future. The manual procedure which were explained in the previous section 4.2 consists the pipeline that needs to be automated plus some extra steps in between.

First thing to mention is the tool used for the purpose of this task. Python programming language have been used in general through this project and therefore for this part too. Furthermore, for the point-cloud process and automatic manipulation a really powerful and helpful library were used named "Open3D" (http://www.open3d.org/). Open3D is an open-source library for handling and process 3D data by using a really clear structure of algorithms in C++ and Python Zhou et al. [2018]. It consists a really easy to use library with many capabilities regarding almost every kind of point-cloud processing, from cleaning and downsampling, to register and classify it.

The procedure implemented so far is the following. Initially the point-clouds that are in .ply format are read and loaded into the code. Afterwards using Open3D is the turn of the voxel downsampling on the point-cloud while the voxel size is chosen for 0.1 i.e. 10cm distance from point to point in the downsampled point-cloud. This method consists of two steps, first creates a Voxel grid and buckets all the points into voxels with a size of 10x10x10cm as mentioned, and then each occupied voxel generates exactly one point by averaging all points inside. Therefore, voxel downsampling with the use of a regular voxel grid is able to form a new downsampled point-cloud. It is great first step for most point-cloud projects because it simplifies the input point-cloud and makes it lighter for further process http://www.open3d.org/docs/release/tutorial/geometry/pointcloud.html.

Afterwards, next step of the preprocess of point-clouds is the cleaning of it or removal of outliers. For this purpose, the statistical outlier removal was chosen. This method it removes all points that are further than the average distance from the rest point-cloud and it takes 2 parameters. The neighbours, which defines how many neighbors are included while calculating the average distance between two points and the ratio which allows the user define the threshold regarding the standard deviation of the average distances across the point cloud http://www.open3d.org/docs/release/tutorial/geometry/pointcloud.html.

Even though the automation task is not complete, and the general future work is presented in the Chapter 6, it is important to provide also an idea of the next steps here. Another small step taken was to convert the pre-processed point-cloud into a 3D array to be able to a better manipulation later on. Ideas for the next step is to get a slice on the point cloud by actually picking the values from the 3D array that are in between a specific range of z (height) values where the most objects occur.

4.3.2. Isovist Parameters Calculation

This part has to do with all the Isovist calculations and analysis by referring to every step and decisions taken through the process. A procedure which was carried out in Rhino7's Grasshopper tool along with the DeCodingSpaces toolbox of Grasshopper.

In order to conduct the Isovist Analysis the choice were between two softwares. The first one was the isovist.org (https://isovists.org/), an open source software for spatial analysis and even more specific for Isovist analysis initially developed by Michael Benedict and Sam McElhinney. A software really user friendly with high resolution analysis although with a total number of Isovist parameters calculation at 9. One of the main goals of this thesis topic is to analyse and explore all capabilities of Isovist regarding Indoor Localisation. Therefore, it is of high importance to check the effect of the most Isovist Parameters regarding the final goal. That was one of the reason why the chosen software to carry the Isovist analysis during this project was eventually Rhino7 and DeCodingSpaces toolbox for Grasshopper. Since it is a toolbox attached to a powerful software like Rhino, with the availability of total 17 Isovist parameters. Additionally, is an interesting topic work on with Rhino since it is not common to use this software for positioning and localisation purposes. The differences regarding the Isovist parameters between the two softwares are available in the following Table 4.2

	Isovist.org	**DeCodingSpaces Toolbox for Grashhoper of Rhino**
Isovist Parameters	Area	Area
	x	Area (Dist Weighted)
	Perimeter & Closed Perimeter	Perimeter
	Compactness	Compactness
	x	Circularity
	x	ConvexDeficiency
	Occlusivity	Occlusivity
	Vista Length	Min Radial
	x	Max Radial
	Average Radial	Mean Radial
	x	Standard Deviation
	Variance	Variance
	Skewness	Skewness
	x	Dispresion
	x	Elongation
	x	Drift Magnitude
	Drift	Drift Angle

Table 4.2.: Table with differences on Isovist Parameters between Isovist.org and DeCodingSpaces Toolbox

The procedure has the following structure and steps. The goal was to implement a code in Grasshopper in order to conduct isovist analysis in the sample area and furthermore to extract the produced information for further analysis and use for the localisation purpose.
The whole process took place in Grasshopper and Rhino. The idea was to create an algorithm able to calculate single or multiple isovists for any 3D drawing was imported. The first step then was to import the modified 2D floorplan of the sample area into Rhino because this is also the base where everything are visualised and imported. A really important factor and detail needed to be mentioned is the scale and the units used in AutoCad and in Rhino must be the same of course and real (meaning the represent the exactly distances as in reality). There is no reason to be georeferenced since all the calculations at this stage happening semi-automatic and relatively to the distances.

4.3.3. Matching, Localisation and Grid Positioning Algorithms

Last part of the technical implementation before the experiments, it is of course about the matching and localisation algorithms. This part is also subdivided into two implementations. The one is taking place in Grasshopper and its purpose is to conduct many artificial tests to evaluate and draw useful conclusions about many factors of the process. This way is helping a lot with better interaction and visualisation during the tests. And the other implementation is about doing just the matching of data and get location through an external code in Python.

Regarding the implementation in Grasshopper which was actually even closer to prove artificially positioning than localisation. As mentioned already, the goal was to explore in better way the interaction of isovist with the localisation and positioning concept. Since the imported 2D drawing is unified and consists of one layer with polylines that are fully closed, a grid was created in the whole area of the building. The grid was created in the whole area since in order to create the grid is necessary to have one fully closed polygon which will be filled with grid cells. The reason behind the grid was to eventually calculate one isovist for each grid cell. Smaller the size of grid cells the higher the resolution of the analysis grid. That is not always mean better results as it will be shown later on the results. But for sure it means that way more computation power is necessary since the total number of Isovist calculations can become enormously large, something that is not affecting the final goal since this computation is needed for the database which will be settled once and used many times after. With the use of the "Analysis Grid" component this task was done along with a connection with Isovist Calculation Block as well a Visualisation block. To enable it and create eventually the grid a single point which defines the space which is going to be populated with the analysis grid. An example of these components is shown below.

Next step was the calculation of multiple Isovists, a task that was carried on the same way with a single isovist mentioned in the previous section. The difference this time is the use of multiple vantage points derived from the analysis grid instead of just one. After these calculations the data consists of a list with thousands sets of 17 parameters one set for each grid cell. These parameters are completely different from each other as well the information that they represent. Therefore, in order to be able later on to compare and match a single isovist with multiple sets of parameters the data has to be normalised. For this purpose the method of Average Normalisation was used.

Then, after normalising the data, both for the set of multiple isovists from the grid as well as the single Isovist which acts as the user's Isovist, comes the eventual comparison and matching. To do that initially was used the most typical distance algorithm, the Euclidean distance between the single's Isovist parameters and the list of the thousands ones from the whole sample area. Additionally the result of the matching was connected in the visualisation block in order to see in a color map the results and how accurate the matching was. Results from this procedure will be shown in the next Chapter 5.

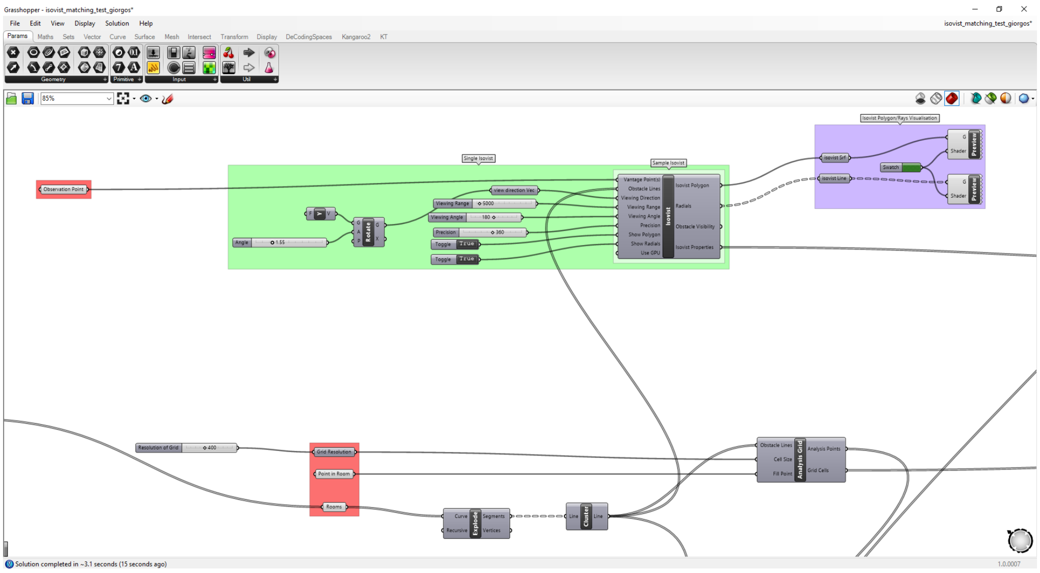


Figure 4.7.: Grasshopper Components for Isovist and Grid Analysis Calculation

Regarding the second implementation for localisation, the difference is that this time the database is containing isovist calculations from 10 random points for each entrance of the sample area's rooms. All of them were took place manually in Grasshopper and exported in .csv file. Therefore the .csv file contains a total of 70 sets with the 17 parameters each of them. This time the normalisation is conducted in Excel and then load it into Python code were the Euclidean distance algorithm runs again comparing a user's single Isovist (it's 17 parameters) with the set of 70.

4.4. Experiments and Tests

The algorithms themselves and the calculations are not enough to prove the concept of the thesis. The probably most essential part of the project is the experiments and tests in order to evaluate and and understand better all the factors of the project. Therefore this section is also subdivided into four subsections regarding the Isovist parameters evaluation and choice, the Data normalisation techniques and Matching algorithms that serve better the scope of the project and finally the localisation tests themselves with the use of artificial and real cases.

4.4.1. Isovist Parameters Analysis

The first and most important experiments has to do with the understanding and evaluation of Isovist parameters that were going to be calculated. From the 17 in total isovists parameters that are calculated in Grasshopper some of them like the perimeter of the Isovist polygon and the area are affecting quite a lot the results but in order to distinguish in a better way which parameters are more or less important several tests should be conducted.

The first idea was to use a Principal Component Analysis (PCA) which is data analysis technique for analyzing a data table with values and observations that are inter-correlated and dependent. The goal of PCA is to take the whole data set and transform it into a new and smaller one containing the most important information Mishra et al. [2017]. The problem here was that the 17 parameters of isovist represent completely different information and don't belong in the same coordinate plane, which makes them invalid for using PCA according to `https://towardsdatascience.com/pca-is-not-feature-selection-3344fb764ae6` and `https://www.projectrhea.org/rhea/index.php/PCA_Theory_Examples`. Additionally, the other important reason was that the goal of the topic is not to reduce the dataset by keeping the most important values of each component but just to evaluate their importance regarding the matching and localisation purpose, something that made the use of PCA difficult to use in first phase. Nevertheless, leaves an open space for work and discussion in future.

Therefore, in order to find out the importance of the parameters in presence, several manual tests have been made in Grasshopper along with the visual interaction in Rhino. That way was possible to check the effect that each parameter had in the results and eventually reach a conclusion about their importance.

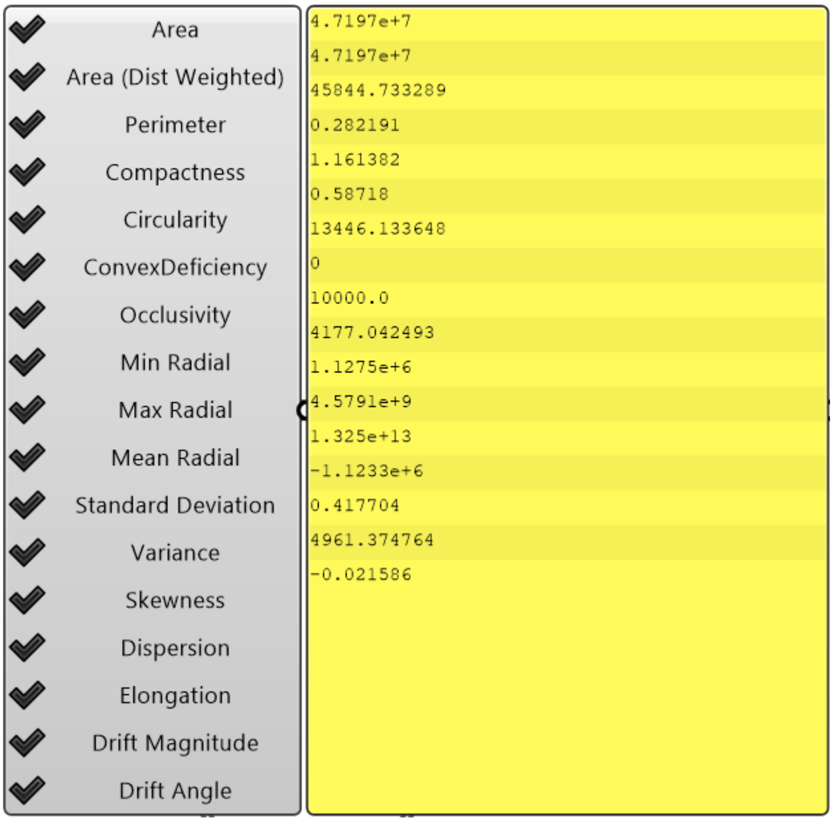


Figure 4.8.: Example from a single isovist calculation. The 17 parameters with their values

4.4.2. Data Normalisation techniques

As mentioned previously, the main data which are eventually being compared and matched, consist of a total of 17 parameters which represent different values and information regarding the Isovist and visibility. And therefore they need to be normalised before compared. There are few different ways to implement this task, one of them is the one used initially by using the Average normalisation. But there are more and in this case two more have been tested to see how the distribution of the data changes.
To do that initially all the data were exported into a .csv file format from Grasshopper by using a C Sharp script and a block of Grasshopper components to define the details of the export. Then the data of the multiple isovists which serve as the database and the single user isovist were structured in right way by using Excel in order to calculate different methods of normalising the data. The methods

checked were by Standard Deviation and by Min and Max normalisation. Results of this procedure are available in the next Chapter 5.

4.4.3. Distance Algorithms for Matching

The final implementation has to do with the comparison of the artificial user's single Isovist with the dataset of the multiple isovists of the whole indoor environment's sample area. And in order to conduct this comparison and possible matching the initial idea was to use a Euclidean distance algorithm. This part even though was implemented in Grasshopper, it used a Python script which runs inside Grasshopper. The results from this implementation already showed that it is indeed possible to get a quite accurate location from Isovists although since the whole idea of the topic is to prove to what extent isovists can support indoor localisation, it was considered important to check every part of the process and therefore check other techniques to implement the final comparison. That means examine some other Distance Algorithms. The algorithms that were researched and examined except Euclidean is:

- Hamming Distance
- Manhattan Distance (Taxicab or City Block)
- Minkowski Distance

The difference in the implementation appears only in the last step where the Python script is used for the comparison and matching. All the previous steps are remaining exactly the same. Regarding the "Hamming Distance" since it needs to calculate the distance between two binary vectors, also referred to as binary strings or bitstrings for short, which in the case of this thesis were not exist, resulted to not be used.

About the second Distance algorithm, the "Manhattan", it actually calculates the distance between two real-valued vectors. It is perhaps more useful to vectors that describe objects on a uniform grid, like a chessboard or city blocks. Even though, there is use of grid for the calculation of isovists before, in this part the interest is to calculate distance not between grid cells themselves but between their vectors consisting of the normalised 17 parameters. It already seems not perfect match for this task's purpose but tests have been conducted and are shown in the next Chapter 5.

Finally, the "Minkowski" Distance algorithm, it is not something new, since it is just a generalisation of Euclidean and Manhattan and therefore it calculates in the same way the distance.

4.4.4. Localisation tests using artificial and real data

The tests regarding the final localisation goal are using hybrid both artificial cases and real life data. The artificial cases were used in the grid method in order to have wider space of changes and testing and eventually to understand better the correlation of all factors regarding isovists and localisation. And of course real data were used in order to make the proof even stronger.

These tests were implemented in Grasshopper by running multiple times the code with different Isovist Parameters used as well range, angle and direction of the Isovists. Furthermore, different user's points from different parts of the sample area were tested. This actually implemented by setting the single vantage point of the user in different rooms or position inside one room in order to evaluate the matching/localisation/positioning.

5. Results and Analysis

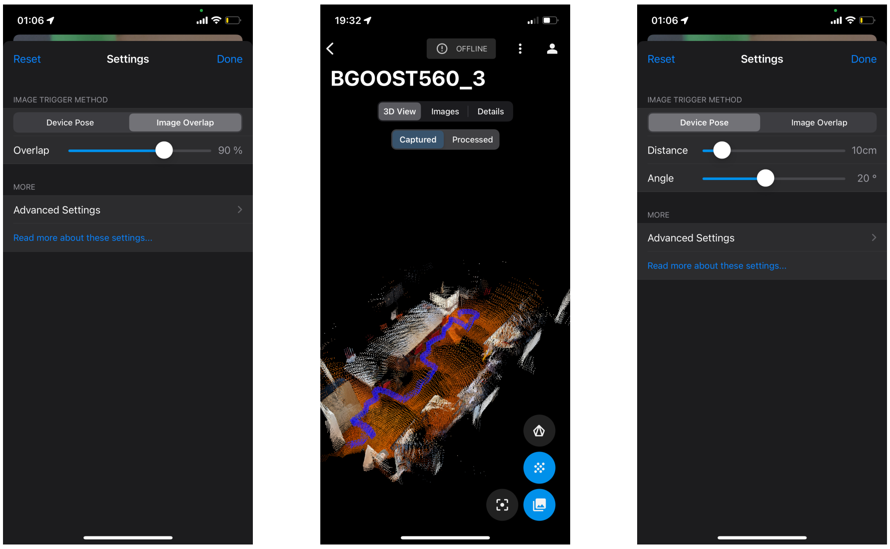
The present Chapter is providing a detailed analysis and discussion about the results of the implementation Chapter 4. Additionally, it gives all the insights and evaluates the results but also all the issues and thoughts that occurred during the implementation of project's tasks.

Therefore the structure of the chapter follows a simpler structure. Is divided in 3 parts. The acquired and modified data, the Isovist Calculations Results and the results from the tests and experiments made.

5.1. Acquired and Modified Data

A great uncertainty even from the beginning of the project was on how and if the data could help in the positive outcome of the project or they were going to be of bad quality and hard to manipulate. Surprisingly, especially the LiDAR point-clouds even if were captured by just using an Apple iPhone mobile were detailed and accurate enough for the purposes of the thesis.

As it is visible on the Figure 5.1, the resolution and the accuracy of the produced point-clouds are really good and therefore regardless the "noise" (unwanted captured objects and points that might cause loss of valuable information on objects of interest), the accuracy is more than enough in order to be able to draw the polylines which form the main obstacles (furniture and walls).



(a) Image Overlap (b) Captured Data (c) Image trigger params

Figure 5.1.: PIX4Dcatch details of meaurements

5.2. Isovist Calculation Results

Anything related to Isovist calculation were implemented in Grasshopper and visualised in Rhino as it was explained in Chapters 3.4 and 4. In this section the results and factors that are related and attached to Isovists are presenting.

After implementing the whole Isovist calculation in Grasshopper, the initial results are all Isovists properties. These properties are actually the 17 isovist parameters. An example set of the 17 parameters after the calculation is visible in the Figure 4.8. Except of the numerical form of results, in the cause of understanding the impact of isovists in the indoor environment it is important to have visual results as well. This is also where Rhino7 proved to be greatly valuable since it gives the opportunity of visualising anything that is implemented, calculated and coded in Grasshopper. In the Figure 5.2 is presented an example of how the several isovist polygons are appearing.

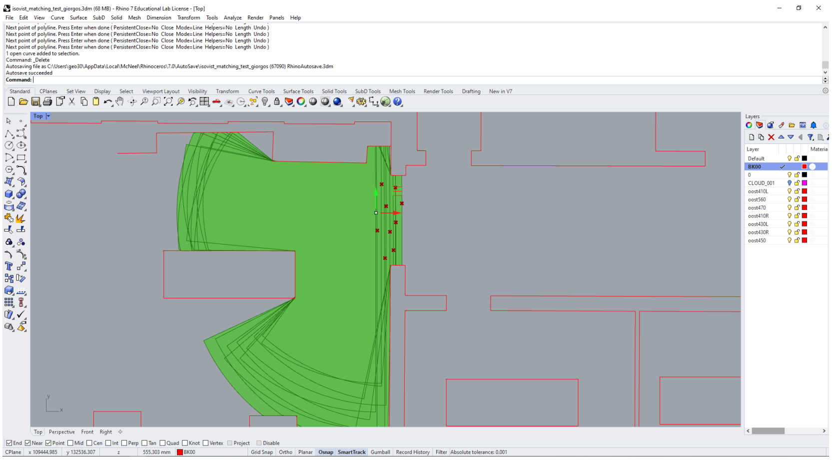
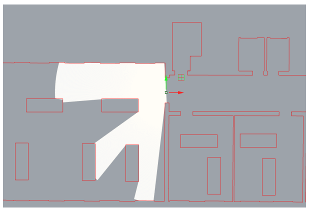
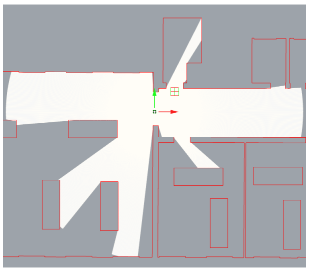


Figure 5.2.: Visual representation of isovists with 180 degrees of angle and 5m range.

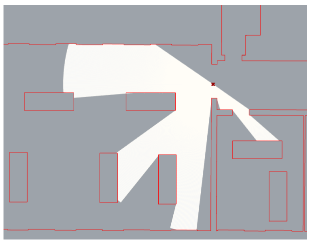
What can be observed of course, is that they are different between them and the values they get are different. Just to observe the values of the parameters though is not enough since without any visualisation is hard to understand how they affect the matching/localisation result. In order to set the isovist calculation few factors need to set up as well. Factors such the direction of the isovist, as well as the angle of the view. Moreover, except of these also the range of the isovist polygon has to be determined. In Figure 5.3 there examples of how these factors can change the isovist polygon and of course the 17 parameters.



(a) 180° angle, direction to interior of room, 5m range



(b) 360° angle, 10m range



(c) 180° angle, direction not fully to interior of room, 5m range

Figure 5.3.: Isovist Polygons with different settings

From these examples can be noticed that definitely, depending of these factors many things can change later on in the matching phase, since any difference in angle or range affects the isovist polygon and therefore all the parameters related to isovist. For example in the Figures (a), (b), (c) 5.3, even though the point is the same, the isovist polygon and parameters are completely different as the range, angle or direction has been changed. What needs also to be noted is that bigger range or bigger angle is not meaning always better results, since depending on the room and its level of uniqueness the algorithm might find more matches and eventually not result the correct location.

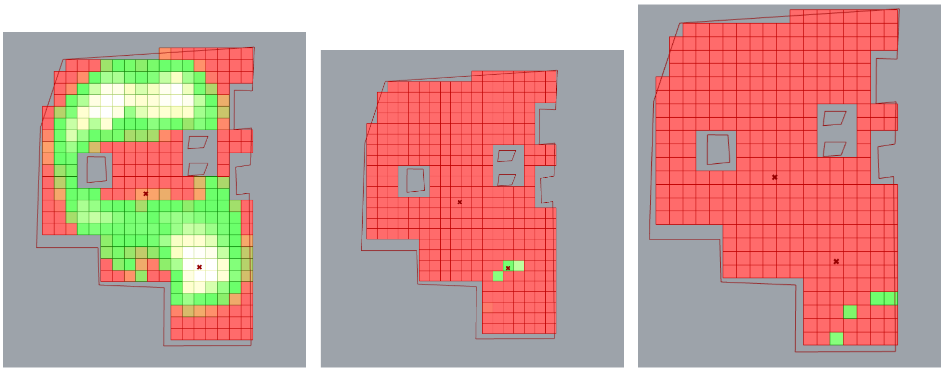
5.3. Experiments and Tests Results

Through this Section results and examples from the tests and experiments conducted will be shown and analysed. First, the results and explanation from the Isovist parameters testing is presented, following from the Normalisation analysis and then the final Localisation tests.

5.3.1. Isovist Parameters testing

As was mentioned, the idea of using PCA in first place was abandoned for the reasons explained in Chapter 4, and therefore several manual tests in Grasshopper with use colormap for visualisation for better understanding of the role of parameters.

From the tests many things can be concluded. In order to reach valuable conclusion the tests done were actually running multiple times the Grasshopper code with different combinations of isovist parameters, while visualising the results like in Figure 5.4. As it was expected, the most valuable and important parameters are the Area and Perimeter. Although just alone cannot be sufficient for accurate results. Surprisingly, the ”Drift Angle” parameter appears to have tremendous affect on the results. Other parameters that seemed to affect the results are ”Occlusivity”, ”compactness” . Another important information extracted is the parameters that seem to have the least role and affection in the process. Such parameters are ”Skewness” and ”Variance” which in the tests seems to not affecting the results. Therefore even without them the results would not be changed for the localisation goal.



(a) 14 params - 360 angle (b) 17 params - 360 angle (c) 15 params - 180 angle

Figure 5.4.: Examples of testing Parameters and other factors in an artificial case.

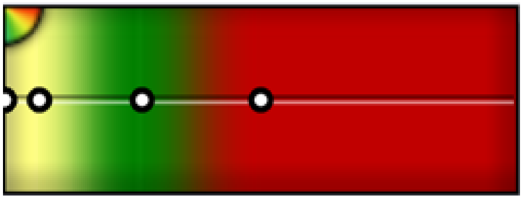


Figure 5.5.: Color ramp showing the color meaning in the test visualisation. From best match (left) to the worst match (right)

5.3.2. Data Normalisation analysis tests

A quite important step was to normalise the data produced from the isovist calculations. Since, without this step the comparison and matching of isovists is impossible. As mentioned also in Chapter 3.4 and 4 the used technique was the Normalisation by Average since it seems to be the best fit for this case.

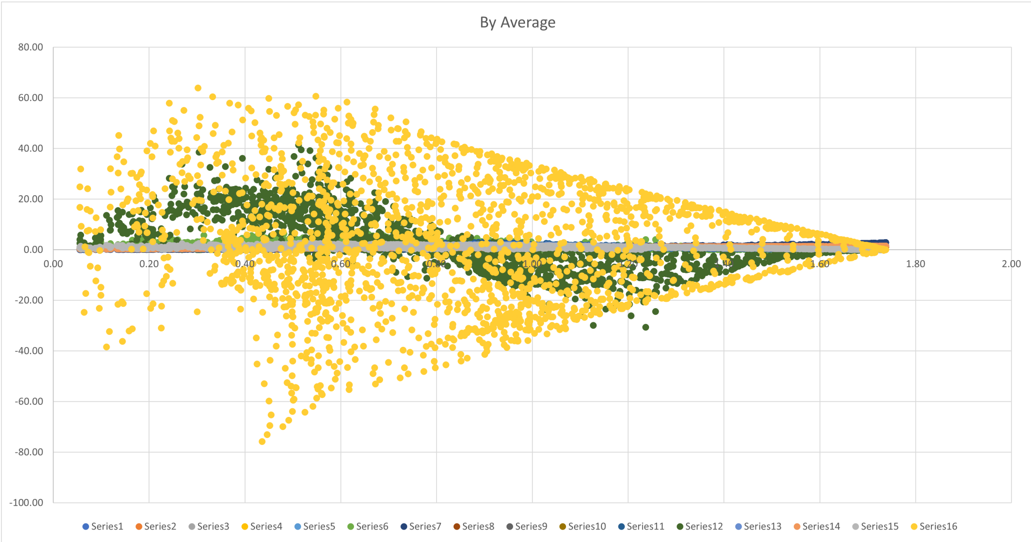


Figure 5.6.: Graph showing the distribution of the parameters after Average Normalisation

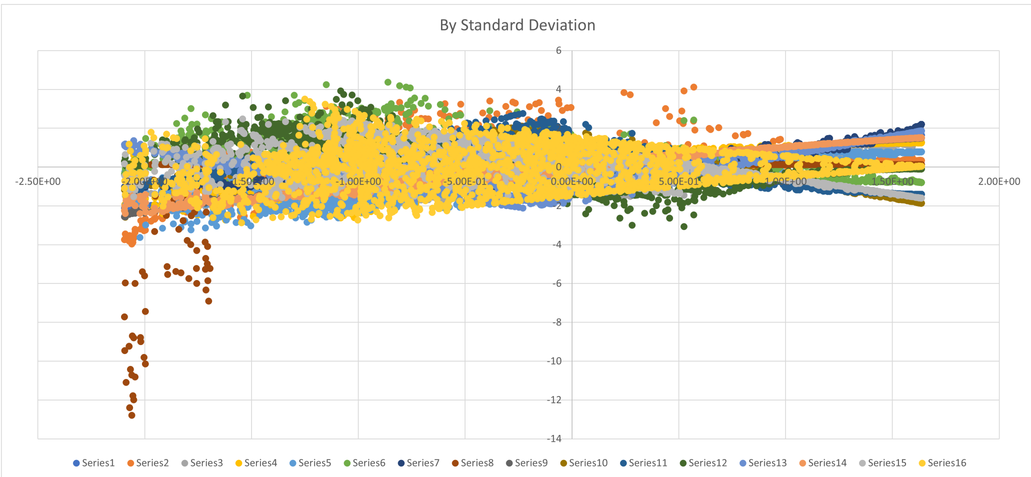


Figure 5.7.: Graph showing the distribution of the parameters after Standard Deviation Normalisation

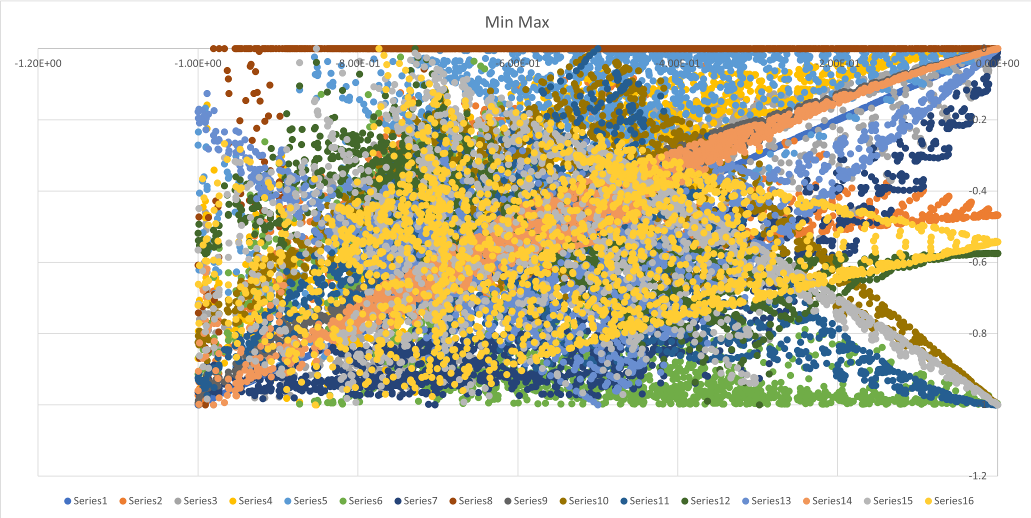


Figure 5.8.: Graph showing the distribution of the parameters after Min-Max Normalisation

As it is visible from the Figures 5.6, 5.7 and 5.8 the distribution of the parameters after the Normalisation process especially in the Min-Max method is very high which makes it totally inappropriate for the purpose of the task. Even though with the Standard Deviation method the results from the graph of the distribution are better still after some tests for localisation later on proved it also inefficient. Therefore the choice was the Average Normalisation which also seems from the graph that all the parameters are in line with similar distribution except of one (yellow color).

5.3.3. Localisation tests results

The most tests regarding the localisation and positioning were conducted in Grasshopper by using both artificial spaces and real ones. Additionally, in order to explore the results even better, tests were conducted with or no furniture, meaning with less objects and therefore less unique environments so to have a conclusion if the method can work on empty rooms by using the less obstacle information possible. An example of rooms with and without extra objects is shown below.

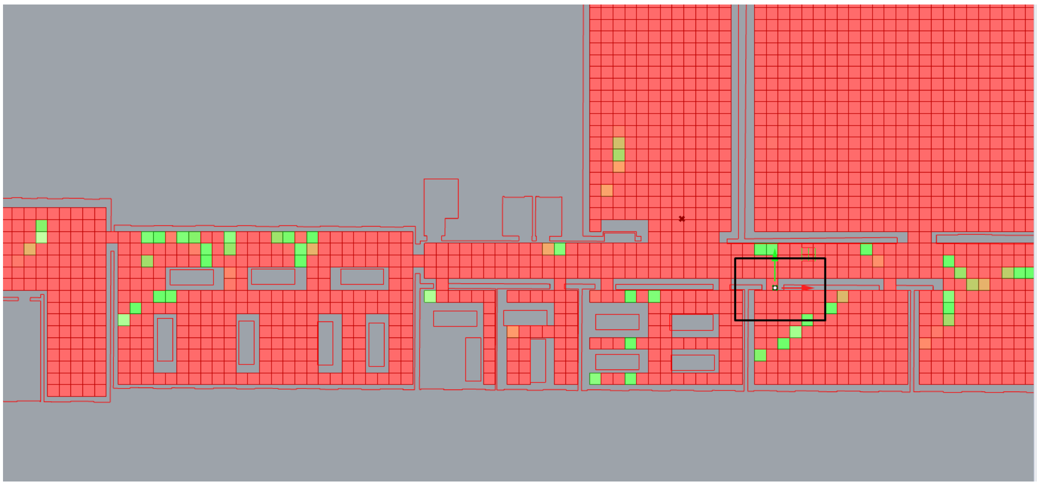


Figure 5.9.: Room without extra furniture

It is visible that in the first Figure 5.9 the single isovist acting as user is inside a grid cell with red color meaning its giving wrong result according to the 5.5. While in the second Figure 5.10, the color of the cell is almost white indicating that is high probable to give the correct result.

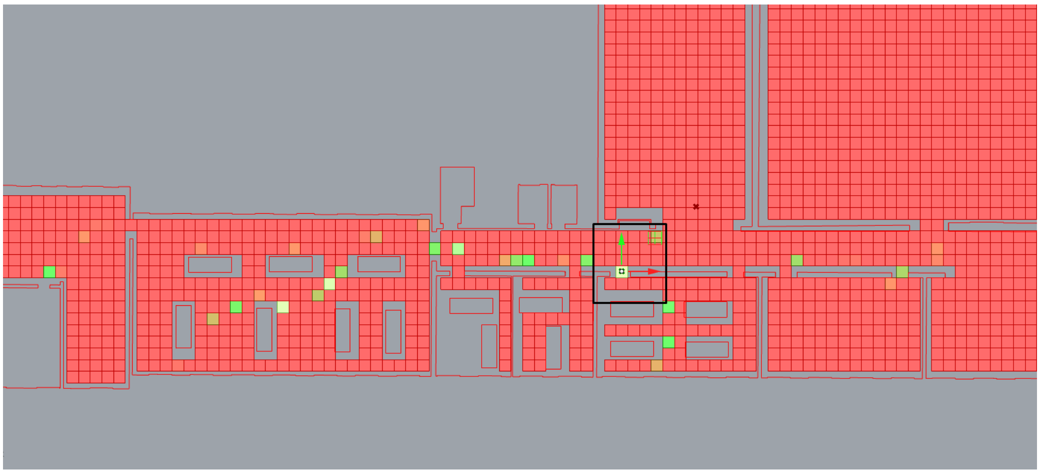
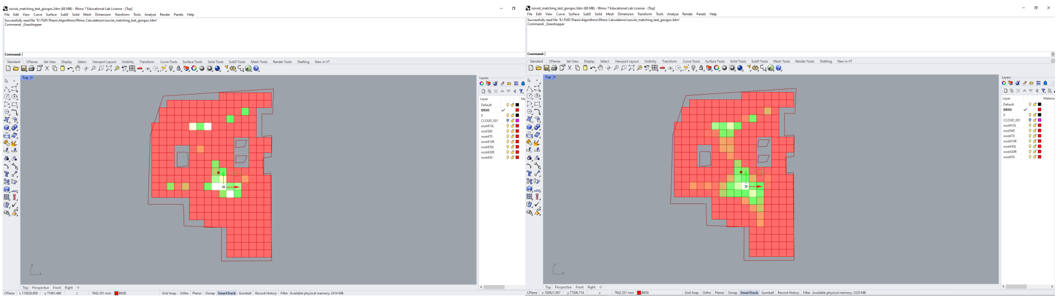


Figure 5.10.: Room with tables as furniture

Some more results regarding the localisation are about the differences between the two distance algorithms that were tested. In the Figure 5.11 the two algorithms were tested in an artificial room and try to determine even the position of the moving point (user) into the room. Even though in this example the algorithms are giving really similar results, the main conclusion is that the Euclidean Algorithm still has more chances to estimate better location than Manhattan.



(a) Euclidean Distance Algorithm (b) Manhattan Distance Algorithm

Figure 5.11.: Examples of testing Parameters and other factors in an artificial case.

The same conclusion comes from another test were the real life sample area was used. In the Figure 5.12 is clear that the Manhattan Algorithm is facing many errors and uncertainties not only in positioning (exact cell) but in Location too. In the other hand, in this particular occasion the Euclidean Algorithm gives an impressive result as is visible in the Figure 5.13.

Figure 5.12.: Manhattan Algorithm

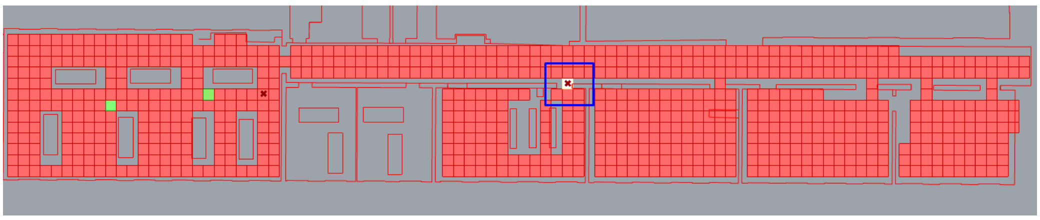


Figure 5.13.: Euclidean Algorithm

6. Conclusion, discussion and future work

Main Scope of this thesis topic is to explore and prove to what extent an Isovist fingerprinting method can support Indoor Localisation. During the previous Chapters the details of the whole project as well as all the implementations and results were presented and analysed. Consequently all these results, problems, ideas are leading into some valuable conclusions and remarks as well as ideas for the future of the topic. Therefore, in Section 6.1 all the research questions are getting a brief answer, while in Section 6.2 a final discussion of the whole topic along with future ideas and work are given.

6.1. Answers to Research Questions

1. How to create/formalize a database with the Space Syntax measures (Isovist analysis, visibility analysis/graph) of the sample area?.

   This question even though is a secondary research question, it is of high importance. The information that eventually provides is critical since is data that will determine the matching and eventually the localisation result. After the implementation of Isovists calculation, the Isovists properties were consisting of 17 unique parameters stored initially in a list of 17 values for each isovist. Even though, the visibility from a vantage point in space is geometrical since the obstacles and uniqueness of the environment determines the final localisation result, the eventual matching and outcome is made from the comparison between only the isovist parameters. Therefore, the database neseccary for the loaclisation purpose it is a list of tenths, hundreds or even thousands sets of isovist parameters with which the user's single set of isovist parameters is going to be compared and matched.

2. How to get accurately the visibility of the user from the point he stands with real life data and get the correct location?

This question is partially answered and that is because in the context of this thesis scope the connection of the user's data with the algorithms are not connected automatically. However, a sufficient answer can be given even though most of the part was implemented manually, there are ideas for the future to make it automated. To answer the question, it is possible to get pretty accurately the visibility of a user either is a human being or even a moving object with the use of LiDAR sensor along with camera and photogrammetry. In this case the use of just a smartphone was implemented with eventually good and promising results for the future of the field of LBS and IPS.

3. Which and how many parameters should be used from Space Syntax measures (Isovist parameters) to determine the location?

   This question is actually answered already in the Chapter 5 and Section 5.3, where the Isovist parameters tests were presented and evaluated. The tests as already mentioned have been made manually in Grasshopper by observing the results of different use and combination of isovist parameters. In short what can be mentioned here is that the Area, Perimeter and Drift Angle are of highest importance while the Variance and Skewness is the least. Therefore, not all 17 parameters are necessary in all situations, meaning that when a room is totally unique with many obstacles then just the Drift Angle, Area and Perimeter are enough to give the correct location while in rooms with less unique characteristics these 3 parameters are not enough and the use of the rest 14 is crucial to increase the possibility of correct match and localisation.

4. How the final comparison and matching of data will be take place in order to estimate the location of a user?

   This question as well is already answered in the previously chapters and sections. During this thesis implementation the eventual decision regarding the final comparison was to use Distance algorithm on normalised data. Therefore, the final comparison and matching of the data will be made between the created database with the sets of isovist parameters and the single set of isovist parameters from the user. Finally, in order to make that comparison in the best way, the Euclidean Distance algorithm is used to estimate the closest fit of user's isovist parameters with the database and provide the possible location of the user.

5. Which distance/matching algorithm to perform according to the form of the data?

   After the research which have been conducted regarding the distance/-matching algorithms has made possible to answer also this research question. And according the nature of the data and their structure the method of computing the distance and eventually get the best match between a single set of 17 isovist parameters with the "database" of multiple sets of Isovists is the classical and most of the times trusted method of Euclidean distance.

6. Is it possible to make it usable as a mobile or web app?

   Yes in theory it is definitely possible to eventually end up as a mobile or web application that can work efficiently. How? and Why can work? Well, after all this research and initial proof of the concept of using Isovist for Indoor Localisation purposes then yes in future it could become an actual application. Since the whole procedure has be done semi automatic already, it can ideally transform to automatic avoiding the use of software like Grasshopper and instead calculating the isovist parameters purely in the back-end of a mobile application. So in theory yes it is possible, in practice might need lots of work to get there but it is promising prospect.

To what extent can isovist support Indoor Localisation?

After answering one by one the secondary research questions it is time for all of them to be combined and at last answer the main and most important question of this topic. So, shortly Isovists and in general the visibility analysis can be a significant role in the continuously developing field of Indoor Localisation. After forming an initial proof of concept for indoor localisation based on Isovists, it appears promising and if not alone, in combination with other methods of Indoor Localisation could lead in a complete and sufficient solution. The exact extend of support that can give might be early to answer with confident at this moment, but one is sure, it works and it can make the difference in the future of indoor localisation.

6.2. Discussion

In the last Section of the thesis comes of course maybe the most important part of every research topic. The final discussion around the conclusions, results, problems, limitations, solutions and of course the future of the topic so it can be further developed to reach the final goal. A goal of such a an importance, the Indoor Localisation. A field that as mentioned in the 1 lacks of complete solutions. However, the last decades attracts great interest from the society, and the biggest driven reason to try and put effort on that field is the daily conversations with people who commonly ask what is about this thesis topic. And after the brief explanation of what is the main scope and goal of it, the feedback is most of the times "Please do it, i am tired of getting lost in the buildings". This simple and brief daily discussions are increasing of course the importance and the motivation of continuing the research on this field. As it is clearly visible, the impact on the society will be enormous and thus gives great value to every research topic regarding the Indoor Localisation.
To address the discussion about the topic in the most efficient way, it is divided into three subsetions. The first one is about the limitations that the topic faces so far. While the second one is about the solutions that provides as well the potentials and value that gives in the greater field of LBS and IPS. It closes up with the Future work and Recommendations.

6.2.1. Limitations

This thesis topic might not reach and produces an end product like a mobile application fully integrated and able to work in real life, but as the main objective and scope define, is trying to get a foot on a new way of Indoor Localisation and add a valuable role in the establishment of a complete LBS and IPS. The way that the concept is addressed by breaking it down is several smaller tasks is helping in order to prove and examine every aspect of the main goal. The whole idea and concept of course has its limitations.
The most general limitation is that is not an end product yet. Since, there is no yet integration between all the steps and under a mobile or web application. Another limitation of an Isovist method is that even though doesn't need any extra infrastructure (i.e. the many Wi-Fi routers for Wi-Fi Fingerprinting method), it still needs some pre established measurements and a database for each building and indoor environment before being ready to use. Regarding the more technical limitations, it needs to be considered that at this stage there is no automation in all parts of the method. The most important part that lacks of automation is

the connection of the data produced by the user with the algorithm that does the matching and estimates the location. Thus, the transformation of the 3D point cloud into 2D form of data.

6.2.2. Solutions and potentials

Besides the profound limitations of the topic so far, there are much more solutions and valuable conclusions already along with great potentials for the future. First of all the main research question where it can be reassured that Isovists can support Indoor Localisation field. Furthermore, it is really important that there are already the means for a user to acquire a point-cloud with just a smartphone and with enough details and accuracy for the Isovist calculation and Location estimation. As already mentioned, for now there are limited devices capable for this task but there is great potential for the future the LiDAR technology to be supported from the majority of smartphones and therefore available to most of possible users of an Indoor Localisation App.
Additionally, the topic it gives an insight regarding the value and importance of Isovist Parameters which are the key for the localisation. Moreover, it provides a pipeline on how and with what to create an Isovist database necessary for the comparison and localisation of the user. And finally, an analysis and solution on how the comparison and matching of Isovists can be made in order to reach localisation. Nevertheless, to reach a successful final product, many small steps and tasks need to be made, but this research topic consists one of the first important steps towards an Indoor Localisation method based on Isovists. It has indeed therefore a lot of potentials to support the already existing methods in the field Indoor Localisation, Positioning and Navigation.

6.2.3. Future Work and Recommendations

Before considering and analysing the next and future steps of the topic, a further evaluation has to be done. By pointing the issues and limitations and of course the solutions already found and then the proposed ones for the future. The biggest limitation at this point is that this research topic is just a proof of concept and not an end product ready to use. However, it gives important insights on the use of isovists and makes the first step towards a new way for indoor localisation.
Another factor to be mentioned for the future, is that it consists a method which can also be applied in theory in more cases and not only for user as human. It could be useful for example to manage expensive equipment in complex buildings like hospitals and airports. To do that it would just need attached on the

top of the moving equipment a LiDAR Camera sensor device which would could capture real time the surroundings and by matching them with the database gives a real time location or even position of the equipment.
To reach all these goals, much more work need to be done. First and most important as already mentioned is to automate the part were the user's side that captures data to be connected with the database in real time. Furthermore, a mobile application or at least a web application that gathers all parts of the method in a fully integrated and functional environment.
Of course besides these, several future recommendations occur. Since Building Information Modeling (BIM) have grown and is more and more wanted. In case that a building have an already BIM model established in theory it could help way more the Isovist method since it will contain all necessary information of objects and obstacles. Additionally, another really important aspect is the 3D isovists, a topic that already started to develop but if this moves further that could benefit this thesis topic even more and open great space for improvements.

A. REFLECTION

The present section is dedicated to highlight the main contribution of the thesis as well as the relation that has with the MSc of Geomatics and with our society in general. Additionally, it consists also of a evaluation on my personal performance during the past months of this thesis.
This thesis proposes a methodology and forms a proof of concept for a new method of Indoor Localisation based on Isovists. The main relationship between the MSc of Geomatics and the topic consists of raise awareness and explore a new method and solution regarding Indoor Localisation and Navigation field. Another important part of the research is the data acquisition and manipulation and visualisation of indoor environments with the use of 3D point clouds. In general the thesis topic and smaller parts are in line with several courses of the Master of Geomatics. Positioning and Location Awareness, Sensing Technologies and Mathematics, Python Programming, Photogrammetry and 3D Computer Vision and 3D Modelling of the Built Environment gave the necessary knowledge during the 2 years of the Master in order to fulfill this research thesis.
Besides the relation with the Master of Geomatics, the research done and the topic has important value and impact for the society as well. As mentioned in the Chapter 1 humans spend most of their time indoors. Therefore the importance of a research which making one more step towards a solution for complete LBS and IPS.
To close up, is always important to consider the personal impact that a research has and also evaluate the work and ourselves during this process. In general the 2 years of the Master and especially the Thesis project have been enlighten for me personally and professionally since the knowledge, abilities, experiences and contacts gained are of enormous value. One really important factor that definitely needs to take into consideration is the COVID pandemic which unfortunately was accompanying my 2 years Master journey from the beginning to the end and made everything way harder than should be. Additionally, i am one of the students that got infected in the midway of the thesis project and also with strong symptoms. That was something extremely hard and took me many steps behind with the work. I didn't want it to be an excuse or the reason that i couldn't finish the thesis on time. So, besides the struggles and according to the situations under which the thesis has been conducted, the work and the results are satisfactory.

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Colophon

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