Isovists-Fingerprinting as new way of indoor localisation

Georgios Triantafyllou
g.triantafyllou-1@student.tudelft.nl
1st supervisor: Edward Verbree
2nd supervisor: Azarakhsh Rafiee

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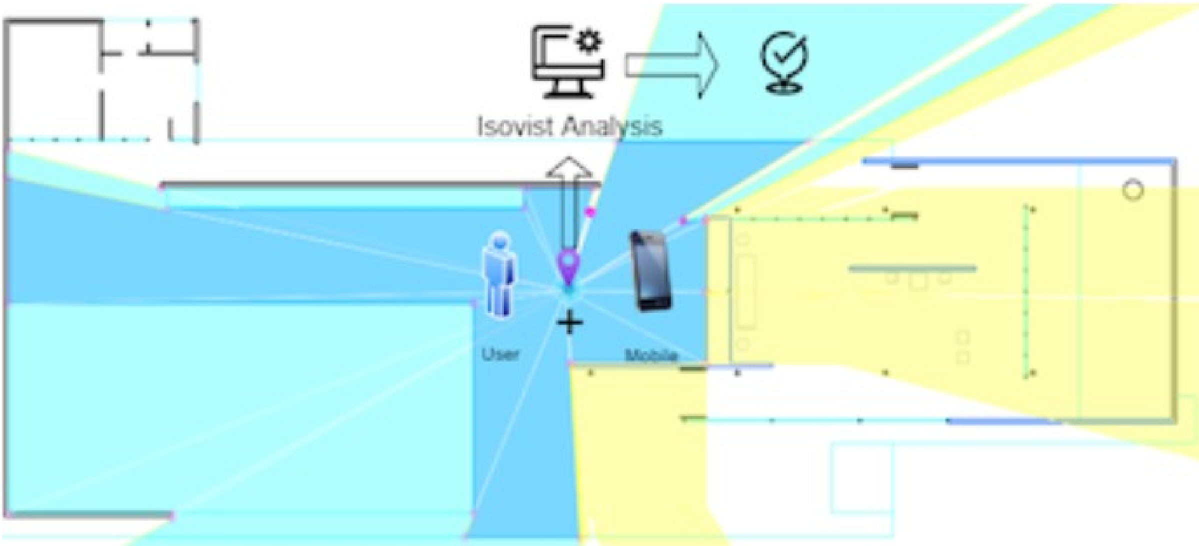

1 Introduction

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 one quarter of electives. During this thesis, the knowledge acquired from the past quarters will be put into practise to deep into new methods, improve existing or propose future ones.

1.1 Problem Statement

Nowadays, technological advances appear to do dramatically big steps forward. In all aspects of life, there is already or on process, 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, navigation systems. 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 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 a bit challenging due to the lack of reliable GPS/GLONAS positioning systems Torres-Sospedra et al. (2019).As (Elrawy, 2019) 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 get the semantic details of the room except the geometric ones. This is meaning, that he can easily understand where exactly stands in the 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 will be 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 "Methodology" chapter.

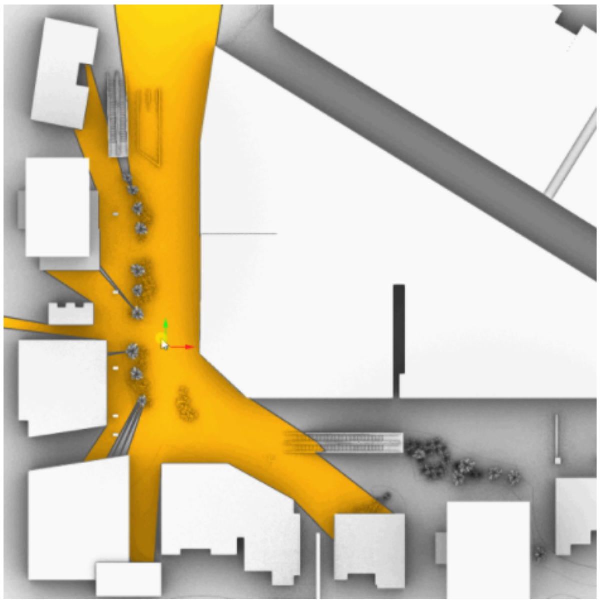

Figure 1: A single Isovist produced in Grasshopper with DeCodingSpaces. Source:toolbox.decodingspaces.net

2 Related work

In order to reach a satisfactory result and succeed in a research topic it actually needs to complete a puzzle of study. A puzzle of various previous and 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.

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.

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 positioning (GPS: Global Positioning System). 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 of someone or something in space (Sithole and Zlatanova, 2016). These concepts were taught as well and accurately in the Positioning and Location Awareness (GEO1003) course of MSc Geomatics in TU Delft (Verbree, 2021).

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 Triantafyllou et al. (2021), who tried to create an indoor positioning system by using micro-controllers (arduino) with Wi-Fi sensors along with Wi-Fi fingerprinting and ArcGis Indoors in order to create a real-time application with location awareness and privacy preserving of its users.

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 not use any of these preexisting methods. However they provide great knowledge and understanding of the main objective which is to determine accurately and easily the location.

2.2 Space Syntax concepts, Isovist and Visibility Analysis

The second core concept of the thesis is Isovists. Isovists consists an element of the general Space Syntax 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 is going to be a valuable help through this research.

According to Akkelies van Nes (2021) 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).

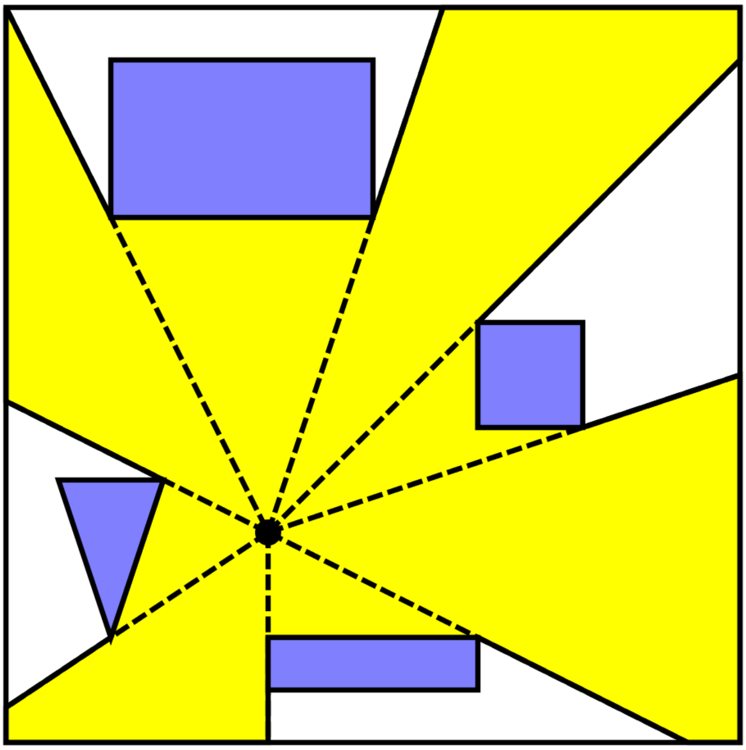

Figure 2: An isovist with the visibility polygon and the obstacles around. Source:https://en.wikipedia.org/wiki/Visibility$_p$*olygon/media/File* : *Visibility*$_p$*olygon.svg*

2.3 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.

2.4 Relevance

Although all the pre-mention topics and research are different than this thesis main objective. In combination, they can lead to a promising result even though there have been really limited studies with similar idea.

3 Research questions

The main objective of this MSc Thesis will be to explore a new proof of concept and provide an initial investigation on how the Isovist, visibility graphs and Space syntax concepts can work together to deliver a new method and solution for localisation and possibly route planning/navigation on indoor environments. Therefore, the general main research question is:

To what extent can isovist support Indoor Localisation?

Of course next to the main question there are several other ones which immediately arise. Such as:

- *How to create an Isovist fingerprinting to a radio map*
- *How to formalize a database with the Space Syntax measures (Isovist fingerprinting, visibility analysis/graph) of the sample area?*
- *How to get accurately the visibility of the user from the point he stands and in real time give him the location?*
- *Which and how many parameters should be used from Space Syntax measures to determine the location?*
- *Is it possible to make it usable as a user app?*

3.1 Scope

In order to better understand and clarify the goals for the final result and what this will or won't include the MoSCoW rules were followed which are the MUST, SHOULD, COULD, WON'T this research will contain. To achieve the above aim, the following objectives (categorized according MoSCoW rules) need to be fulfilled:

Must have

- Space Syntax Measures
- Isovist analysis and Visibility Analysis of sample area from 2D data
- Algorithm capable to determine the location from isovists
- Results from different artificial tests

Should have

- Database with Space Syntax measures of the sample area
- Algorithm which is capable to transform a point cloud into 2,5D data

Could have

- To notify user of his rough current position
- Routing / Navigation
  - Route to and from desired location in the building
  - Shortest route to location
  - Safest route to location
  - Simplest route according to obstacles

Would not have

- A Mobile application
- Fully integrated and functional mobile application
- Real time localisation of the user
- 3D Isovists produced from point cloud

4 Methodology

The key to successfully conduct this research is to plan and divide the work carefully and thoroughly. In order to, reach a complete framework for localisation by using Isovists Fingerprinting and present the possibility for this to be expanded into navigation too, the work is split into several smaller tasks which have as goal to answer the main research question mentioned in previously chapter. Most of the tasks up to this moment are pretty clear and for the rest there are options which need to be evaluated and reach the final conclusion. A big challenge of the project is 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. The main idea here is, that since the smartphone industry advances rapidly and already there are mobiles with LiDAR technology, it could be assumed that the user possess mobile with LiDAR in order to capture his surroundings.

Therefore, the overview of the steps is firstly creation of a radio map and database with all the necessary space syntax measures, secondly formation of the algorithm who is going to convert the data given by the user into a correspondent format with the database, and finally the algorithm who is going to determine from the comparison of user's data with the radio map, the location of the user. Below is visible a single example of a comparison from isovists. With the green arrows there is matching and correct estimation, and with the red there is no matching. Yellow isovists are from the user and are comparing with the ones already produced in the radio map/database.

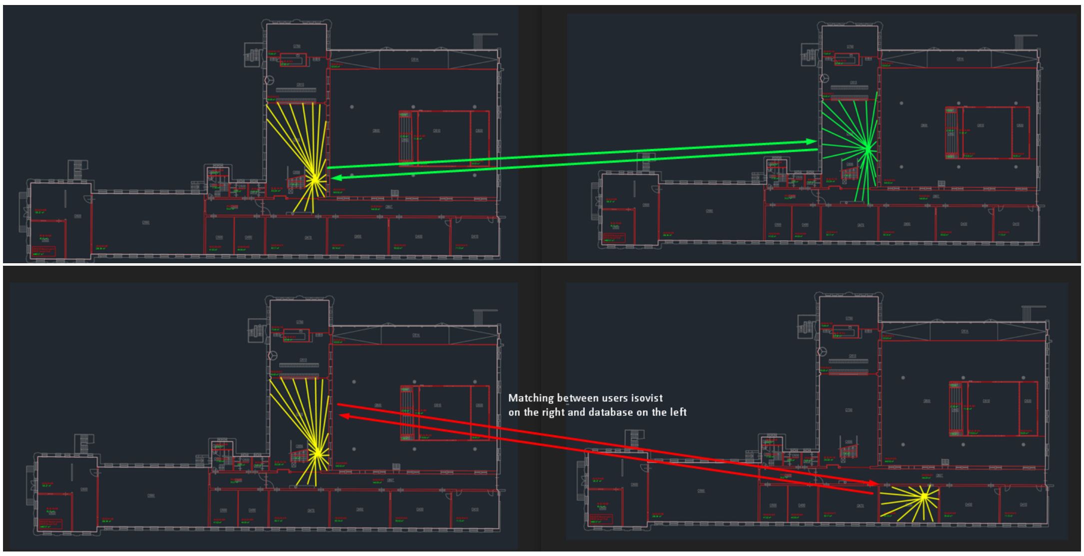

Figure 3: Simple visualisation of the comparison with the database and the matching or not for the estimation of location.

4.1 Data Acquisition

First step in the process is the gathering of the data necessary for the project. First part of that is the gathering and formatting of some 2D drawing floor plans of the sample area which is going to be 2-3 strategically chosen rooms of the faculty of Architecture of TU Delft.Strategically in order in first phase all of them to be significantly different and hopefully easy to do the matching with the database (containing all the Space Syntax measures see next section) and reach a result for the localisation. Second part is capturing some point cloud with 3D scanner or just with personal mobile iPhone 12 Pro with the LiDAR technology. The reason to do that, is to evaluate the possibility of producing isovist from an LiDAR scan and match it with the isovist data in the database.

Figure 4: iPhone 12 Pro LiDAR scan Sourse: Polycam Channel in Youtube

4.2 Space Syntax Measures and Database

Second Step and really important one is calculating all necessary Space Syntax measures regarding the sample area. This is going to happen by using a free licensed software given by TU Delft, called Rhinoceros 7. Specifically, what is going to be used is a plugin of ”Grasshopper” of Rhinoceros 7 which provides huge capabilities for calculating isovists, visibility analysis graphs and many other parameters of isovist field.

Additionally, an important assumption must be made in order for the main idea to work in first place. All the calculations are going to happen approximately in the center of each room and space of the building. Therefore, the user will be advised to go in approximately the center of the room in order to get the best estimation of his location.

After the first two steps of the workflow, it is important to gather all this information into a database easily to access in order later to be able do the matching and determine location.

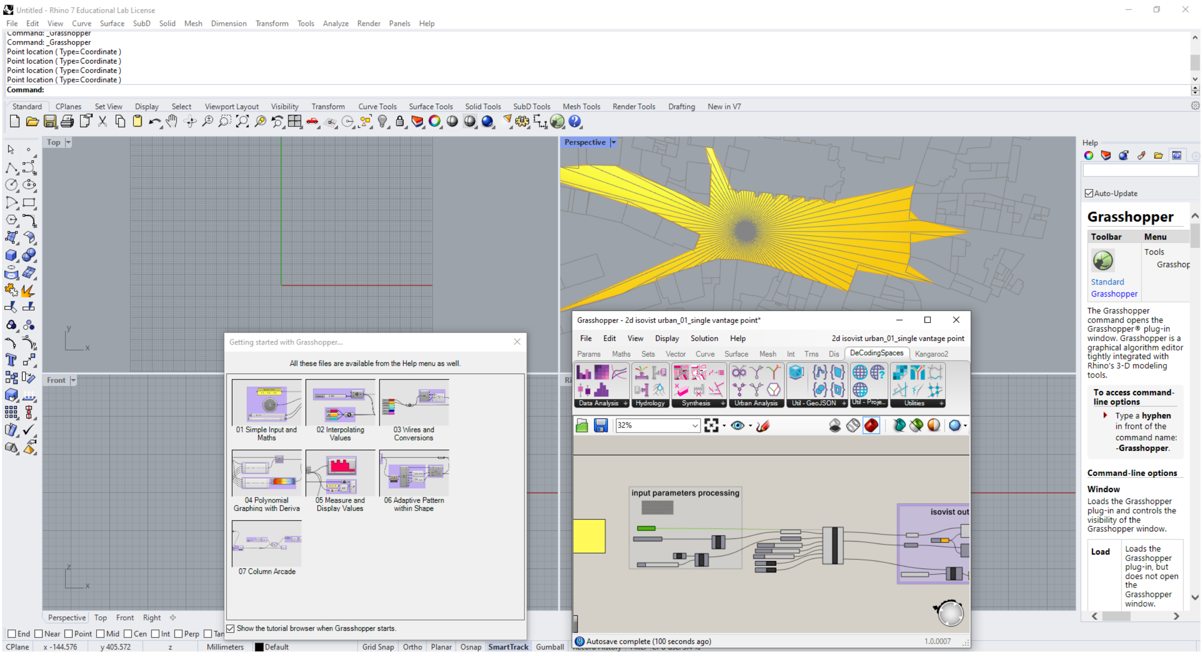

Figure 5: Single Isovist example visualisation in Grasshopper of Rhino7

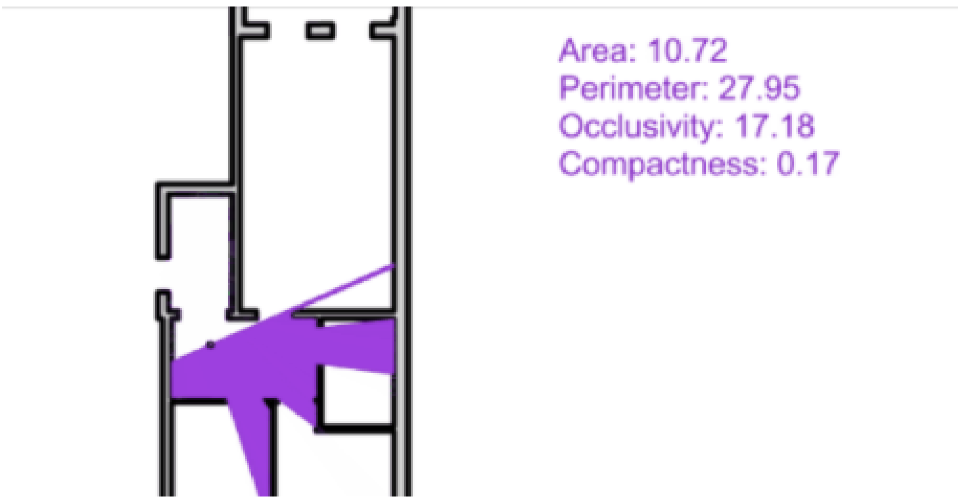

Figure 6: Example parameters from 180 degrees view isovist produced in Grasshopper of Rhino7

4.3 Algorithm

The algorithm part is going to be divided into two sections and written in Python by using libraries mainly from opencv. The first one, is going to get the LiDAR scan from the user and transform it into 2D. What actually is going to do, is creating a slide in a particular height from the point cloud data and draw the borders in order to eventually get the 2D drawing. The second part of the algorithm, is going to try and match the result from the first part with the already measures in the database and reach the answer of where the person is located at this moment.

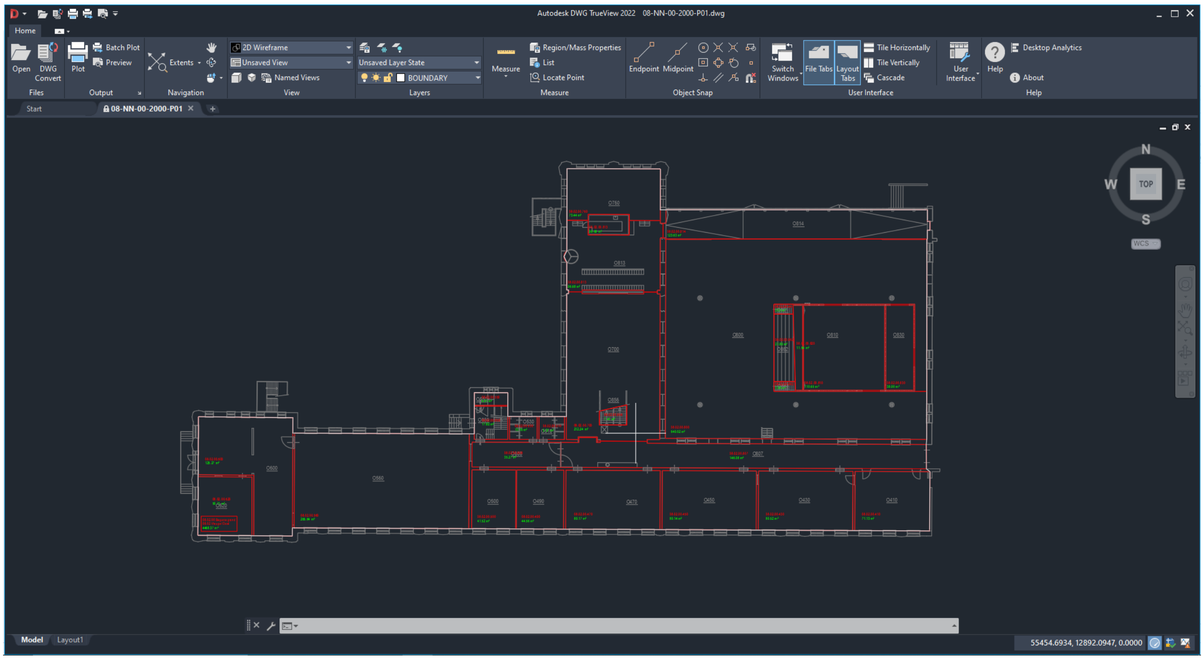

Figure 7: Example of an 2D drawing in the AutoDesk TrueViewer

4.4 Future work/ideas

The possible future work and idea is based on this thesis's is to integrate everything into o real mobile application which could use the previous mentioned methodology in real time and determine the location of the user.

5 Time planning

Thesis Schedule	Jan	Feb	Mar	Apr	May	June
Exam Dates	P2 : 26th		P3		P4	P5
Regular meetings with Supervisors per 1-2 weeks						
Preparing of Data and Acquisition						
Space Syntax measures (Isovist-Visibility Analysis)						
Keeping the appropriate parameters						
Algorithm Implementation						
Writting parts of the thesis						

6 Tools and data-sets used

The implementation of the project requires some specific data-sets and tools in order to make it happen. The data used in the thesis is combination of a real case with some artificial touches.

Regarding the data, the sample area will be 2-3 rooms in the Faculty of Architecture of Delft (Bouwkunde). The floor plans of the decided rooms of the building which are already acquired since the Synthesis project "Building Rhythms: Reopening the workspace with indoor localisation" (Triantafyllou et al., 2021), with some artificial modifications in order to add some more details (furniture), will be initially used to calculate the 2D Space Syntax measures. Additionally, there will be some data acquisition of 3D LiDAR scans by using personal mobile phone (iPhone 12 Pro) for the creation of Point Cloud of the rooms.

About the tools used, there are software and programming languages as well scanning devices. The software used is the Rhinocerus 7 (free license by TU Delft) and more specifically the plugin ”DeCodingSpaces” for ”Grasshopper” in Rhino. Additionally, ArcGis from ESRI (free license by TU Delft) will be used to host the database in a server. Furthermore, an iPhone 12 Pro will be used for the scanning of the rooms. And finally, Python is the programming language which will be used for creating the algorithm for the localisation.

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