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Indoor localisation through Isovist fingerprinting from point clouds and floor plans

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ABSTRACT
The objective of this paper is to investigate and propose a method for Indoor Localisation based on Isovists, with the aim of extending the fields of Location-based Services and Geomatics. Various methods and combinations incorporating Isovist concepts, Space Syntax, and visibility graphs are examined and assessed. By investigating these approaches, this study aims to create a comprehensive methodology to achieve localisation using Isovists. The main conclusion drawn from this research is that an Indoor Localisation method based on Isovists is not only feasible but can also effectively support Location-based Services. The analysis and evaluation of all the components have been thoroughly conducted, indicating that when properly integrated, they can provide substantial value for LBS applications. As this is a new method for Indoor Localisation, there is significant scope for future work, particularly in terms of connecting it with existing techniques and integrating them into user applications.

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Indoor localisation; space syntax; Isovists; fingerprinting; point clouds

1. Introduction

The ability to determine one's location accurately or approximately is crucial for effective navigation. In the recent years there have been several studies about methods for indoor localisation and positioning system, such as Wi-Fi fingerprinting and monitoring, Ultra-Wide band Positioning, Visible Light Communications (Obeidat et al. 2021). Most of the methods for indoor positioning systems use actually the technique of fingerprinting which require using of sensors and different hardware devices and software in order to determine the location. However, there have not been many studies which focus on direct conversion of point clouds from LiDAR scans into Isovists. Hence, this paper

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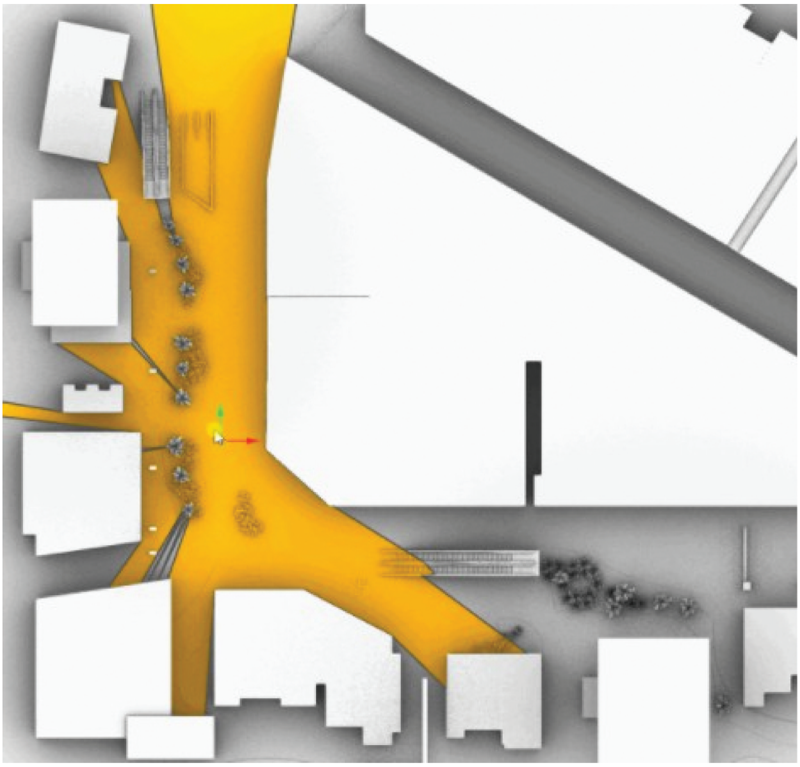


Figure 1. A single Isovist produced in Grasshopper with DeCodingSpaces. Source: toolbox. Decodingspaces.net.

explores the possibility of obtaining location information solely based on the visibility from a specific point in space. This concept is known as Isovist, which Benedikt (1979) defines as ‘the set of all points visible from a particular vantage point in space with respect to the surrounding environment’., see Figure 1.

The methodology is divided into four main sections. Firstly, the Data Acquisition section utilises the Light Detection and Ranging (LiDAR) technology supported by smartphones for capturing the necessary data. The second section, Space Syntax and Isovist Analysis Measures, delves deep into the analysis of various concepts related to Isovist Parameters, providing a comprehensive understanding of their effects. The third section focuses on Matching and Localisation Algorithms, exploring different possibilities and options to achieve accurate localisation. Finally, the Tests and Experiments section evaluates the aforementioned stages of the methodology.

The evaluation involved rigorous testing and analysis of different techniques, with an emphasis on their effectiveness in determining accurate locations. Overall, this research seeks to establish a reliable foundation for utilising Isovists in localisation and navigation applications, offering insights into the potential benefits and limitations of this approach.

2. Objective and scientific relevance

The research presented in this paper encompasses two primary scientific fields. The first field is localisation, specifically focusing on indoor environments. While localisation and positioning techniques for outdoor environments have been extensively researched and well-established, the indoor domain has gained significant attention only in recent years. Several techniques, such as Wi-Fi Fingerprinting, Bluetooth beacons, and Near Field Communication (NFC), have been developed to address the unique challenges of indoor localisation.

The second field explored in this research is Isovists, which is a fundamental component of the broader Space Syntax theory. Space Syntax, initially developed by Hillier et al. (1976), investigates the spatial configurations and their social impact in urban areas, studying the interaction between humans and space. Although primarily applied in architecture and urban planning, the theory encompasses various concepts, with Isovist being one of them. Isovist, defined by Benedikt (1979), refers to the space visible from a specific point in space.

While these two fields, indoor localisation and Isovists within the Space Syntax theory, may seem distinct and separate, their combination holds great promise. Despite the limited studies exploring the use of Isovists for indoor localisation purposes, the convergence of these fields can lead to compelling results. By integrating the insights from indoor localisation techniques with the spatial understanding provided by Isovists, a new and potentially powerful approach to indoor localisation can be developed.

Overall, this research seeks to bridge the gap between indoor localisation and the Space Syntax theory, utilising Isovists as a means to enhance the understanding and effectiveness of indoor localisation techniques.

3. Theoretical background

3.1. *Localisation versus positioning*

The fundamental concept at the core of this research is localisation. It aims to determine the general whereabouts of a person or object, such as within a city, on a street, or within a specific room in a building. It is essential to distinguish localisation from positioning. While localisation focuses on providing a general idea of the entity's location on a map, positioning seeks to determine the exact coordinates of an entity within a Coordinate Reference System (CRS) with high precision (Sithole and Zlatanova 2016).

In recent years, numerous studies have focused on developing methods for indoor localisation and positioning systems. These include techniques such as Wi-Fi fingerprinting and monitoring, Ultra-Wideband Positioning, Visible Light Communications, and many others (Obeidat et al. 2021). An interesting approach was presented by Spinoza Andreo et al. (2021), where they devised an indoor positioning system utilising microcontrollers (Arduino) equipped with Wi-Fi sensors. They combined this hardware with Wi-Fi fingerprinting and ArcGIS Indoors to create a real-time application with location awareness and privacy-preserving features for its users.

By clarifying this distinction, we can establish a foundation for comprehending the primary objective of this research, which is to develop effective techniques for localisation in indoor environments. The aim is to provide users with accurate information regarding their general location within a building or indoor space, rather than focusing on precise positioning coordinates.

3.2. Space syntax and isovist

The second core concept explored in this research is Isovist, which is an integral component of the broader Space Syntax theory. Therefore, it is essential to introduce this influential theory. Space Syntax, initially introduced by Bill Hillier, Julienne Hanson, and their colleagues at The Bartlett, University College London, around 1979, encompasses a vast and comprehensive framework that applies to numerous topics and applications.

In essence, Space Syntax theory seeks to provide insights into and explain the relationship between society and space. It has found significant applications in the fields of architecture and urban planning, among others. To gain a deeper understanding of this theory, a valuable resource employed in this research was the book by van Nes and Akkelies (2021), which serves as a comprehensive introduction to the entire Space Syntax theory.

Benedikt, widely regarded as the father of Isovist analysis, 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 are closely associated with 2.5D visibility analysis, which has applications in orientation and pathfinding both indoors and outdoors (R. C. Dalton et al. 2015; Dalton et al. 2015).

As stated in (Sedlmeier and Feld 2018), 'human perception of location and space forms the basis upon which the interaction with location-based services (LBS) takes place'. They presented 'a complete framework, starting from the collection of Isovist measures along geospatial trajectories on indoor floor plans, over the statistical analysis of the data, the extraction of meaningful structure using unsupervised machine learning techniques, up to the training of models using supervised machine learning that generalize to previously unseen environments'.. Although they showed the Isovist measures do reflect the recurring structures found in different buildings, in this paper we use the unique characteristics of Isovists to identify locations.

In order to delve deeper into the concept of Isovists, it is important to introduce and explain the main parameters derived from Isovist calculations and analysis (see: Isovists.org), and also (Sedlmeier and Feld 2018):

- Area: This parameter represents the total area of space that is visible from a given vantage point in space.
- Perimeter: The perimeter parameter indicates the length of the boundary or edge of the space visible from a specific location. It corresponds to the geometric Isovist perimeter at that location (Benedikt 1979).
- Compactness: Compactness reflects the shape property of the visible space in relation to a circle. It identifies regions within the Isovist field where an observer's spatial experience remains consistently contiguous. It signifies opportunities for the emergence of new surfaces in the visual field during movement (Peponis et al. 1997).
- Occlusivity: Occlusivity expresses the proportion of edges in an Isovist that are not physically defined or obstructed. It indicates the extent to which previously unseen space may be revealed during movement. For example, occlusivity is high when passing through a doorway but zero in a convex room (Benedikt 1979).
- Average Radial: This parameter represents the mean view length of the visible space from a given location.
- Drift: Drift denotes the distance from a reference point to the centre of gravity of its associated Isovist. It identifies the inherent flow or pull/push experienced within a series of spaces, providing insight into the volume and layout of the space itself (R. Dalton and Dalton 2001).
- Variance: Variance expresses the mean square deviation between the lengths of individual radial lines and the average radial length of an Isovist (Benedikt 1979).
- Skewness: Skewness reflects the mean cube deviation between the lengths of individual radial lines and the average radial length of an Isovist (Benedikt 1979).

In the following Figure 2 there is a visual representation of some typical Isovist parameters for further understanding of the concept.

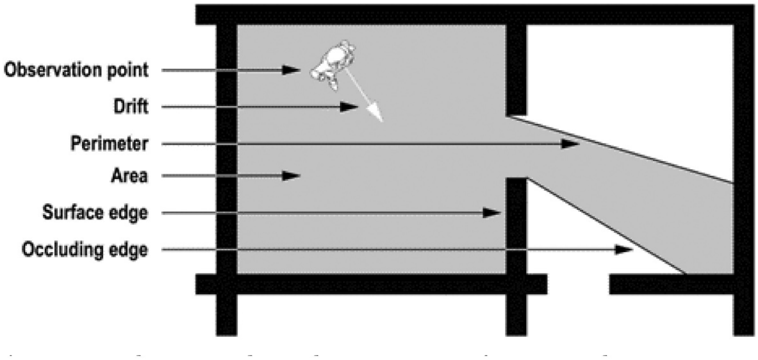


Figure 2. Explanation with visual representation of some typical Isovist parameters source: Ostwald and Dawes (2020).

3.3. LiDAR point clouds into isovists

LiDAR, an acronym for Light Detection and Ranging, is a method commonly employed for scanning the world in three dimensions. This technology utilises laser beams to create a comprehensive 3D representation of the surrounding environment. LiDAR finds application in various industries, including automotive, robotics, industrial, and mapping, among others.

What sets LiDAR apart is its ability to generate its own light, enabling its use in diverse lighting conditions and environments. This self-illumination feature makes LiDAR a versatile and practical tool for professionals and everyday users alike. Notably, Apple recently introduced and adopted LiDAR technology in their smartphones, making it more accessible and widely available.

The data obtained through LiDAR scanning consists of a multitude of 3D points in space, collectively forming a highly detailed representation of real-world objects (Cao 2021). These data points enable accurate measurement and analysis, facilitating a range of applications such as mapping, object recognition, and spatial understanding.

The direct conversion of point clouds from LiDAR scans into Isovists is a relatively rare topic in the existing literature. Most studies involve transforming the 3D LiDAR data into at least a 2.5D representation before generating Isovists. However, there are a few noteworthy research papers that explore the use of LiDAR for generating Isovists and quantifying the spatial configuration of locations.

Schmid and von Stülpnagel (2018) proposed the idea of using LiDAR to produce Isovists for quantifying the spatial configuration of a location. Although direct conversion of LiDAR point clouds into Isovists was not explored in their work, it laid the foundation for the concept.

Díaz-Vilariño et al. (2018) developed a fascinating methodology that directly creates 3D Isovists from point clouds by employing a voxel-based structure. Their research focused on generating Isovists without the need for prior transformation to 2.5D representations, showcasing the potential of integrating LiDAR data into Isovist analysis.

Another relevant study by De Cock et al. (2021) aimed to create an adaptive mobile indoor route guidance system. This work shares similarities with the present research, as it incorporates several core concepts and techniques related to Isovists. Although not directly focused on the conversion of LiDAR point clouds, it provides valuable insights into the integration of Isovists and indoor navigation.

3.4. Fingerprinting

Most of the existing indoor positioning systems rely heavily on the technique of fingerprinting. According to Guan and Harle (2017), fingerprinting systems typically consist of two stages. The first stage is the surveying stage, where a surveyor walks around the building and collects sufficient fingerprints to create a radio map. This radio map serves as a database that contains essential information about the indoor environment and its corresponding locations. The second stage is the online stage, where the building user captures a new fingerprint, which is then compared to the radio map to estimate their location.

It is worth noting that while the aim of this paper is to investigate a new method for indoor localisation, the existing methods provide valuable insights and understanding of the main objective, which is to accurately and easily determine the location of users. Many of the established methods rely on a variety of sensors, hardware devices, and software tools to achieve location determination. These approaches have contributed to a wealth of knowledge in the field and have paved the way for further advancements in indoor localisation techniques.

4. Methodology

The primary objective of this research is to demonstrate the feasibility of using an Isovist fingerprinting method to determine the location of a user within a complex indoor environment. One of the significant challenges encountered in this project was establishing a connection between the data collected by the user and the pre-existing Isovist fingerprints stored in a radio map for matching and localisation purposes.

The chosen methodology involves utilising 2D floor plans for the calculation and storage of Isovist parameters, which will serve as the database for the localisation process. These 2D floor plans provide a simplified representation of the indoor environment, capturing the layout and spatial relationships of rooms, hallways, and other architectural features.

Using the 2D floor plans, the necessary Isovist parameters will be calculated and stored. These parameters capture important characteristics of visibility and spatial configuration from specific vantage points within the building. By organising and storing these parameters, the floor plans act as a reference for fingerprinting (comparison and matching) during the localisation process.

On the other hand, point clouds are generated from simulated user movements within the indoor environment. These point clouds represent the three-dimensional data captured by LiDAR technology or similar scanning methods. They provide a more detailed and realistic representation of the actual physical space.

During the localisation process, the point cloud data from the simulated user's movement will be compared against the stored Isovist parameters in the database. This comparison will enable the determination of the user's location within the building, see Figure 3.

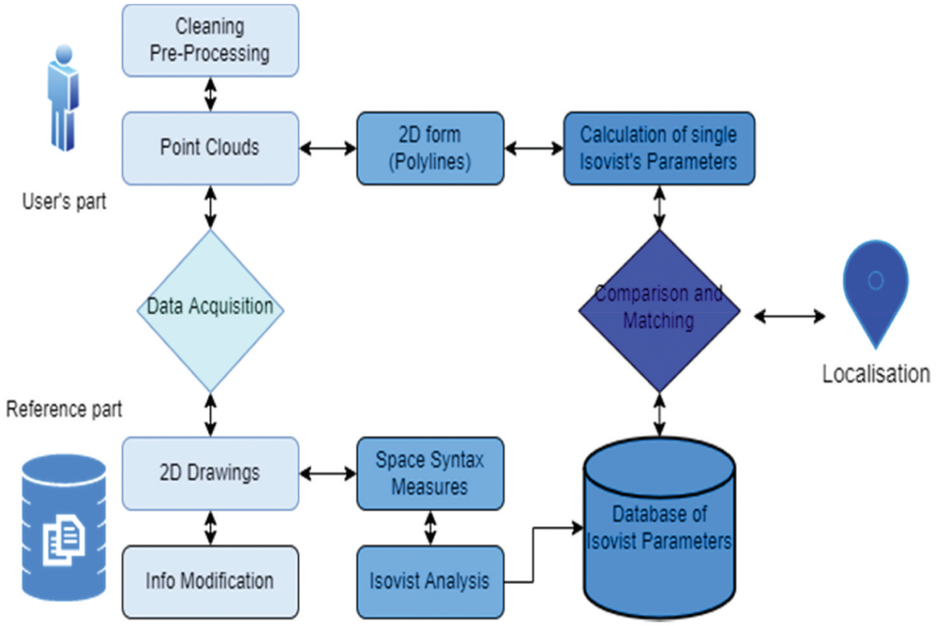


Figure 3. Research methodology in flowchart.

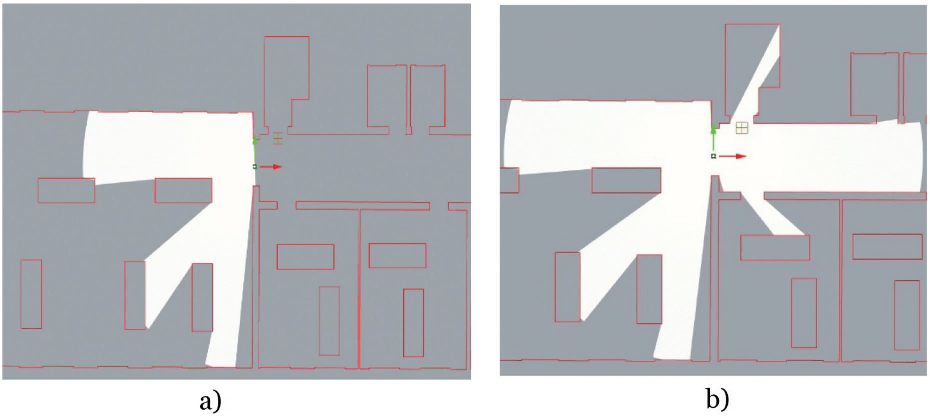
4.1. Experimental design and development

Additionally, selecting a suitable indoor environment to serve as a sample and test area was crucial to achieve the desired proof of concept. The chosen building for this project is the Faculty of Architecture and the Build Environment, which is renowned for its unique and intricate layout. With its multitude of rooms, stairs, and hallways, the building is known for being easy to get lost in. This selection provides an ideal setting to thoroughly analyse and evaluate the proposed methodology.

Throughout the following sections, the underlying idea and the step-by-step methodology employed in this research will be carefully examined. The focus will be on showcasing the approach taken to address the challenges of integrating user data with the existing Isovist fingerprints in order to facilitate accurate localisation within the complex indoor environment of the Faculty of Architecture and the Build Environment.

4.2. Data acquisition

The Isovist analysis in this project is conducted entirely in 2D, using 2D data as input. To facilitate this analysis, the official 2D floor plans of the Faculty of Architecture and the Build Environment have been gathered. These floor plans serve as the basis for the calculations and measurements involved in the Isovist analysis.


a)

b)

Figure 4. a) 180° directed to entrance room, 5m range; b) 360°, 10 m range (own figure).

To ensure a comprehensive and robust proof of concept, six rooms have been strategically selected as the sample areas for testing. These rooms have been chosen to cover a range of different scenarios and characteristics. Specifically, the selected rooms possess doors, windows, and furniture, and are distinct from other spaces within the building. Doors play a central role in the measurements and tests conducted during the implementation of the methodology. Windows, while not essential in most buildings, offer an additional level of complexity in the walls of the sample area, making the rooms even more unique. Furniture is particularly important for this technique, as it provides a high level of distinctiveness between the rooms.

For capturing the point clouds representing user movements, an iPhone 12 Pro was utilised, along with the PIX4Dcatch app. PIX4D is a Swiss company specialising in 3D digital mapping, photogrammetry, and computer vision. The choice of using an iPhone and the specific app was made to align with real-world scenarios, as users are likely to want to determine their location before entering a room. Consequently, the point cloud captures were taken from the entrance of each room, capturing the initial perspective of a user, see Figure 4.

By utilising the 2D floor plans, strategically selecting rooms, and capturing point clouds with the designated equipment and app, this project created a realistic and comprehensive dataset for the implementation and evaluation of the Isovist fingerprinting methodology.

4.3. Space syntax and isovist analysis measures

The next crucial step in the project involves calculating the necessary Space Syntax measures for the selected sample area. This includes the calculation of Isovists and conducting the Isovist analysis. To perform these calculations, the project utilises a commercial software called Rhinoceros 7. The project leverages its plugin Grasshopper, along with the specially designed DecodingSpaces toolbox (available at https://toolbox.decodingspaces.net/), to access a collection of analytical components tailored for architecture and urban planning. The toolbox provides extensive capabilities for calculating Isovists, conducting visibility analysis, generating graphs, and exploring various parameters of the Isovist field, Koenig et al. (2019).

To ascertain the significance of parameters in the presence context, a series of manual tests were conducted using Grasshopper, coupled with visual interaction in Rhino. This approach allowed for a thorough examination of the impact each parameter exerted on the outcomes, ultimately leading to conclusive insights into their importance.)

Average Radial denotes the mean view length of all observable space from a specific location. In Isovist terminology, it signifies the average radial length at that location, expressed as:

$$Q_V = \frac{1}{n}\sum_{i=1}^{n} L_i$$

Where n is the total number of sampled radials and L_i is the radial length.

Variance quantifies the mean of the squared deviations between all radial lengths and the average radial length within an Isovist (Benedikt 1979), which is expressed as:

$$T_V = \sqrt{\frac{1}{n}\sum_{i=1}^{n} |L_i - Q_V|^2}$$

Compactness characterises the shape property, relative to a circle, of the entire visible space from a given location. Within an Isovist field, compactness delineates the areas of a plan where an observer's spatial experience maintains contiguous consistency. Isovist compactness is expressed as:

$$C_V = \frac{4\pi A_V}{{P_V}^2}$$

Where P_V is perimeter and A_V is area.

Skewness (Sv) quantifies the average of the cube of deviations between all radial lengths and the average radial length within an Isovist (Benedikt 1979). In the terminology of visibility graphs, it serves as the third moment for a location. Skewness conveyed in the form of:

$$S_V = \sqrt[3]{\frac{1}{n}\sum_{i=1}^{n} |L_i - Q_V|^3}$$

Where Q_V is the average radial length from V.

Drift represents the distance from a subject point to the centre of gravity of its Isovist (R. Dalton and Dalton 2001). Within an Isovist field, drift discerns the natural ‘flow’ among a sequence of spaces, indicating the perceptible ‘pull’ or ‘push’ experienced from the volume of space itself (Isovist user guide, 2023). Drift parameter is expressed as:

$$M_V = \frac{\sum_{i=1}^{n} \left| {L_i}^2 . R_i \right|}{\sum_{i=1}^{n} {L_i}^2}$$

Where R_i is the coordinates of the nearest radial intersection.

Occlusivity quantifies the percentage of edges within an Isovist that lack a physical definition. It illustrates the extent to which previously concealed space becomes apparent during movement (Benedikt 1979). Occlusivity is conveyed in the form of:

$$O_V = \frac{k}{nP_V} \sum_{i=1}^{n} \left| {E_{i\_occ}}^2 . L_i \right|$$

where and k is the number of samples in a 360 degree cycle and E_{i_occ} is the fraction of the detected occluded edge.

4.4. Matching and localisation algorithms

The initial step is the transformation of point-clouds from LiDAR scans into a 2D projection/slice at a certain height, which is – in fact – the Isovist from the given viewpoint. While this process was primarily carried out manually, efforts were made to automate it as much as possible. The aim of automation was to streamline the process and reduce the manual workload involved.

The automation procedure involved several key steps. Firstly, the initial point-cloud data was subjected to voxel down-sampling. This technique reduces the size of the point-cloud by aggregating points within a defined volume, effectively simplifying the data representation. Additionally, a statistical outlier removal algorithm was applied to eliminate any ‘noise’ or erroneous points present in the point-cloud.

The algorithm developed for this project performs the following key steps:

- Connection and Loading: The algorithm handles the connection and loading of both the 2D data obtained from the floorplans and the 2D components derived from the user’s point-clouds. This step ensures that the necessary data is available for further processing.
- Isovist Calculation: The algorithm computes the Isovists, both for the database of pre-existing Isovists and for the single Isovists generated from the user’s side. Isovists represent the set of all points visible from

a specific vantage point in space, providing valuable information about the spatial configuration.
- Matching: The crucial task of the algorithm is to match the single Isovist from the user with the database of pre-calculated Isovists. This matching process involves comparing the features and characteristics of the user's Isovist with the stored Isovists. The algorithm identifies the most similar Isovist from the database, enabling the determination of the user's location. In addition to Euclidean distance algorithm, other distance algorithms were, such as Manhattan and Minkowski algorithms were applied and their performance were investigated:

$$\text{Manhattan Distance: } d(\mathrm{x},\mathrm{y}) = \sum_{i=1}^{n} |x_i - y_i|$$

$$\text{Minkowski Distance: } d(\mathrm{x},\mathrm{y}) = \left(\sum_{i=1}^{n} |x_i - y_i|^p\right)^{\frac{1}{p}}$$

5. Implementation

The testing phase of the project is divided into three main parts, each focusing on different aspects of the implementation:

- Evaluation of Isovist Parameters: In this part, the goal is to examine and evaluate the Isovist Parameters that are calculated using the DeCodingSpaces Toolbox in Grasshopper. The parameters generated provide valuable insights into the spatial configuration of the indoor environment. By analysing and assessing these parameters, their effectiveness and relevance for the research question can be determined.
- Evaluation of Distance Algorithms: The second part of the testing process involves evaluating different distance algorithms for the matching process. Matching the user's Isovist with the database of pre-calculated Isovists requires a suitable distance metric to determine similarity. This part aims to assess the performance and accuracy of various distance algorithms and identify the most effective one for the specific application.
- Localisation: The final part of the testing focuses on the actual localisation process. It involves applying the chosen distance algorithm to match the user's Isovist with the database and determining the user's location within the indoor environment. This step verifies the feasibility and accuracy of the proposed Isovist fingerprinting method for indoor localisation.

To facilitate the comparison and matching process, a grid was created to cover the entire building area. Each grid cell represents a specific location, and for each cell, an Isovist calculation was performed, resulting in a dataset comprising thousands of sets of 17 different parameters. These parameters capture diverse information about the spatial configuration of each grid cell.

In order to compare and match a single Isovist with multiple sets of parameters, it was necessary to normalise the data. The Average Normalization method was employed for this purpose. By normalising the data, it becomes possible to establish a consistent and meaningful comparison between the user's Isovist and the dataset of Isovists derived from the grid.

Once the data is normalised, the comparison and matching process can take place. Initially, the Euclidean distance, a commonly used distance algorithm, was applied to measure the similarity between the parameters of the user's Isovist and the thousands of Isovist sets in the dataset. This distance calculation provides a quantitative measure of the similarity or dissimilarity between the Isovists.

By employing the Euclidean distance algorithm, the project can assess the similarity between the user's Isovist and the dataset of Isovists based on the parameter values. This comparison process serves as a crucial step in determining the user's location within the building.

6. Results and analysis

To ensure reliable and meaningful conclusions, extensive tests were conducted by running the Grasshopper code multiple times with different combinations of Isovist parameters. The results were visualised to facilitate analysis and interpretation. The tests aimed to identify the most valuable and important parameters for accurate localisation.

In this study, a strategic selection was made of six rooms to encompass various testing scenarios. These rooms were required to have doors, windows, furniture, and be physically separated from other spaces within the building. The point clouds of these rooms were captured using an iPhone 12 Pro and processed using the PIX4Dcatch app, which is part of a suite of applications developed by PIX4D, a Swiss company specialising in 3D digital mapping, photogrammetry, and computer vision.

During the planning phase of data acquisition, it was determined that point clouds should be captured from the entrance of each room, providing a 180-degree view with a focus on the interior. Figure 5 illustrates the obtained point clouds for two distinct rooms.

The obtained point cloud data was initially subsampled to decrease its size and complexity. Additionally, the outliers within the data were eliminated using the 'Statistical Outlier Removal' function of CloudCompare software. Next, a cross-section was generated, ranging from 0.6 m to 1.20 m, to include the most significant information. One could oppose that positioning the cross-section at this height makes it susceptible to various dynamic challenges, such as moving furniture and people in the room. Consequently, opting for a cross-section at a 2-metre height may be a preferable choice, albeit with the trade-off of generating less rich/unique Isovists, see also Figure 8.

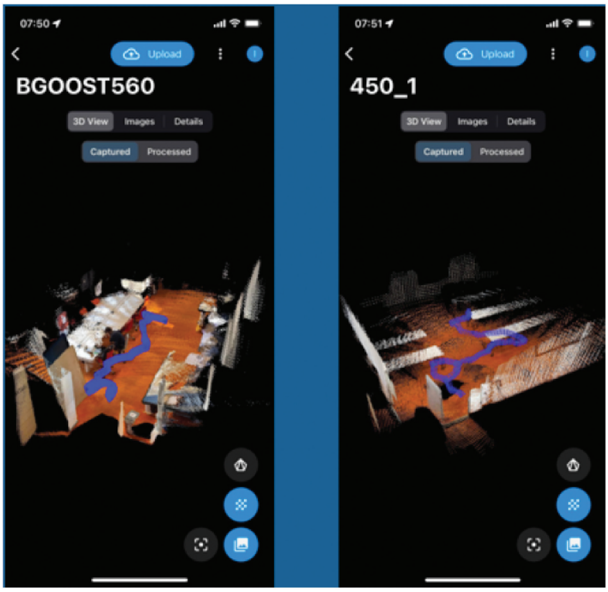


Figure 5. Example of acquired point-cloud from two different rooms, with the 180 degrees view and direction the interior of the room.

The dataset was then divided into two distinct parts: the 2D floorplan and the user point cloud. The 2D floorplans were created by processing the acquired point cloud data with AutoCAD software, as depicted in Figure 6.

The acquired point cloud data was utilised to generate Isovists and compute their parameters using the Grasshopper tool in Rhino7, alongside the DeCodingSpaces toolbox. Within Rhino, there are 17 Isovist parameters that can be directly calculated.

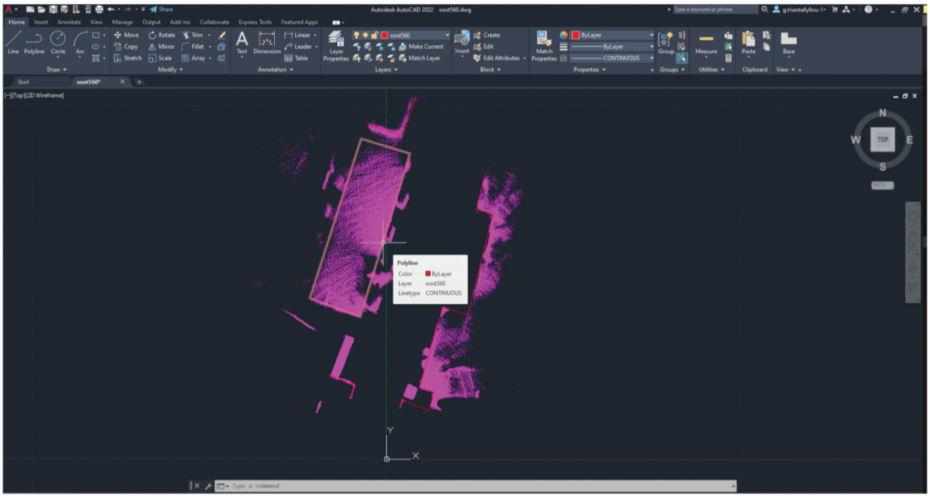


Figure 6. Example of creating 2D floor plan in AutoCAD.

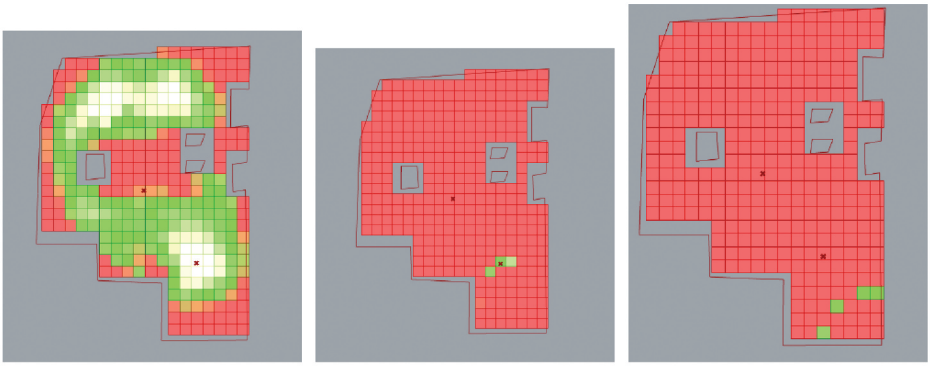
To apply the matching algorithm, a grid was established on the 2D floor plan. For each grid cell, the 17 Isovist parameters were computed. The similarity between each grid cell and the user's single Isovist was determined using a distance algorithm, employing the normalised values of the Isovist parameters.

Multiple experiments were conducted, varying the combinations of Isovist parameters, in order to examine the impact of different parameters on the matching results between the user's single Isovist and the database of pre-calculated Isovists from the entire sample area of the indoor environment (see Figure 7).

The parameters that emerged as highly influential for the results were Area and Perimeter. However, relying solely on these parameters was found to be insufficient for achieving accurate localisation. The parameter 'Drift Angle' exhibited a significant impact on the results, indicating its importance in the process. Other parameters, such as 'Occlusivity' and 'Compactness', were also found to affect the results to a notable extent.

Conversely, certain parameters played a minimal role in the localisation process. For instance, 'Skewness' and 'Variance' appeared to have negligible effects on the results during the tests. Consequently, the exclusion of these parameters would not alter the localisation outcomes significantly.

The majority of the localisation and positioning tests were conducted in Grasshopper, utilising both artificial and real spaces. Furthermore, to gain deeper insights into the results, tests were performed with and without furniture, creating scenarios with varying levels of object density. This allowed for an



(a) 14 params - 360 angle

(b) 17 params - 360 angle

(c) 15 params - 180 angle

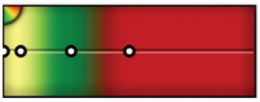


Figure 7. Example of performing tests with different parameters.

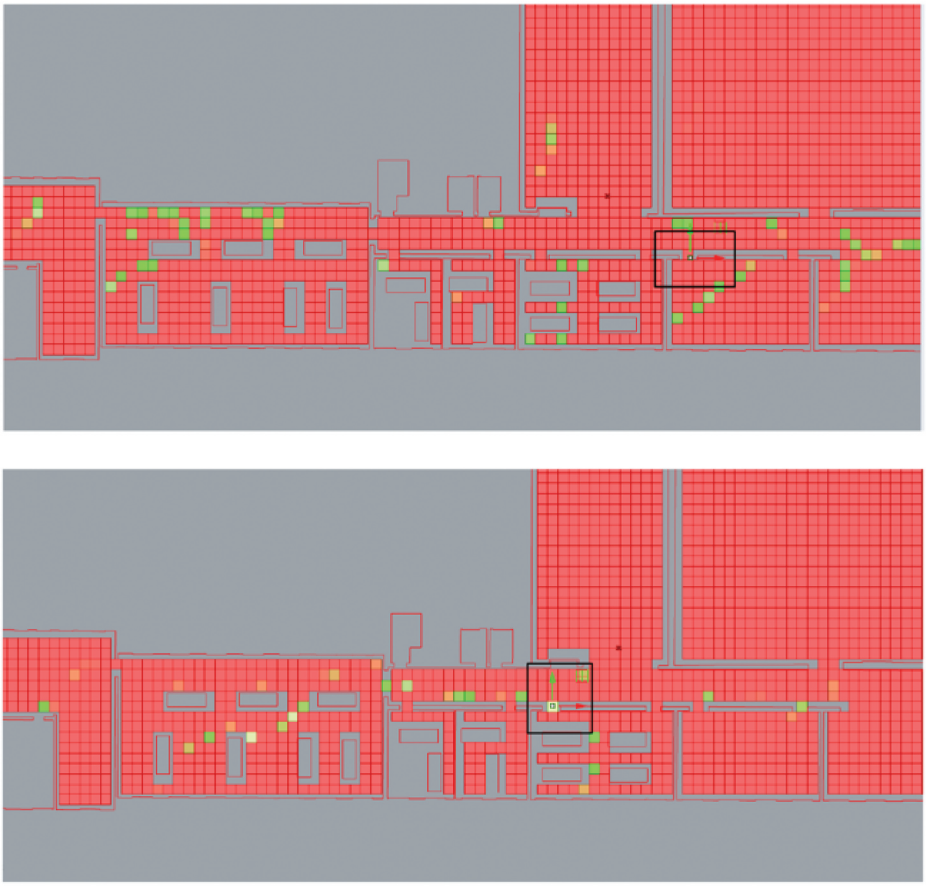


Figure 8. Matching result for a room without (above) and with (below) furniture colour ramp from red (no match), over green, to white (full match) as in Figure 7.

exploration of the method's effectiveness in empty rooms with minimal obstacle information.

Figure 8 illustrates an example of rooms with and without additional objects. In the first image, the single Isovist representing the user is located in a grid cell that is highlighted in red, indicating an incorrect result. Conversely, in the second image, the cell is nearly white, suggesting a high probability of obtaining the correct result.

Furthermore, another test was conducted to investigate the effect of using different distance algorithms (Figure 9). The results indicate that the Euclidean distance algorithm outperforms the Manhattan distance algorithm when it comes to Isovist matching.

By conducting comprehensive tests with diverse parameter combinations, both in artificial and real environments, the project was able to evaluate the impact of different parameters on the localisation process. These findings

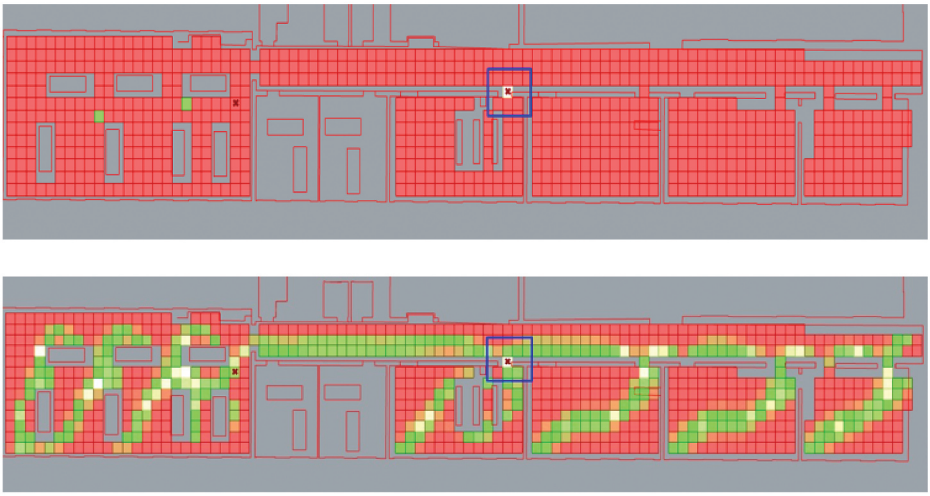


Figure 9. Matching outcome on applying Euclidian (above) and Manhattan (below) distance algorithms. Take note that the cell's colour in the blue box is nearly white, signifying a high probability of yielding accurate results.

contribute to a better understanding of the method's performance and its potential application in various spatial contexts.

7. Conclusions

The visibility from a specific vantage point in space is determined by the geometric configuration of obstacles and the unique characteristics of the environment. In the context of this research, the final localisation result is influenced by these factors. However, it is important to note that the matching and outcome of the localisation process are solely based on the comparison between the Isovist parameters.

To enable accurate localisation, a database comprising numerous sets of Isovist parameters is necessary. This database can contain tens, hundreds, or even thousands of such sets. The user's single set of Isovist parameters is then compared and matched against the sets in the database. This comparison forms the basis for determining the user's location within the environment.

The importance of different Isovist parameters varies depending on the uniqueness and complexity of the environment. The Area, Perimeter, and Drift Angle parameters are found to be of highest importance in determining the correct location. On the other hand, the Variance and Skewness parameters have the least impact on the localisation results.

This implies that not all 17 parameters are equally necessary in every situation. In highly unique and obstacle-rich rooms, the combination of Drift Angle, Area, and Perimeter parameters is sufficient to achieve accurate localisation.

However, in rooms with fewer unique characteristics, these three parameters alone may not be enough, and the inclusion of the remaining 14 parameters becomes crucial to increase the likelihood of a correct match and localisation.

By understanding the relative importance of different Isovist parameters in different environments, it becomes possible to optimise the selection and combination of parameters for accurate localisation. This flexibility allows for adaptability to various room types and levels of uniqueness, enhancing the effectiveness of the localisation method.

In order to perform the final comparison and matching of the data, the created database consisting of sets of Isovist parameters is compared to the single set of Isovist parameters obtained from the user. To determine the closest fit and provide the possible location of the user, the Euclidean Distance algorithm is used.

The Euclidean Distance algorithm calculates the distance between the user's Isovist parameters and each set of parameters in the database. By measuring the Euclidean distance, which represents the straight-line distance between two points in the parameter space, the algorithm identifies the set of parameters in the database that is most similar to the user's parameters.

The matching process involves finding the database entry with the minimum Euclidean distance to the user's Isovist parameters. This indicates the closest fit or the best match between the user's data and the database entries. The location associated with the matched set of parameters in the database is then considered as the possible location of the user within the indoor environment.

By employing the Euclidean Distance algorithm, the method aims to estimate the user's location accurately by comparing their Isovist parameters with the database. This approach provides a quantitative measure of similarity and allows for efficient matching, contributing to the effectiveness of the localisation process.

8. Recommendations

This research serves as a proof of concept rather than a final product ready for use. Nevertheless, it provides valuable insights into the use of Isovists and represents the first step towards this approach to indoor localisation.

One important limitation to acknowledge is that further work is required to fully automate the data capture process from the user's side and establish real-time connection with the database. This would enhance the practicality and efficiency of the method, allowing for seamless integration and real-time localisation.

Looking ahead, the proposed method has the potential to extend beyond human users and be applied in various scenarios. For instance, it could be utilised to track and manage expensive equipment within complex buildings such as hospitals or airports. By equipping the equipment with a LiDAR camera sensor device and matching the captured data with the database, real-time location or position information can be obtained.

To achieve these goals, additional research and development efforts are necessary. The implementation of a dedicated mobile or web application that integrates all components of the method into a functional and user-friendly interface would be beneficial.

Furthermore, considering the growing prominence of Building Information Modelling (BIM), utilising BIM models of buildings can greatly enhance the effectiveness of the Isovist method. BIM models contain detailed information about objects and obstacles within the building, which can further improve the accuracy and efficiency of the localisation process.

Additionally, exploring the concept of 3D Isovists, see Díaz-Vilariño et al. (2018) holds promise for future advancements. By incorporating three-dimensional information, the research can be further enriched, opening up new opportunities for improvements and enhancing the accuracy of the method.

In conclusion, while the current research represents a proof of concept, there is significant potential for future development and application in various domains. With further automation, integration, and the exploration of advanced techniques such as BIM and 3D Isovists, the method can be refined and expanded to offer enhanced indoor localisation capabilities.

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