Laying a foundation for landmark-based navigation by exploring a pure landmark-based approach for indoor localisation

MSc Geomatics Thesis Proposal

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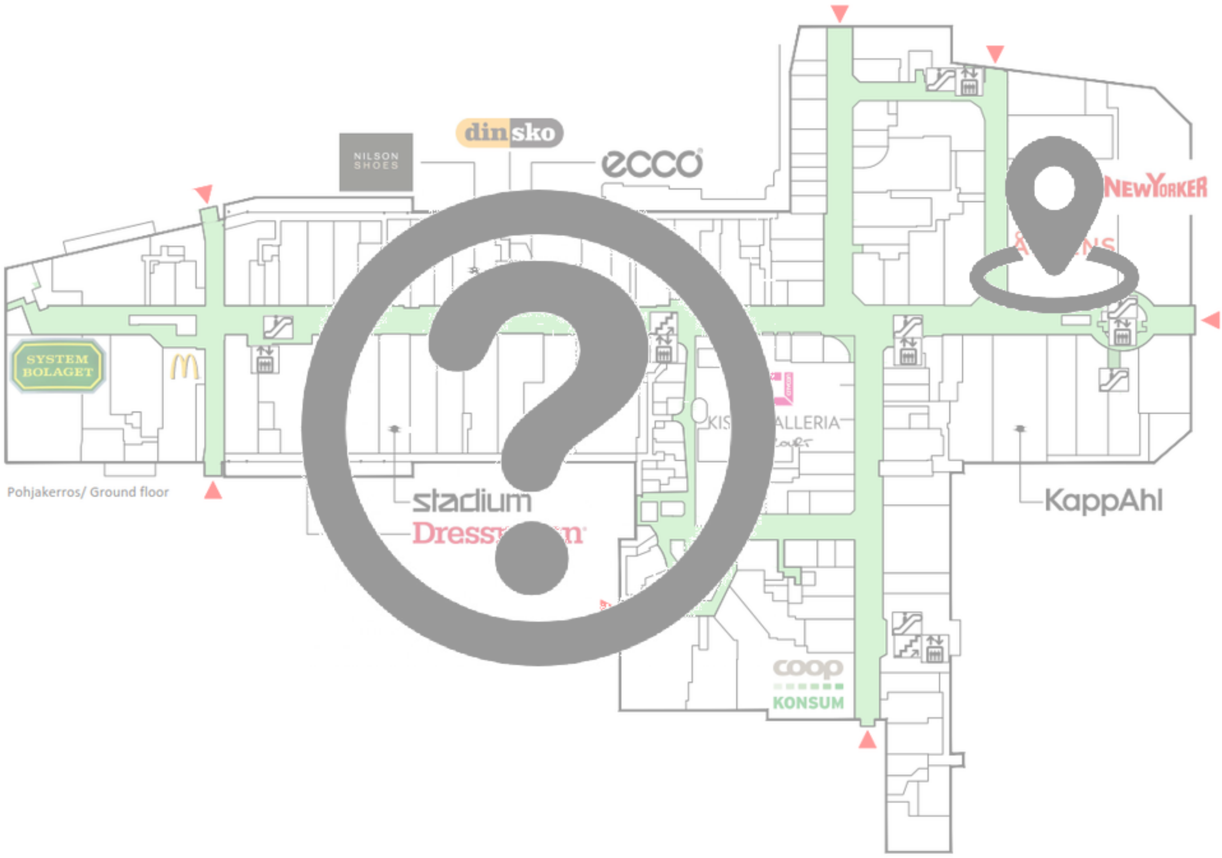

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1 Introduction

This thesis is part of the master's program of Geomatics at the Faculty of Architecture and the Built Environment, as the culmination of one year of core courses and a quarter of electives. The thesis will try to push the boundaries of what is known and what is possible, by experimenting with existing techniques and methods in order to create a new method or enhance existing methods. By looking at challenges in the daily routines within the built environment, this thesis will try to solve one (or multiple).

1.1 Problem statement

Nowadays, humans depend on a lot of (smartphone) applications in order to save time and effort. Localisation and navigations tools are among the most used tools when leaving the house to go somewhere and to get around, but due to the reliance on these services humans are starting to lose their navigational skills making them rely even more on navigation technology according to McKinlay (2016). These services are expected to always be available and always be reliable, however with the challenges of localisation in the 'indoor environment', where GPS/GLONAS/etc. positioning systems don't function adequately, navigation becomes quite the challenge. There is an increase in public areas that are considered outdoors (out of the home and office) but are technically indoors, i.e. shopping malls, underground infrastructure: public buildings with a roof. Performing outdoor activities in these indoor environments can pose a challenge to GPS signals to for example navigation, gaming and GPS-based fitness, see Figure 1.

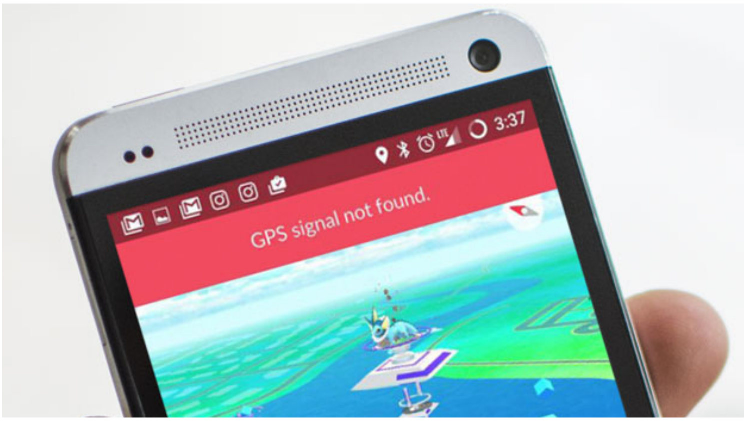


Figure 1: Example of a lack of GPS signal during an 'outdoor' activity in a shopping mall

In ancient times before GNSS, sailors used their relative position to the stars to determine locations on open seas. Roman strategists drew maps with context to give a sense of location and bearing to know what is north and south, left and right, and how to march toward the battlefield. In the ages before smartphones and navigation systems, humans navigated based on context, where relative positions (in front of, next to, behind, above) were linked to identifiable objects, known as landmarks (church, the baker, a park, etc.), to determine where one was within the context, and then navigation based on instructions that only used these objects/landmarks, see 'A brief history of navigation' by Sobel (1998). A precise location in Cartesian space (x,y,z) was after all impossible due to the lack of positioning systems and paper maps, the best approximation of location within space was "in proximity of a certain object (i.e. church)" or "roughly x amount of miles/hours away from the closest landmass".

The gap between localisation and navigation in indoor compared to outdoor environments has resulted in number of techniques to bridge the gap: applications that use triangulation, trilateration of users based on Bluetooth, Wi-Fi, or other sensor beacons (comparable to the GPS approach, but on a more local level), or the fingerprinting of the (static) indoor environment based on signal strengths of Wi-Fi access points, or cameras to localise users within the indoor environment. Many of these techniques are applied to a select set of indoor environments since these are techniques that are very location specific and costly.

A challenge in the field of localisation and navigation is to find a technique that doesn't depend on costly indoor sensor networks, and that is not location specific, i.e. by using commonly available features of the environment and exploiting existing human capabilities. With the emergence of new technologies that range from being able to recognise features in the surrounding environment (i.e. Google Lens), to optic sensors in autonomously driving cars that provide real-time object tracking and recognition (i.e. Tesla's autopilot), to added reality layers with augmented reality technology (Google Glass), see Figure 2, it is now possible to use previously impossible techniques in daily challenges, by using advanced image processing and recognition there are new ways to conquer the urban (indoor) environment, and specifically our way of interaction and navigation within this environment.

(a) Google Lens technology, source: Google

(b) Tesla's Autopilot with sensors, source: Tesla

(c) Google Glass with augmented reality, source: Google

Figure 2: Technological advances for interaction with context

1.2 Relevance

Within the field of navigation there is already a lot of work done in navigation centred around high precision localisation (GNSS but also Wi-Fi and Bluetooth) due to the availability of these precision localisation systems, however, the field of contextual navigation has not seen as much interest. The same goes for open space navigation compared to network-based navigation: network-based navigation is a field that usually has the network as a given and applies algorithms on that network, where open space navigation first has to deal with a way on how to move around on which network (if traditional network navigation wants to be applied). Solving (or the attempt of solving) the challenge of (open-space) indoor localisation and navigation based on context without a network of sensors that is specific to a location, could be the next leap for providing the same services indoor that are already commonly relied upon outdoors.

2 Related work

The challenge of indoor navigation is threefold: you have to localise a user first (due to a lack of GNSS), then give the user a set of directions, and lastly, make sure the user knows its orientation within the context/built environment in order to execute the directions. Then there is the context of the environment that determines the navigational behaviour and needs. By combing the challenge of navigation centred around the (open-space) indoor context with navigation based on objects, the following topics can be explored more in depth: 1) general navigation, localisation, orientation, and specific challenges arising from open-space and the indoor environment and 2) the (open-space) indoor environment itself that includes landmarks and specific challenges for the indoor environment.

The following subsections will provide an overview of existing research on each part.

2.1 General navigation

Getting from A to B in the urban context is a daily activity, where the concept of wayfinding and navigation are often interchangeably used. According to Montello navigation can be called *" the coordinated and goal-directed movement of one's self (one's body) through the environment"* Montello (2005). He proposed the conceptualisation of navigation as existing of two components: *wayfinding*, localising oneself and the destination in the urban context and picking a route to take; and *locomotion*, which describes the movement of one's self (one's body) in the direction of the intended destination while avoiding obstacles and barriers.

Although wayfinding and navigation are commonly used interchangeably, Montello sees a sharp distinction, wayfinding is only "the goal-directed and planned travel of one's self around an environment in an efficient way" without specifically denoting how to physically move Montello (2005). Within wayfinding, Redish elaborates on three types of wayfinding applicable for humans (random navigation, route navigation and locale navigation) Redish (1999) based on animal research into ways an animal can find a platform.

1. *Random navigation*: If the subject has no information about the location of the destination within the context, it must search randomly for it.
2. *Route navigation*: Route navigation can be thought of as chaining sequences of taxonomic and praxic sub-strategies, where the subject can learn to associate a direction with each sensory view and sequence tasks.
    a) *Taxonic navigation*. The subject can find a landmark toward which it can always navigate. For example, if the landmark is visible, it can simply "walk towards the landmark".
    b) *Praxic navigation*: The subject can execute a constant motor program. For example, the subject follows a fixed distance with a fixed orientation (walk 100 metres in a straight line westbound or turn left in 100 metres), it can use the praxic navigation to reach the destination.
3. *Locale navigation*: The subject can learn the location of the destination relative to a constellation of cues. It can learn a map on which the location of the destination is known. If it knows both its own location and the location of the destination in the same coordinate system, then it can plan a path from one to the other.

What is interesting is that 'locale navigation' is the way humans usually read maps if they don't have access to their real-time precise location: find oneself, find the destination and find clues in between to get there. If humans have access to a real-time precise location they tend to use route navigation with praxic navigational instructions (go left in 100 metres, continue for 50 metres straight and you have reached your destination). Route navigation using taxonomic navigational instructions would be to use the context to navigate a user, even though the exact location of the user is not known to the user.

Richter developed a framework that would apply the concepts of Redish into strategies on navigation through the environment based on context, by asking the question "how humans actually find their way" with the answer planning the route in advance and following it Richter and Klippel (2004) or getting constant updates. So for navigation, it is important that the subject/the user/the human has a sense of its own location, has an awareness of the context, knows where the destination is and is able to find clues and follow cues. And depending on localisation techniques, a taxonomic or praxic approach to route navigation will result in successfully reach a destination.

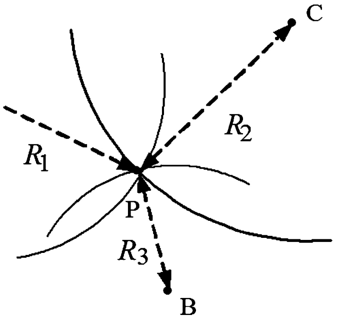
Chun & Kim filed for a patent in 2003 that describes a now commonly used traditional vehicle navigation system as a "navigation apparatus has a satellite signal receiver and a mileage calculator, which determines a current location of a vehicle based on a satellite signal and a mileage of the vehicle to its destination, and transmits information about the vehicle location from a mobile terminal to a base station transceiver system (BTS) periodically" Chun and Kim (2003) where nowadays the BTS is computationally powerful enough and compact enough to fit on your car's dashboard (car navigation) or in your hand (smartphones).

2.2 (Indoor) localisation

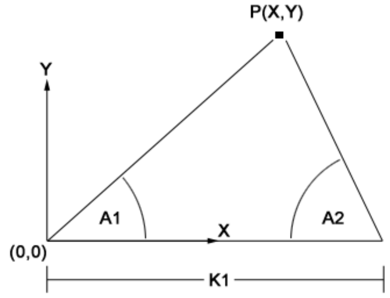
Localisation is the field that looks into accurately positioning subjects in the (urban) context, by using sensors and/or positioning/localisation systems. The difference between localisation and positioning is that localisation tries to pinpoint where you are on a map or within the context and where positioning aims for the Cartesian location with x,y coordinates according to robotics researcher Gezici et al. (2005) (like the P in GPS, Global Positioning System). Werner (2014) distinguishes three types of positioning/localisation approaches based on their working principle:

1. 1) *"Terminal-based positioning in which the mobile device calculates position without depending on some infrastructure"*
2. 2) *"Terminal-assisted positioning in which the positioning is distributed between infrastructure elements and the mobile device"*
3. 3) *"Terminal-free positioning in which a mobile device is located while the mobile device is passive"*

Terminal-assisted or system-based localisation uses a network of transmitters and receivers to send signals to the receiver (usually carried by the subject) and either through a one-way connection (in the case of GPS) or a two-way connection (localisation through cellular, Wi-Fi or Bluetooth). Liu et al. (2007) surveyed wireless systems and distinguished several ways to position objects/user indoors, systems that rely on the time it takes for a signal to travel back and forth between transmitter and receiver (round-trip time of flight, RTOF), one-way time of arrival (TOF) or received signal strength (RSS) in order to trilaterate a position, and wireless systems that use angle of arrival (AOA) for triangulation, see Figure 3. By mapping the RSS of the different beacons the environment can be subdivided into regions with a certain fingerprint of RSS, Xiao et al. (2011) for example applied this method on a Wi-Fi based wireless system, which resulted in a method called Wi-Fi fingerprinting, each area has a unique combination of signal strengths for each beacon.



(a) Positioning based on TOA/RTOF measurements (trilateration), Liu et al. (2007)



(b) Positioning based on AOA measurement (triangulation), Liu et al. (2007)

Figure 3: Principle of indoor positioning using wireless systems

The user-based localisation(off-line) uses information presented to the user (through physical maps, an app or service) and let the user or the user's device use this information to localise oneself/itself, the user uses visual clues in the context to find a position on a (paper) map or the device is able to identify objects in the environment (QR codes, through object recognition, etc.).

2.3 (Open-space) indoor navigation

In the field of robotics and automated mapping, there is a clearer definition of open-space environments within navigation and mapping. Yamauchi's research in the automatic mapping and navigation of robots distinguishes between open-space environments and unexplored space. Robots perceive the open-space environment as the connectivity or arrangement of open regions with accurately mapped obstacles (usually these obstacles are mapped in advance by humans) Yamauchi (1997). This perception of an open-space environment within robotics research combined with common understanding of open-space result in the following definition: *open-space is defined as a (series of) bounded/enclosed geometric open region(s), optionally containing obstacles.*

When talking about the indoor environment there are actually two 'indoor' environments: the actual indoor environment within buildings/structures (i.e. shopping malls, museums and underground) and the outdoor environment where existing GNSS systems don't function adequately (i.e. close to buildings where GNSS signals are blocked or delayed by multipath effects, or inside buildings) according to research into GPS signal strength indoors by Peterson et al. (1997).

Within the indoor environment, there is the added challenge of not having a set network to navigate on, compared to the availability of outdoor navigation networks for cars and other road users. The open-space with obstacle characteristic of the indoor environment creates a chaotic and cramped environment where objects and destinations are visibly blocked on a very local scale, and where navigation becomes an art of dodging obstacles, moving around barriers and anticipate moving objects (i.e. humans, cars or ROVs). Mortari et al. (2014) lists several reasons why indoor navigation is such a challenge: "positioning is not very accurate, users can freely move between the interior boundaries of buildings, path network construction process may not be easy and straightforward due to the complexity of indoor space configurations."

Using traditional navigation methods, that rely on an edge-node network, in the open space and indoor environment requires that the environment is prepared appropriately for these methods. Usually, the indoor space is therefore subdivided into spaces through which a subject can move and information about how to move between these spaces. There are several methods developed that deal with the subdivision of space, Krūminaitė and Zlatanova (2014) and Xu et al. (2016) proposed a methods for subdivision of space that would "provide the most optimal path and guidance." by subdividing space "into navigable and non-navigable areas considering human perceptions of the environment and human behaviour [...] by applying a constrained Delaunay triangulation", see Figure 4. Zlatanova et al. (2013) proposed a framework that can do an "automatic subdivision of indoor space and on-the-fly creation of a gridded or irregular network." where space is tiled rather than subdivided by context. Later this model is extended by Sithole and Zlatanova (2016) by including different types of placement (i.e. XYZ and room number), attributing resources and agents with modifiers to determine access and usage, sub-space inherent modifiers from resources and agents, and where there is no distinction between obstacles and resources, but just resources with modifiers about access and usability (not accessible equals an obstacle).

The next step after having a subdivision of space is to get an edge-node network that supports network-based navigation and route calculation. One method of determining a route within the subdivided space is to calculate paths using the duality of the subdivided space, like you would

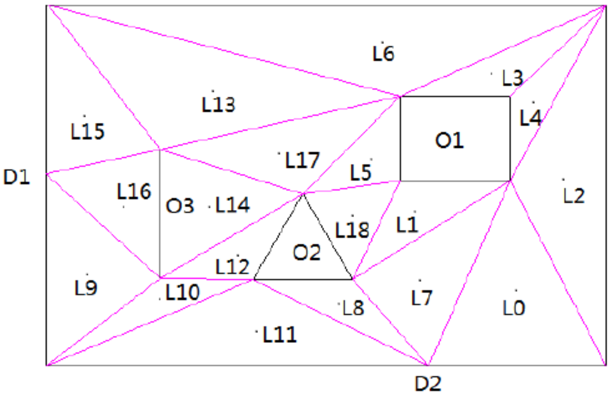


Figure 4: Subdivision of space using a constrained Delaunay triangulation, Xu et al. (2016)

on an edge-noded vehicle navigation network, as Xu et al. (2016) demonstrates in their framework: transversal between adjacent spaces is possible if the shared edge is not one of the edges from the constrained Delaunay (i.e. walls or obstacles), calculating the shortest route on this duality-graph provides a route, by simplifying this route afterwards, a more appropriate human route is the results, see Figure 5.

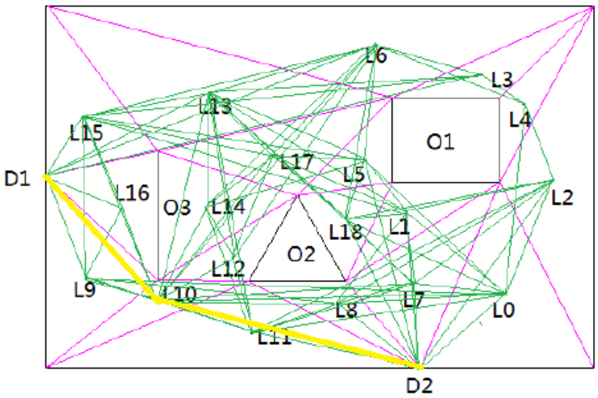


Figure 5: Duality-graph from subdivision of space, and simplified shortest path, Xu et al. (2016)

2.4 (Indoor) orientation

Within the field of image processing and remote sensing, orientation is usually linked to optic sensors, think interior and exterior orientation of camera's, where there are 6-degrees if orientation and calibration of these degrees are vital, per Zhang (2000). Orientation determines the relative position (XYZ) and rotation of the optic sensor in regards to the context. Orientation also has a close connection to topology, they both describe relationships between subjects/objects in a context, where topology can be more the physical relation and orientation a more directional relation (angular relation). In the paper about position and location,Sithole and Zlatanova (2016), direction to objects is highlighted as an important part to determine position, knowing if you are in front or under an object if you are with your back against an object or facing an object, all determine quite specifically one's relative position to an object, not geographically (XYZ) but contextually. Both principles apply to humans (technically also consisting of optical sensors as with remote sensing), where orientation deals with the subject's sense of position and 'rotation' within an environment, it is about being able to relate (known) objects within the context of one's location, the angular relation of human with context, i.e. in front, behind, above, below. Knowing where you are in the (built) environment is not enough, it's just a part, knowing where you have to go within the context and how the context relates to you while you are moving towards one's destination is equally important.

German researchers, led by Ramirez created the ad-hoc application called Landmarke, that provides firefighters with a navigational support system, that ties wayfinding and orientation within the context together by using landmarks to help in getting around Ramirez et al. (2012). Orientation within the environment was achieved by using, for example, thermal cameras to be able to locate warm surfaces, have fire-lighters recall object that stood out of the context to determine where they had last seen their colleagues. Landmarks were used to determine the position based on their orientation in regards to the fire-fighters.

Russo et al. (2014) created a qualitative directional model, that would classify the 360-degree space around a user or wayfinding cue into quadrants that are associated with the human sense of direction, see Figure 6. This helps in directing the subject to follow the right path. The same method of direction could be applied to have a sense of bearing towards landmarks and for indoor localisation, compared to the approach Russo employed that only touched on the use of landmarks for indoor wayfinding.

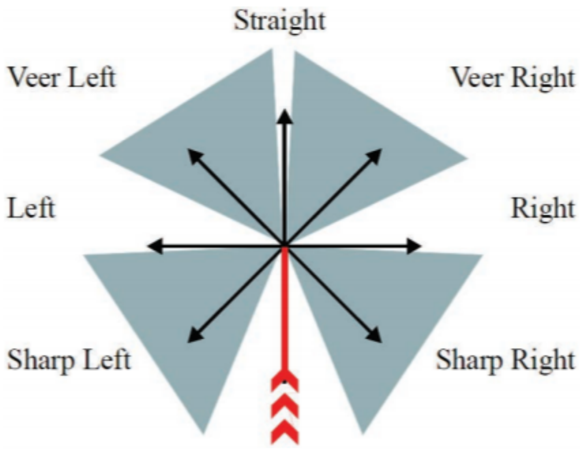


Figure 6: Qualitative directional model, Russo et al. (2014)

2.5 Landmarks & context

For context aware application, there has to be a definition of objects that make up the context, in history and in literature objects that stand out from the surroundings are labelled landmarks to be commonly accepted, in the early days of sailing it could be celestial constellations, land features, and lighthouses, see Sobel (1998). Roman generals would draw maps with features that stood out within the landscape. Tourists get around cities by following skyline outlining structures, i.e. the Eiffel Tower in Paris, or the Big Ben in London. Classically landmarks are large structures that are highly visible.

Golledge (1999) determines two important roles of landmarks for wayfinding: 1) helping in organising space by providing categories to pinpoint objects within the fabric of to the environment, and 2) serve as objects within navigation where a decision can be made by functioning as directional cues and wayfinding clues. In this sense, landmarks can be anything that helps a subject in wayfinding, from the tallest Eiffel Tower to the smallest pebble on the road (if it is a bright colour and stands out from other pebbles).

There are still numerous challenges when it comes to landmarks, Richter (2013) highlights the potential of landmarks after comparing a multitude of approaches using landmarks, he establishes that landmarks play an important part in the visual communication of (indoor) space, and sees the emerge of user-generated information (such as OpenStreetMap) and services that work through images, like Flickr, as stepping stones for a commercial use of landmarks.

Raubal and Winter (2002) and Klippel and Winter (2005) in collaboration with Stephen Winter of The University of Melbourne have extended the *'wayfinding choreme theory'*, formalised theory for wayfinding to also integrate landmarks into route direction with the formalisation of *'the salience of landmarks as dominant objects in route knowledge and route directions'* as the recognition of the added value of landmarks within wayfinding and *'the conceptualization of wayfinding actions in relation to landmarks, i.e., the integration of landmarks in the formal specification of a conceptual route language'*, which describes the role of landmarks within instructions.

Research from Graser (2017) into landmarks resulted in an interesting addition to traditional network-based (car) navigation, where landmarks were used to add context to a route, and have directional clues not just on XY location and praxic instructions (i.e. turn left in 100 metres), but also have taxonomic instructions that use the visibility of landmarks within the context. Graser as one of the key figures behind open source GIS applications (OSGeo's QGIS) used objects stored in OpenStreetMap as landmarks and based on their characteristics enrich navigational instructions, to make users more aware of their environment when navigation (rather than staring at a smartphone screen when the 100 metres have passed).

Landmarks can come in all sizes, shapes, and appearances: Ramirez et al. (2012) talked about heat images from a thermal scanner to orient oneself in the building, Anacta et al. (2017) describes landmarks as recognisable places that humans can (abstractly) draw when having to explain the context on a hand drawn map to a stranger, Vasardani et al. (2017) labels landmarks within an indoor environment as "to either not belong to the set of usual building structural features and furnishings, or if they do, then their properties (and perhaps functions) deviate from the prototypical ones of the set", Presson and Montello (1988) determines the minimal definition of an (elusive) landmark as any distinct object that is noticed and remembered, for an example see Figure 7. All research into landmarks uses the visibility of landmarks in the generation of instructions or to familiarise the user with its context.

(a) Eiffel Tower source: WikiCommons

(b) A distinguishable door source: Pixabay

Figure 7: Two objects that could be labelled as landmarks

3 Research questions

In order to address the challenge of indoor localisation and navigation by using the context, the main research question for this thesis is:

> *To what extent can a pure landmark-based approach achieve adequate indoor localisation in order to lay a foundation for landmark based indoor navigation?*

Where the '(open-space) indoor environment' is considered as an 'enclosed (series of) geometric open regions without a clear path for navigation and with obstacles, either in 2D or in 3D', and where a 'landmark' is considered as 'any object, resource (destinations and obstacles) or agent that is distinguishable from its context (i.e. noticeable and can be remembered), and should, therefore, be used for navigational cues for wayfinding and orientation'.

In order to answer the main research question, the capabilities of the landmark-based approach will be researched, by developing a proof of concept for landmark based localisation indoors:

1. *Within the indoor environment what can be considered a landmarks for localisation (and navigation)?*
2. *Which localisation principle shows potential for a pure landmark-based approach?*
3. *Which landmark parameters are most salient for indoor localisation?*
4. *How can a landmark be semantically described in a database in terms of description, hierarchy and context relation?*
5. *How can a landmark be geometrially represented in a database for visibility analysis?*
6. *Does the geometric or semantic representation of landmarks influence the visibility analysis?*
7. *Does the number and constellation of landmarks influence accurate localisation?*
8. *Can the relative position of a subject in relation to landmarks (orientation) be used to improve localisation?*

After evaluating landmarks for indoor localisation, the provided insights from achieving indoor localisation through a pure landmark-based approach can be used to lay a foundation for landmark based indoor navigation in future studies, by answering the following questions:

1. *Can landmark based fingerprinted regions be used for navigation?*
2. *Can the location of landmarks be solely used in navigational instructions or are additional characteristics required that describe the landmark in its context?*
3. *Are landmarks only usable if they are in close proximity of a computed path or are far away visible landmarks also usable?*
4. *Which landmark parameters are critical for creating navigational instructions?*
5. *Which criteria are most significant for selecting landmarks along the computed path (sub-selection of navigational instructions)?*

3.1 Scope

During this research the focus will be on developing a proof of concept for indoor localisation based on landmarks and writing a future work recommendation for landmark-based navigation The research will have an artificial test cases as starting point where there are fictitious landmarks within the indoor environment, in different constellations, where there is a floor plan of the indoor environment with obstacles, and where there is (existing) technology/human/device that can recognise objects (i.e. that is not part of the research), where the output from the sensor is conceptualised and explored to fit the principle of landmark-based indoor localisation. This will be a research into landmarks and how they can work in existing indoor localisation principles or if a new principle has to be conceptualised, Figure 8 shows how indoor localisation and indoor navigation are tied together where the combination of indoor localisation and indoor navigation results in a real-time/dynamic navigation. The focus of this research within the broader picture of indoor navigation will be on solving the indoor localisation (marked with red rectangle).

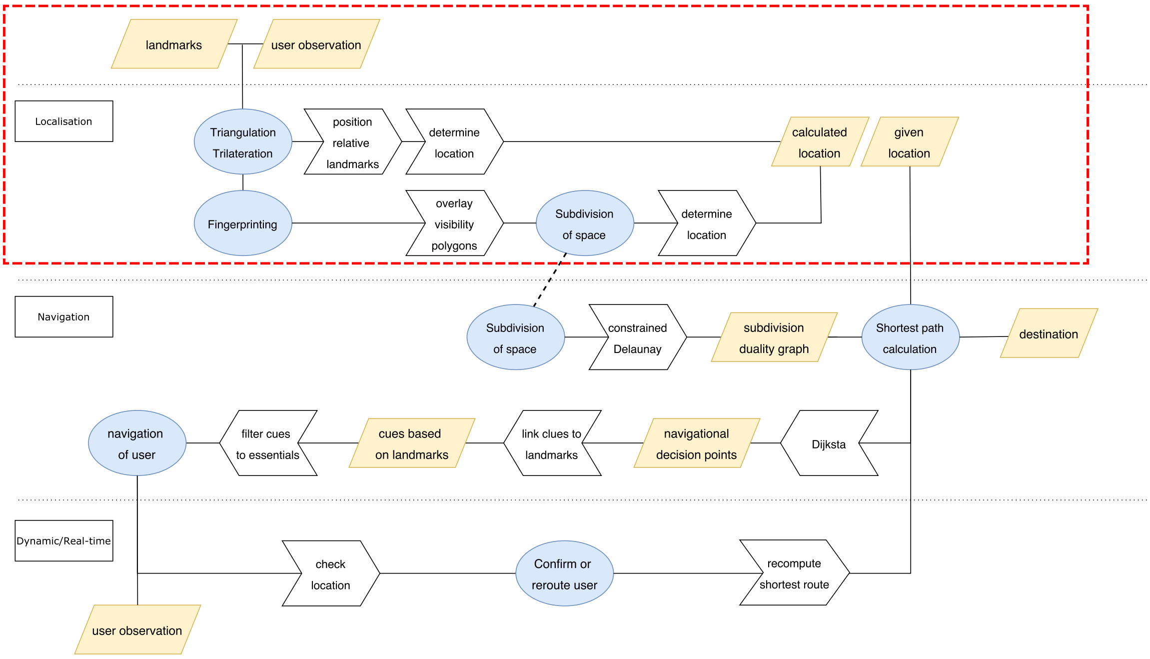


Figure 8: Cyclic approach to indoor navigation with (landmark-based) indoor localisation

4 Methodology

In order to get a fully integrated framework for localisation and how in the future it can be incorporated into navigation, the research is split into a few smaller pieces of research that will look how landmarks can work in localisation principles: 1) the research into the formalisation of landmarks both geometrically as well as semantically in a database, 2) developing and implementing a proof of concept for the visibility fingerprinting of landmarks, 3) getting an approximate location based on a fingerprinted subdivision of space, either regions derived from landmarks or regular subdivision of space, and 4) a recommendation on how landmarks could be used do instruct a user to go from A to B.

There are the different principles of (indoor) localisation (lateration, angulation, fingerprinting), for each principle the same workflow can be applied, see Figure 9: the formalisation of geometry, proving the visibility based analysis for a principle, the localisation based on a subdivision and an evaluation on how to incorporate in future navigation.

4.1 Define landmarks for indoor localisation (and navigation)

Before landmarks are formalised into a logical schema to be implemented in a database, the conceptual schema of what is considered a landmark has to be explored. By looking around in the indoor environment and making an inventory of objects that are distinguishable from their context, a hierarchy and classification can be identified, this will form the basis for the semantic and geometric representation of landmarks. This step reflects on the literature about landmarks, where any object could be a landmark, however one landmarks is more salient than others. Identifying this salience results in a better grasp of what a landmark makes a landmark.

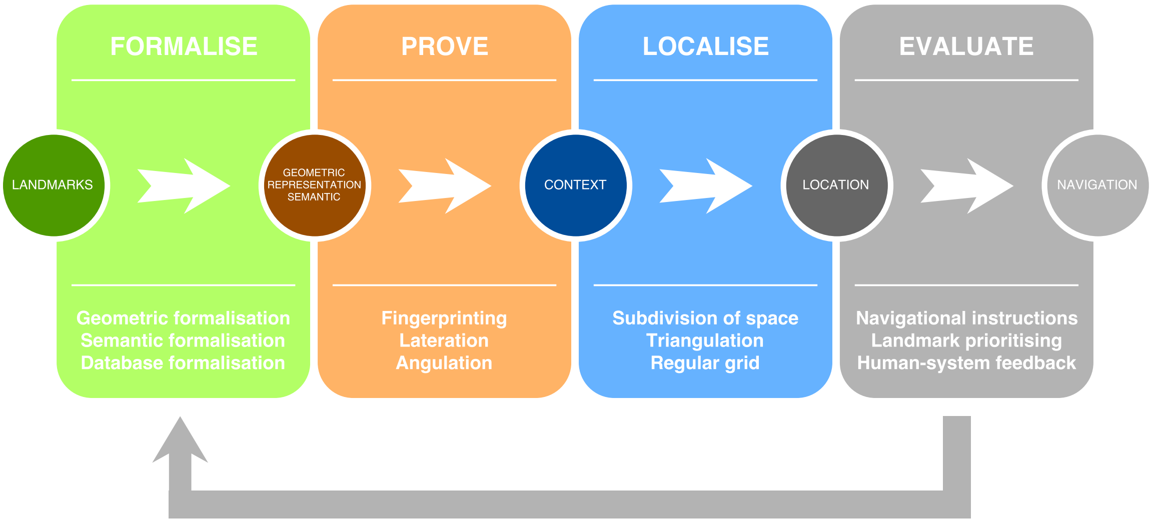


Figure 9: Research steps for exploring a localisation principle

4.2 Semantic and geometric formalisation

Semantically a landmark has a description that matches the description that a human would give of a landmark: each landmark or object has a type (logo, furniture, sign, etc.) based on human classification, characteristics (color, size, angle, etc.), a description (text of a logo, brand of an object, etc.) and a series of other attributes that make a landmark unique (enough). The landmark must be identifiable through a description provided by humans. This also introduces hierarchies of most salient landmarks based on either one of the semantics, see Figure 10

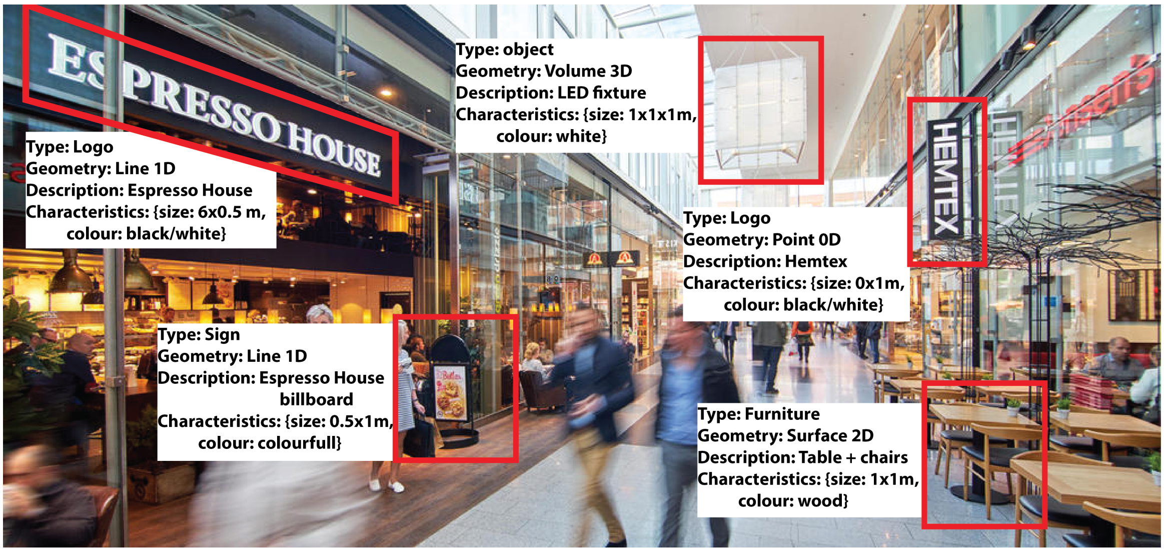


Figure 10: Semantic representation of landmark objects (0D, 1D, 2D, 3D

Assuming there is a database with a floorplan having a local coordinate system (or world coordinate system) and the general location of obstacles/landmarks, the first step is the formalisation of landmarks in a database, in this part, the different ways of representing a landmark are explored both geometrically and semantically. Geometrically there are 4 ways to represent a landmark: as a point object (0 dimensional), a linear object (1 dimensional), a surface/polygon (2 dimensional) or a volume (3 dimensional), see Figure 11.

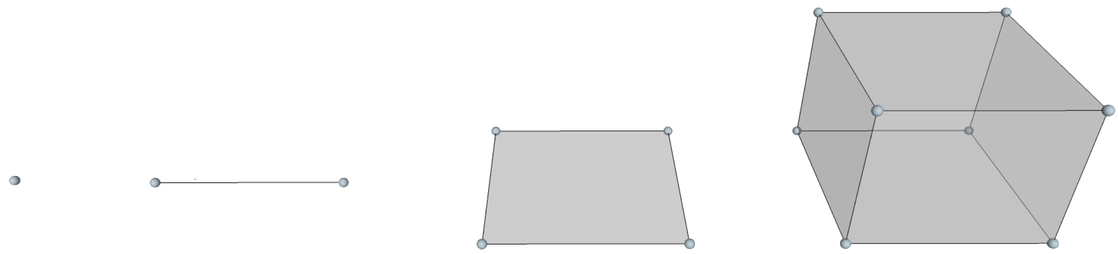


Figure 11: Geometric representation of landmark objects (0D, 1D, 2D, 3D

4.3 Visibility analysis for localisation principles

In parallel with research of Anita Graser, the visibility of landmarks could be a measure for localisation combined with the principle of (Wi-Fi) fingerprinting to get for each region a unique set of visible landmarks that results in a subdivision of space. The research of Russo into the angular relationship of the user to context (landmarks) could be an interesting angle into trying to triangulate the location of users. When the location has been established the research of Kruminaite, Xu and Zlatanova into the subdivision of space and the computation of shortest path on that could provide useful for the future challenge of indoor navigation.

The principle of localisation through fingerprinting will subdivide space in such a way that the position of a user is narrowed down to a specific enough location. By looking at a combination of the principle of (Wi-Fi) fingerprinting and visibility/viewshed analyses: the indoor environment is subdivided into areas where each area has a unique set of visible landmarks. By cross-referencing these visible landmarks with the landmarks a user is able to see, a location can be determined. *Note: the research will not look into ways for a user to identify objects.*

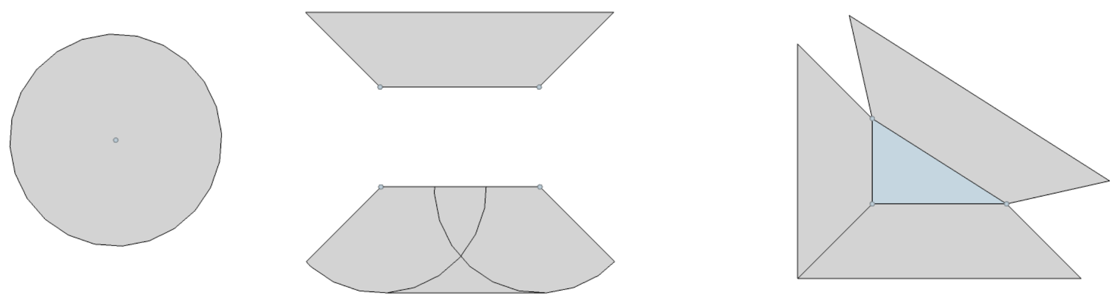


Figure 12: Geometric dependent visibility (0D, 1D, 2D

The geometric representation of a landmark might impact the visibility, different representations have different rules for when they are visible, see Figure 12, following the rules of visibility, the visual workflow (Figure 13) describes the steps to create a visibility analysis, where the visibility of each landmark is calculated by drawing a line to each corner point of an obstacle (ray-tracing), and from each of those lines take the first intersection with an object, then stitch the points together into a polygon following the algorithm from Case (2017). By overlaying the visibilities of different landmarks a unique subdivision of space is generated, that in the future could be used for shortest path calculation (if enough landmarks divide space into small enough regions).

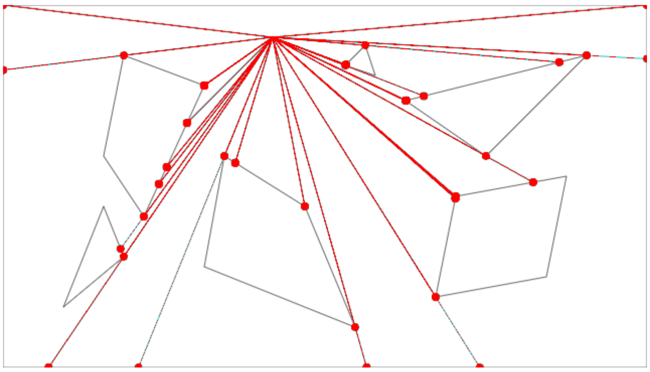
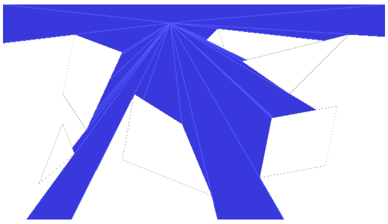
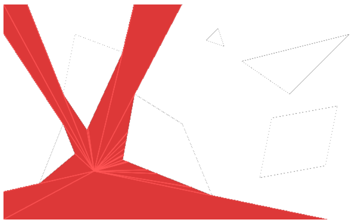


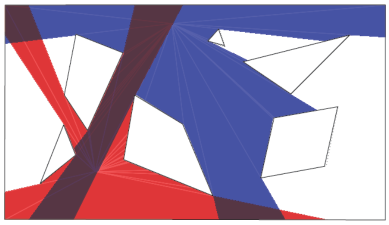
Figure 13: Ray-tracing visibility of landmark, Case (2017)



(a) Visibility of landmark A



(b) Visibility of landmark B



(c) Overlay of visibility landmark A/B

Figure 14: Overlaying visibility polygons to create 'fingerprinted' regions

4.4 Localisation: Constellation, salience and orientation

After it is possible to fingerprint the indoor environment and subdivide space (as a result of fingerprinting or through a regular grid), research into accurate localisation can begin. Based on the constellation of landmarks the fingerprinted subregions of the indoor environment should ideally be unique enough to accurately determine location, in order to enhance localisation the constellation and salience of landmarks can be experimented with to improve the unique fingerprints, Figure 15 is an example that would show that there is clearly a need for more landmarks since not all areas are covered.

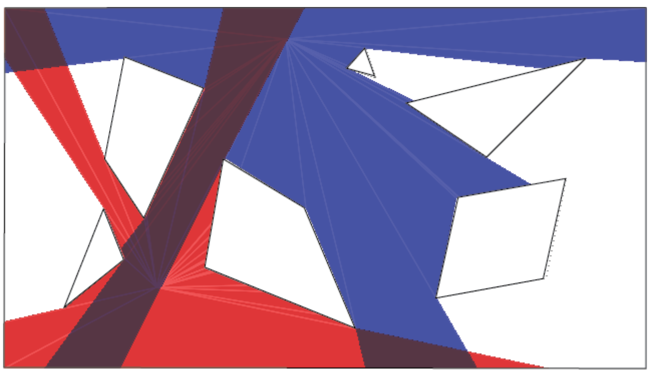


Figure 15: Blind spots in the fingerprinted subdivision

Introducing the relative position of the user in relation to the context (orientation) makes it possible to localise the user more easily and accurately (though through a more complex process), if a user knows that it is facing an object and standing next to another it adds more information than simply saying it sees a certain amount of landmarks. Figure 16 shows the region where a user could be based on the information that it can see Landmark A and Landmark B, but that it can see Landmark A on his right hand side, this eliminates the area where Landmark A would be on his left hand, this could even be pulled to a more accurate location if the formalised definition of right hand side is used, meaning the quadrant from 45 to 135 degrees.

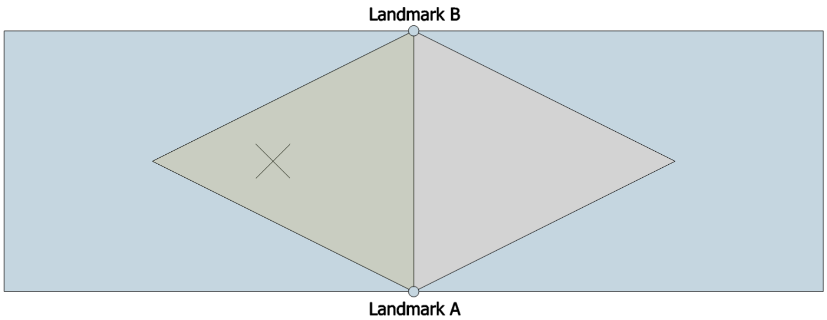


Figure 16: Knowing the orientation of user to context, areas are further subdivided for higher accuracy localisation

4.5 Future implementation of indoor navigation

In order to run network analysis and graph algorithms a subdivision of space should be obtained (either as a result of indoor localisation or as an independent step) and based on a determined or given location and destination the shortest routes will be computed, on decision points cues will be created and these cues are related to landmarks using the angle of incidence towards the landmarks to signal direction. Figure 8 shows that for indoor localisation without precise location there are two approaches fingerprinting and triangulation (using orientation) or trilateration (estimating the distance to three landmarks) that result in either a accurate enough position or a fingerprinted subdivision that can be used in indoor navigation.

During the research into landmark-based localisation, any findings that are linkable to navigation are recorded and provided as future work and recommendations.

5 Tools and datasets used

Data used in the project is mainly dummy data for the artificial case: a simple floor plan resembling an abstract shopping mall or museum with a few open space obstacles, landmarks (initially just points, lines, polygons with no attributes or dummy attributes). The research project can be extended to a real case where an existing shopping mall or museum can be used.

The programs and programming languages that will be used for the creation of the methods/algorithms are PostgreSQL with PostGIS extension along with Python.

6 Time planning

Figure 17 outlines the schedule for the thesis work

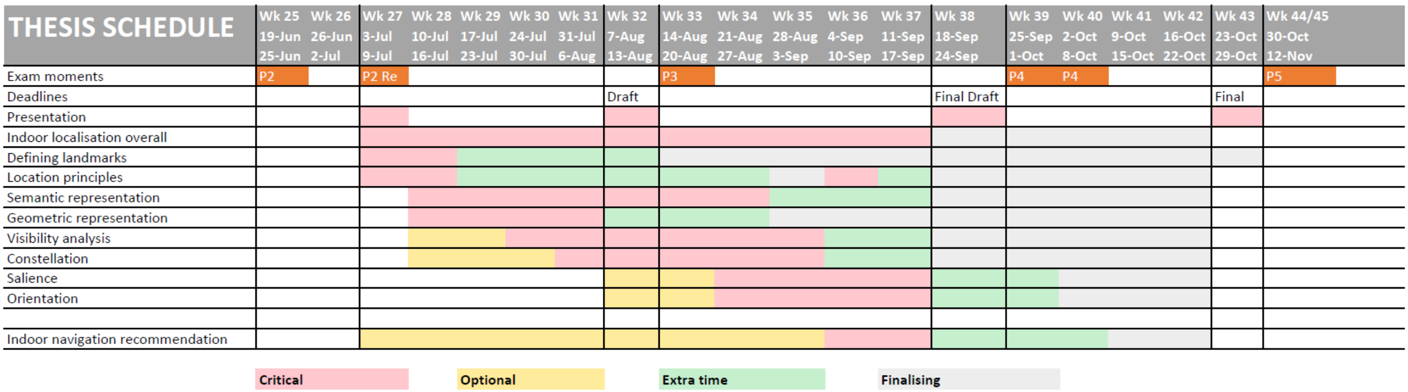


Figure 17: Time schedule of thesis work

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