Thesis in geographical information techniques nr 29

Indoor positioning systems in office environments

- A study of standards, techniques and implementation processes for indoor maps

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EXTM05 Master thesis, 30 ECTS
Program in surveying and land management

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June 8, 2020

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Examensarbete i geografisk informationsteknik nr 29

Printed by E-tryck, E-huset, 2020

ABSTRACT

As people spend most of their daily time indoor today, the interest and usage of systems for indoor environments, called indoor positioning systems (IPSs), are increasing. The last couple of years, new data formats for indoor mapping and commercial IPSs have been released and they are not yet extensively studied. Hence, this thesis provides an overview of the main parts of IPSs: data formats for indoor mapping, positioning techniques and the system for visualization of an indoor map with required functionalities. The thesis also evaluates the process of implementing an IPS, in addition to the chosen data format and IPS for implementation and how they reach requirements set for an IPS in office environments.

A described use case with required functionalities of an IPS in office environments lies as a base in this thesis to set requirements especially for that environment, on both data formats and IPS. First, the requirements are used for evaluation of described data formats and IPSs. Second, a data format and IPS are chosen due to the result of this evaluation but also due to limitations in the thesis. The chosen data format IMDF and the IPS Apple Indoor Maps are used in a case study where implementing an IPS in an office environment is performed. The building used in the case study is the company Sweco’s office in Malmö.

The resulting IPS is not a complete IPS with all the required functionality but consists of the most basic parts: an informative and accurate indoor map and approved positioning in terms of accuracy. Even though the IPS can reach all requirements, one negative aspect is that the positioning for Apple Indoor Maps is only available in iOS devices, limiting the availability for users. The IPS is not user tested as intended, due to the COVID-19 outbreak.

A conclusion of the thesis is that the accuracy of an indoor map is dependent of the accuracy of the structure, details and georeferencing of an IPS. The different parts affect the accuracy in several ways. Another conclusion is that easier integration between source data and data format is desired, and could avoid some error sources. Requirements adapted to the application and required functionality are concluded to be carefully selected and stated in similar projects. Finally, further testing and development of the IPS are proposed to evaluate it more thoroughly, as well as studies or implementations of described data formats and IPSs in the thesis.

SAMMANFATTNING

Eftersom människor tillbringar större delen av sin dagliga tid inomhus idag, ökar intresset och användningen av system för inomhusmiljöer, så kallade inomhuspositioneringssystem (IPS). De senaste åren har det därför tillkommit nya dataformat för inomhuskartläggning och kommersiella IPS och har ännu inte studerats ingående. Därför ger rapporten en översikt över huvuddelarna i IPS: dataformat för inomhuskartläggning, positioneringstekniker och system för visualisering av inomhuskartor med krävda funktioner. Rapporten utvärderar också processen för implementering av ett IPS, utöver utvärdering av det valda dataformatet och IPS för implementering och hur de når krav som ställts för en IPS i kontorsmiljö.

Ett beskrivet användarfall med nödvändiga funktioner för ett IPS i kontorsmiljö används som en bas i rapporten för att ställa krav särskilt för den miljön, både för dataformatet och IPS. Först används kraven för utvärdering av beskrivna dataformat och IPS. För det andra väljs ett dataformat och IPS med hjälp av resultatet i utvärderingen, men begränsningar i rapporten vägs också in i valet. Det valda dataformatet IMDF och systemet Apple Indoor Maps används i en fallstudie där implementering av ett IPS i en kontorsmiljö utförs. Byggnaden som används i fallstudien är företaget Swecos kontor i Malmö.

Resultatet av implementeringen i fallstudien är inte ett komplett system med all nödvändig funktionalitet utan består av de mest grundläggande delarna: en informativ och korrekt inomhuskarta och godkänd positionering gällande precision. Även om systemet kan uppnå alla krav är en negativ aspekt att positioneringen för Apple Indoor Maps endast är tillgänglig på iOS-enheter, vilket begränsar tillgängligheten för användare. Systemet har inte genomgått planerade användartester på grund av COVID-19 pandemin.

En huvudsaklig slutsats i rapporten är att noggrannheten för en inomhuskarta påverkas av noggranheten i struktur, detaljer och georeferering. En annan slutsats är att enklare integrering mellan källdata och dataformat är önskvärd, vilket minskar felkällorna. Krav anpassade till applikationen och den nödvändiga funktionaliteten bör vara noggrant utvalda och angivna i liknande projekt. Slutligen föreslås ytterligare tester och utveckling av systemet för att utvärdera det mer noggrant, såväl som studier eller implementeringar av beskrivna dataformat och system i rapporten.

PREFACE

This master thesis is the result of a degree project in geographical information technology for the program in surveying and land management, Faculty of Engineering, at Lund University of Technology. The degree project is written and published for the Department of Psysical Geography and Ecosystem Science at Lund University with a collaboration with Sweco Position in Malmö.

I would like to thank my supervisor at Lund University, Lars Harrie, for great support and suggestions throughout the whole process. Your accuracy in countless readings of the thesis has been truly appreciating, as well as your questioning of parts for improvement.

I also would like to thank my supervisor at Sweco Position, Ulf Månsson, for your incredible decication in the subject and all ideas that helped me move forward in the thesis. All collegues at Sweco Position, thank you for welcoming me well both at the office, as well as digitally this past few month when a lot of changes in the world occurred due to the COVID-19 outbreak.

Lund 2020-06-08
Isabelle Andersson

LIST OF ABBREVATIONS

API	Application Programming Interface *A specification and an interface between a library and a software.*
BIM	Building Information Modeling *A 3D-model process to enable physical and functional characteristics of places.*
CAD	Computer Aided Design *An automated technology for design and technical documentation.*
CSS	Cascading Style Sheets *Stylesheet language used to describe the presentation of a document written in, for example, HTML.*
ETL	Extract, Transform, Load *A process where data flows from source to target systems, with desired translation of the data.*
FME	Feature Manipulation Engine *ETL platform for transformation and translation of data from Safe software.*
GIS	Geographical Information System *Framework for gathering, managing, and analyzing spatial or geographic data.*
GML	Geographic Markup Language *XML-based encoding standard for expressing geographical features.*
GPS	Global Positioning System *Satellite-based radio navigation system owned by the United States.*
GNSS	Global Navigation Satellite System *Standard generic term for satellite navigation systems.*
HTML	Hypertext Markup Language *Standard markup language for documents designed to be displayed in a web browser.*
IETF	Internet Engineering Task Force *Open international community developing open Internet standards.*

IMDF	Indoor Modelling Data Format *Spatial data format based on GeoJSON and used for indoor positioning, developed by Apple Inc.*
iOS	iOS *Mobile operating system created and developed by Apple Inc.*
IPS	Indoor Positioning System *Network of devices and technologies used to locate people or objects.*
JSON	JavaScript Object Notation *Open standard file format for storing and transporting data.*
LOS	Line of Sight *The direct path of, for example, radio waves from source to the receiver without obstacles between them.*
LBS	Location-based service *Software services providing services or information based on geographical data and information*
NIC	Network Interface Card *Hardware component installed on a device and enables it to connect to a network.*
OGC	Open Geospatial Consortium *International consortium developing and promoting open standards for geospatial information.*
POI	Point Of Interest *In cartography, a way of representing interesting features in a map as points.*
RF	Radio Frequency *The rate of oscillation of electromagnetic radio waves.*
RP	Reference Point *A geometrical point used to define the location of another point.*
RSS	Radio Signal Strength *Measurement of the power present in a received radio signal.*
Safari	Safari *A graphical web browser developed by Apple Inc.*
WAP	Wireless Access Point *Networking hardware device that allows other devices to connect through a wireless standard, such as Wi-Fi or Bluetooth.*

WebKit	WebKit *A HTML/CSS web browser rendering engine developed by Apple Inc.*
Wi-Fi	Wi-Fi *Wireless networking technology*.
WLAN	Wireless Local Area Network *Wireless computer network which links two or more devices using wireless communication, creating a local area network.*

TABLE OF FIGURES

TABLE OF CONTENTS

1 INTRODUCTION

1.1 BACKGROUND

Today, we often take outdoor maps and positioning for granted as it is a part of our daily life. Going from reading maps on paper, to being able to search for specific targets in your mobile phone and to receiving route guidance in seconds has been a huge development process. Now, this process has transitioned in to indoor mapping and positioning. As indoor mapping is a relatively new field, there are several obstacles to overcome. One major challenge is that indoor mapping needs to be more accurate and faster than outdoor positioning because indoor spaces are often narrow and limited.

People nowadays spend most of their daily time indoor (Jeamwatthanachai et al. 2016; Liu et al. 2018, p. 3), which increases the pressure on information and guidance in the visiting environments, e.g. location-based services (Bardaki et al. 2019). This is where indoor information, positioning and navigating systems becomes important. Finding the right way to a colleague's room in an office building or walking through a shopping mall while receiving information about products could be examples of user applications (Bardaki et al. 2019).

There are two important parts for a navigation system, whether you are indoor or outdoor. An accurate map over the area of interest and a positioning technology for localization in that area. The map must be adapted for the usage, for example buildings and roads are required in a map over a city. Furthermore, in a map over an office for example, the map requires an accurate floor plan with rooms and transitions, such as corridors, stairs and elevators.

Global positioning system (GPS) and other global navigation satellite systems (GNSS) provides outdoor positioning with good quality and accuracy. These systems do not work as desired indoor, due to the lack of direct line of sight (LOS) between the satellites and the user with a receiver or GPS tracker as a smartphone (Akopian et al. 2017). Roofs, walls and other building constructions block the satellites navigation signal and make it too weak. Therefore, alternative technologies are now developed and used for indoor positioning systems (IPSs), including WiFi signals, Bluetooth Low Energy and LED lights (Arisandi et al. 2018).

Indoor spatial information is more complex compared to outdoor spatial information, which often is easier to access (Jeamwatthanachai et al. 2016). Kang and Li (2018) discuss this complexity as indoor space consists of cells defined by walls, ceiling and floor surrounding it. These cells are horizontally and/or vertically connected with components like doors or stairs. They also stress the fact that the connectivity structures differ depending on the type of the building, as well as that buildings often have areas with different purposes which have unique requirements.

This thesis is about indoor positioning systems and the technologies used to develop them. It is written in cooperation with Sweco Position, Malmö.

1.2 PROBLEM DEFINITION

For many, IPSs and the techniques and technologies behind them are an unknown territory. Hence, there is a high need for investigating an overview of the most common IPSs. The lack of knowledge could be explained by the lack of usage of IPSs – but this is starting to change as more and more people are interested in using IPSs in different ways. The increasing interest in IPSs can be detected by how larger actors like Apple Inc. and Esri are starting to develop their own data formats and systems for indoor mapping and positioning (Apple Indoor Maps 2019; ArcGIS Indoors 2019).

IPSs could be described in three parts: indoor data format representing indoor structure and information, the positioning technique, used for locating a user in a map, and the system for visualisation of the indoor map with featuring functions for the specified usage. This rapport focuses on the first part, indoor information model and data format, which includes several aspects. The first aspect is looking at what kinds of data formats already exist today and trying to limit the investigation to only a few. The second aspect is looking at how and what is required to implement the data format, in terms of platforms and requirements on source data. Finally, other aspects are about how the data format would work in navigation applications and to see if there already exists an IPS that could support it.

Indoor mapping differs from outdoor mapping in the terms of floor levels in a building. This is one of the larger difficulties for indoor mapping. In navigation, this could also present a difficulty as it sometimes exists several choices to move between floor levels, as stairs, elevators and escalators (Adhinugraha et al. 2017). Hence, connections between rooms and floor levels are required to be represented in a correct way to enable navigation. Another important aspect is to clarify how these connections are represented in the data format model.

Several requirements will be set for the data formats and IPSs in which they will be evaluated from. These requirements can differ depending on the aim of usage of the IPS. Depending on the technique used for positioning, the accuracy of a desired position can vary which is important to know when choosing one for an IPS.

1.3 AIM

The general aim is to provide an overview and evaluation for some of the data formats used in IPSs to achieve a greater understanding of the structures behind these systems. The overview includes a description of the data format standards for representing indoor map data, and the evaluation looks into how the data formats are implemented while discussing the advantages and disadvantages of various data formats based on set requirements in office environments. To facilitate the general aim, a short description of some positioning techniques is provided, as well as an overview of some IPSs which also are evaluated.

One main objective of the thesis is to set requirements for data formats and IPSs in office environments. A second objective is to choose data format and IPS based on the evaluation with the requirements as a base and then implement the IPS. Another main objective is to practically evaluate the requirements for an IPS in office environments, as well as evaluating the process for implementing the IPS. A fourth objective is to compare the implemented IPS with the current IPS at Sweco’s office in Malmö.

1.4 METHOD OVERVIEW

To understand how an IPS works, it is important to understand the technology behind it. Therefore, an overview of some information models and data formats, as well as positioning techniques are provided in the first part of the thesis. A couple of IPSs are also described.

Applications of an IPS in an office environment are used as a base to set requirements for both data formats and IPS. These requirements are used to evaluate data formats and IPSs. The evaluation is then used to choose data format and IPS for the the case study.

The thesis includes a case study with the purpose to implement and evaluate an IPS at Sweco's office in Malmö. The new IPS is compared to an already implemented system at the office, named Nimway. The case study evaluates how the indoor data formats and IPSs would function in a real project, including any difficulties or limitations that may occur during the process and how it reaches the requirements that are specified in the beginning of the thesis.

1.5 DELIMITATIONS

Generally, there are few data formats for indoor mapping, but this thesis will limit the study on the ones available from the larger actors and an OGC standard. IPSs and data formats from Esri and Apple Inc. have been launched and therefore these are of interest for further investigation.

The position techniques chosen in the thesis are techniques that are available in smartphones based on Bluetooth and Wi-Fi receivers. Thus, no other device should be necessary. It is important to note that there are other techniques that already exist that may yield better accuracy than the ones mentioned in this thesis. However, the focus in this thesis is not the positioning technique, it is only on the most common techniques to get a deeper understanding of the IPS structures.

The accessibility of data of indoor spaces limits the case study of implementing a data format and an IPS to an area with the possibility of achieving this data. Therefore, the case study is conducted at Sweco Malmö's office at Drottningtorget 14 where floor plans are available. Availability of IPSs is a limitation, and the chosen IPS must meet the requirements set in this thesis. This way Apple Indoor Maps (section 4.3.1) is chosen for the case study because it is available at Sweco.

The COVID-19 outbreak limits the testing of the implemented IPS, as access to the office building is limited and also that few persons are available for testing. As a result, a greater focus is on the literature study than originally planned.

1.6 DISPOSITION

The thesis consists of two parts. Part one of the thesis is a literature study. Chapter two includes related studies of indoor positioning and navigation, to get an overview on different perspectives on the subject. It introduces some scenarios with applications of indoor positioning to provide an understanding for why these systems are needed, and a user case in an office environment which is the basis for the requirements. Chapter three provides the specified requirements used for evaluation later in the literature study, as well as evaluation in the case study. Chapter four initiates the main part of the thesis: an investigation in information models and data formats for indoor mapping. The following section in the chapter provides an overview of some of the techniques used for indoor positioning. The third section of this chapter describes IPSs, including the data format and positioning technique needed for the system. Chapter five provides a comparison and evaluation of the data formats and IPSs, based on the specified requirements in chapter two.

Part two of the thesis is the practical part. It starts with chapter six, a case study which includes implementation of the chosen IPS. The implementation is then evaluated based on the specified requirements in chapter two. One important aspect of the case study is the process to implement the data format needed for the IPS. A comparison with the existing IPS at Sweco's office is also provided. The thesis ends with conclusions.

2 APPLICATIONS AND USER ASPECTS OF INDOOR POSITIONING SYSTEMS

In this section, different applications of IPSs are described.

2.1 EXAMPLES OF APPLICATIONS AND USER ASPECTS

Amirian et al. (2017) state from a survey that indoor location-based systems (LBSs) can be divided into five application categories: indoor navigation and tracking, marketing, entertainment, location-based information retrieval, and safety and security applications.

Indoor navigation and tracking include for example pedestrian navigation, path finding and routing, tracking, and asset finding. Bu et al. (2017) provides an example of navigating in a library where users get navigation and help to locate books in library shelves for picking up or storing. Many also mention applications with navigation in larger arenas such as shopping malls, airports, office buildings, and hospitals (Al-Omary and Al-Sabbagh 2019; Letavin et al. 2019; Werner 2011).

Examples of applications in marketing are location-based advertisement and marketing, and proximity-based vouchers, offers or rewards (Bu et al. 2017). As Bardaki et al. (2019) mention, this could include personalized offers or coupons while walking through a retail store, in which the IPS uses the position of the user to provide these offers when the user is close to the products.

Entertainment has several user applications: LB social networking, gaming, chatting, dating, as well as “find your friend”-applications (Bu et al. 2017). Chin et al. (2010) discuss that many LB social networks exist in outdoor environments using GPS positioning, such as sharing location with friends, interact with objects or connect with people that relate to a specific location. They have implemented an indoor LB social network, used in office environments for managing office resources and connecting people.

LB information retrieval are useful in galleries or museums, to achieve information about art or tours based on your location in the venue. Real-time underground information is also one of the use cases mentioned by Bu et al. (2017). Bottino et al. (2013) discuss different functions of an implemented framework for museums, with the purpose of enhancing the experience of a museum for the user. This could include the possibility to deliver multimedia contents to provide insight about the surrounding environment and works of art, through textual commentaries, high resolution images, videos and audio contributions. This is accessed and browsed through a device’s display, for example a mobile phone. Another example of a function are thematic tours, where visitors choose their own path throughout the museum, only seeing things they are interested in.

In the safety and security area, some applications could be useful in emergency services and alert services, ambient assisted living and security surveillance (Bu et al. 2017). It is crucial for first responders to know their exact locations, possible escaping routes, and potential risks in the surrounding area of large and complex indoor emergency scenarios. If the rescuers are better coordinated, commanded and guided, by being properly localized and well informed about risks, the possibility of disorientation and/or failures in localizing victims is reduced (De Cillis et al. 2020). De Cillis et al. (2020) present a hybrid indoor positioning system designed for emergencies, which integrates inertial navigation system with a smart environment based on radio frequency identification (RFID) technology for assessing personal indoor localization and tracking.

In navigation, the use of landmarks is necessary when describing the paths. A landmark could be described as a fixed object or area in a map or surrounding. The distinctive features of landmarks can be defined into three attributes: visual, semantic and structural characteristics. The visual characteristics can be divided into four aspects: area, shape, colour and visibility (Feng et al. 2020). These characteristics are also discussed by Fellner et al. (2017), as how and which landmarks are suitable to be used in an indoor map. They divide all characteristics into smaller aspects, just like Feng et al. do with the visual characteristics, to help decide suitability. For the visual characteristics, Fellner et al. say that the physical size, or area, of a spatial feature is not always relevant as it must be visible for the user. In other words, it is the visible size of a spatial feature that is important, but still larger spatial features are better candidates for landmarks than smaller features. If a spatial feature is visually prominent, it is a better candidate for a landmark, as well as if it is typically different from its surroundings. Fellner et al. also mention the availability of a unique and visible label as an aspect, which can be used as a reference in route instructions. Further on, they divide the semantic characteristic into two aspects. They state that spatial features that are ubiquitous and familiar are preferable, and features that require shorter description are more suitable to be landmarks. Last, they describe the structural characteristics as the spatial extents and permanence of features. Point-based spatial features are less ambiguous than features with spatial extents and therefore more suitable landmarks. A spatial feature that is expected change or move less frequently, has higher permanence and is therefore more suitable to use as a landmark. It is stated that the use of landmarks is necessary and as many landmarks can be suitable, it is not always better to use all possible candidates in a navigation route. The information given can be redundant and instead of helping the user, cause confusion.

De Maeyer et al. (2014) also discuss how people use landmarks when navigating and how this differ indoor from outdoor. Indoor, buildings are often structured in fragmented areas with limited field of view. The change of direction also occurs more frequently indoor, as well as the problem with the third dimension as buildings mostly have several floor levels. The authors also state that these elements of indoor space lead to one of the main difficulties while moving through a building: disorientation. Hence, they investigate in the usage of landmarks in navigation and how people use them to locate themselves in an environment. When describing a coordinated relocation in an environment, distinguishable physical objects are required to specify where an action should take place.

For a service like an LBS to work, it could sometimes need access to personal information to use for positioning, and therefore it is interesting to know the degree of security of both map data and user data – some services need higher security than others. Amirian et al. (2017) mention in a survey that strong privacy preservation is the most important feature for users of LBS where navigation and tracking are the main parts of the system. This can be compared to low privacy preservation in safety and security services. They also discuss how the privacy concern can affect and limit the development, adoption and growth of LBS, as storage of personal information can be seen as a threat to users if server providers misuse the data. One solution that they mention is that the new generation, which may social media networking in a larger scale, could possibly have milder privacy concerns and could therefore help the development.

As Ding et al. (2019) discuss, many mobile applications today use the location of a user, such as Facebook, Ebay, Tripadvisor, games like Pokemon Go, and Google Maps, to provide the desired service of the application. They investigate if the location privacy affects a user when choosing a new LBS with a questionnaire survey. Their result implies that location privacy has an impact on users, and they mention that it is crucial to develop techniques to improve the location privacy of users.

2.2 OFFICE APPLICATIONS

Several functions could be useful in a IPS, and combinations of different application categories, mentioned in section 2.1, are therefore sometimes required to reach the wanted service of an IPS in a certain environment. In an office environment, one aim is to use all resources in the building as best as possible. What kind of functions could be useful in an office environment and what requirements are there in the environment itself? First, the office must be large enough that some sort of IPS is needed. Thus, an interesting function is to search for and find points of interest (POIs) such as meeting rooms or nearest writer. For meeting rooms, it is useful to know if a chosen room is occupied or free to use. Therefore, an integration with the booking system in the office is an advantage. Some may need help with navigating to the POIs. Navigation is a function that could vary in different ways, either with real-time directions as the user is walking towards the POI or just a static route on the map from where the user is positioned at the moment.

Sweco's office has several floorplans and open landscape for employees. Meetings are therefore mostly held in meeting rooms, sometimes at a different floor level than their own working desk. There are two basic scenarios for meeting rooms:

1. You booked a meeting in a room where the location is unknown, or
2. You need to book a room, but you do not know which rooms are available or where they are located.

In the first scenario, the possibility to search for a known POI (in this case a meeting room) is an important function. This should provide information about which floor plan it is located on, as well as where it is located on the map for some sort of navigation. In the second scenario, there is a functional need to find a large enough room for a specified time. In this scenario the need for integrating the room booking system with the IPS is proven, so that the user does not have to use several devices for the different services (searching for a POI, i.e. meeting room, and booking). Navigation is also a significant function in this scenario if the meeting room is located in an unknown part of the office.

One important aspect for these scenarios to make sense, is that the user must see his or her location on the map for navigation. Therefore, a positioning technique with good accuracy and map positioning support is required. Devyatisilnyi et al. (2019) concludes from a study that 1-2 meter is enough for navigation inside buildings. The required accuracy based on that statement is therefore 2 meters or less and the positioning should be done in less than 1 second, so that the update of the position is done constantly without delays that would aggrevate the localization of a user.

Searching for a destination and achieve navigation are the most important features in the IPS. Hence, the system and the data format must be able to handle buildings with multiple floors, and therefore also handle challenging features such as stairs, escalators and elevators in the navigation. If restricted areas exist in different ways (locked doors or only employees allowed for example), then they need to be featured in a correct way too.

An API or equivalent to support further development for other services, such as integration with room booking system, should be available. Amirian et. al (2017) mention this as one of the most important features for developers of LBS applications, such as navigation apps for offices.

Other important aspects are the pricing and what kind of installations of equipment that are needed for the IPS to work properly in an office like Sweco's. It is desirable that no further installations in the office environment would have to be done for the positioning technique. The system needs to be easily installed on a mobile phone and in the best case, no installation would be needed.

A general requirement for both data formats and the IPS is that they must be provided by a reliable supplier, or accessible in a way that makes it reliable for the user and developer. If an IPS support a certain data format that reach requirements for the environment, it facilitates the development of an IPS.

It is important that features in the map correlate with those in reality. Worm (2020) mentions this as one of the most important aspects when developing indoor maps for Copenhagen Airport. Manual processing of source data performed by different indoor map suppliers results in dissimilarity in delivered indoor maps. Thus, the responsibility of producing indoor maps is set to the airport before delivering indoor maps to their map suppliers for vizualisation. This aspect applies to maps in office environments as well. It is also desirable that the complete system is not dependent on the supplier when updating and changing map data to ensure the developer is in control of the development and features in the map. When updating existing map data, it would be desirable to use only updates and changes instead of complete system revisions.

3 REQUIREMENT SPECIFICATION

Depending on the usage of an IPS, the requirements differ. What is important for one type may not be required to be included for another type. In this thesis, the focus is on a system for an office building, and the chosen IPS in the case study is evaluated based on the requirements specified here. The requirements are based on the use case for IPSs in office environments described in section 2.2 Office applications and 2.3 User aspects; they are developed in consultation with Ulf Månsson, Sweco Position. 'Data format' in this text refers to both the data format and the information model for the data format.

3.1 REQUIREMENTS FOR DATA FORMATS

DF 1 The data format must be well documented.

DF 2 The data format must be provided by reliable supplier.

DF 3 Importing and transforming data should be partly automatized.

DF 4 Validation of imported or created data for the data format should be possible.

DF 5 The data format must handle multiple floor levels in a building.

DF 6 Transitions between rooms and floor levels and corresponding network, or available APIs must be featured to enable navigation in an IPS.

DF 7 It must be possible to add restrictions to areas, so accessibility is known if needed in an IPS.

DF 8 POIs must be featured in the data format.

DF 9 An established and frequently used IPS must support the data format.

3.2 REQUIREMENTS FOR INDOOR POSITIONING SYSTEMS

IPS 1 The IPS must consist of a map with accurate information of the building.

IPS 2 The position of the user must be visible in the map.

> **IPS 2.1** The accuracy of the position must be 2 meters or less.
>
> **IPS 2.2** The position must be updated in less than 1 second.

IPS 3 Searching for POIs in the IPS must be a featured function.

IPS 4 Achieve navigation from position to chosen POI must be a featured function.

IPS 5 The IPS should be independent of supplier.

> **IPS 5.1** It should be possible to use only updates and changes in the data instead of whole datasets when updating the map data in the IPS.

IPS 5.2 Updates and changes in the map data should be possible to be done by the developer (from a company developing an IPS, not the supplier of the system).

IPS 6 API or equivalent must exist for further development of the IPS and integration with room booking system.

IPS 7 The IPS must be provided by a reliable supplier.

IPS 8 The degree of security and exchange of personal data must be enough for the usage.

IPS 9 The system should require no or small installations in the building to enable positioning (use what is accessible as far as possible).

IPS 10 The IPS should be easily installed on a smartphone, iPhone or Android.

4 TECHNIQUES AND STANDARDS

This chapter aims to review and describe some of the techniques and standards used to implement an IPS, as well as a couple of IPSs. Section 4.1 describes information models and data formats for indoor mapping. Section 4.2 provides an overview of the most common positioning techniques. Section 4.3 describes several information positioning systems.

4.1 DATA FORMATS

To enable positioning, an accurate map of the area and its components is required. The following sections describe some of the data formats used to represent indoor geospatial information.

4.1.1 Indoor Mapping Data Format

Indoor Mapping Data Format (IMDF) is a data format developed by Apple Inc. It is expressed as an archive of GeoJSON files and describes an indoor space. The GeoJSON files must meet specific data model requirements in the specification of IMDF, in addition to the requirements of GeoJSON itself (Apple Indoor Maps Guidelines 2019). When no other source is stated, this section is based on the Indoor Mapping Data Format documentation, see Apple (2019).

GeoJSON is a data format based on JavaScript Object Notation (JSON). By encoding a variety of geographic data, the data format can represent a region of space (a *Geometry*), a spatially bounded entity (a *Feature*) or a list of *Features* (a *FeatureCollection*). Several geometry types are supported, such as points, lines and polygons. GeoJSON follows the Internet standard RFC 7946, set by the Internet Engineering Task Force (IETF). *Feature* objects in GeoJSON can contain a *Geometry* object (the coordinates described as an array, or with value null) and additional properties. These properties could vary depending on what type the *Feature* represents. The *FeatureCollection* object contains an array of *Feature* objects (Butler et al. 2016).

The representation of an IMDF data set has three requirements:

1. It must be delivered as a *ZIP* compressed GeoJSON archive using the ".zip" filename extension.

2. An archive must contain a *Manifest* object: a JSON object with metadata describing the content and origin of the archive.

3. *Features* must be packaged as homogenous *FeatureCollections*.

Furthermore, there are two more required feature types in addition to the *Manifest* object: a *FeatureCollection* of all *Address* features and a *FeatureCollection* of the lone *Venue* feature. Additional feature types are optional: *Amenity, Anchor, Building, Detail, Fixture, Footprint, Geofence, Kiosk, Level, Occupant, Opening, Relationship, Section, Unit.* Figure 4.1 below visualizes the layer hierarchy of IMDF for the most common features (Kossovsky 2019). The three features in the top left corner, with grey backround, are the mandatory features for IMDF as mentioned.

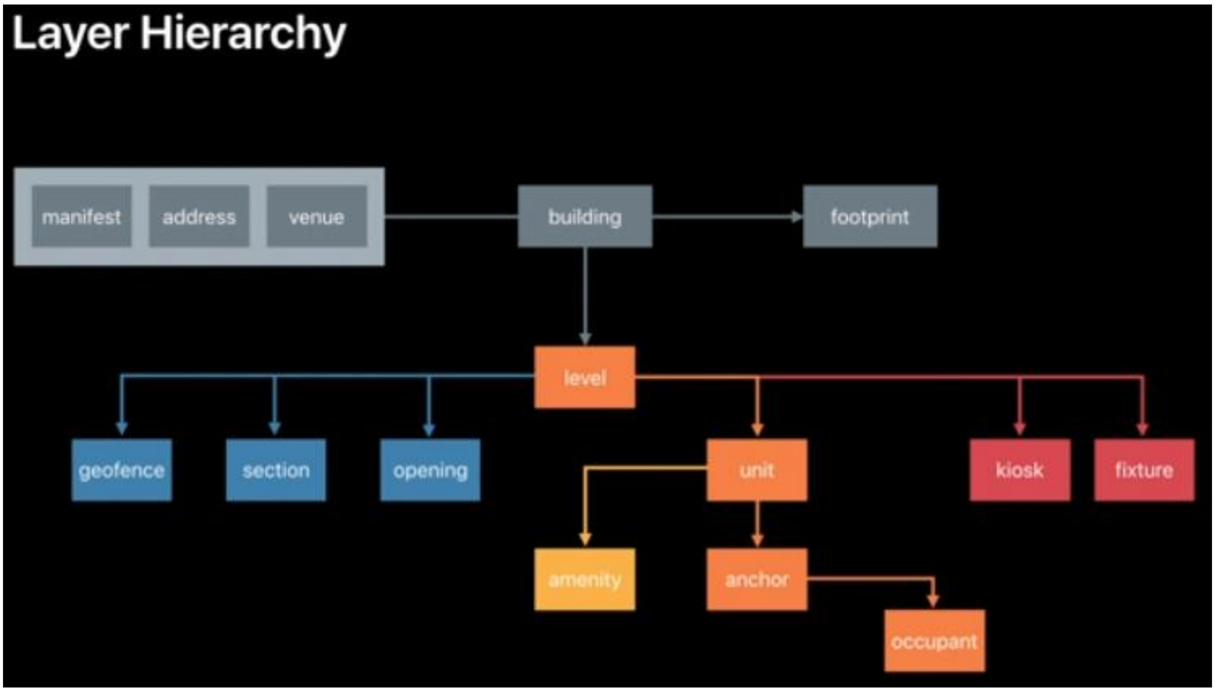


Figure 4.1 The layer hierarchy of the most common features in IMDF (Kossovsky 2019).

A *Venue* must have a *geometry* member with a polygonal value, which represents a formal boundary associated with the venue. It is an abstract modeling concept whose only tangible elements are the properties and the other feature types that lay within it. Those features model physical items such as buildings, floors and rooms. One of the properties of a *Venue* is *category*, which describes the main function or service provided by the *Venue* such as airport, hotel, museum, shopping center etc.

To represent the building structure associated with the venue, a *Building* feature is used. The object does not consist of any geometry, but only a *display-point* which models the point-based representation of the *Building*. This point is required to be located within a *Footprint* feature referencing the *Building* (Apple 2019). The *Footprint* models the approximate physical extent of one or more referenced *Buildings*, hence why the geometry is not stored in the *Building* feature itself.

The feature object *Level* handles the problems of different floorplans as it models the presence, location and approximate physical extent of a floor area. The property *ordinal* of each object reflects the *Level's* position within the total range of floors that exists within a building as seen in figure 4.2 below. To connect different floors, the feature *Unit* contain several categories to model the presence, location and approximate extent of the space of these connections, such as stairs, elevators, escalators or ramps. It is also possible to model the mentioned connections with the feature *Amenity*, which models the presence and approximate point location.

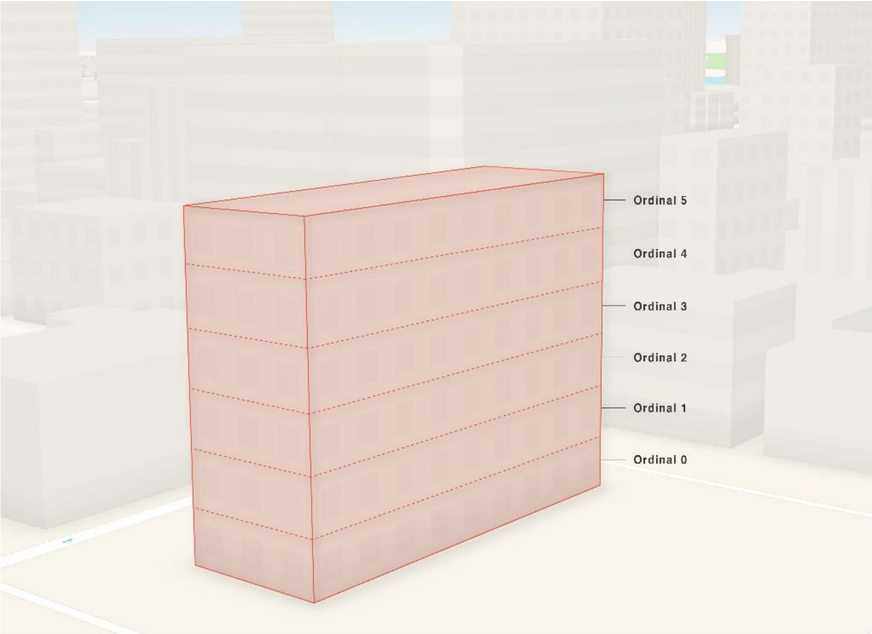


Figure 4.2 Ordinals of a building.

To describe the structure of each floor level, several features could be used. A *Unit* features space which usage is categorized by the property *category.* The *unit-category* could be *room, walkway, restroom, office* etc. The one that best describes the function of the physical *Unit* should be chosen. An object of this feature must have a polygonal *geometry* property.

The property *display-point* uses the curated location for a point-based representation of a feature. It must be located within the geometry of the feature and should be positioned where a map label collision is least expected. This enables the representation of POIs in the final indoor map. In figure 4.3 below, this property is shown as a label for a *Venue.*

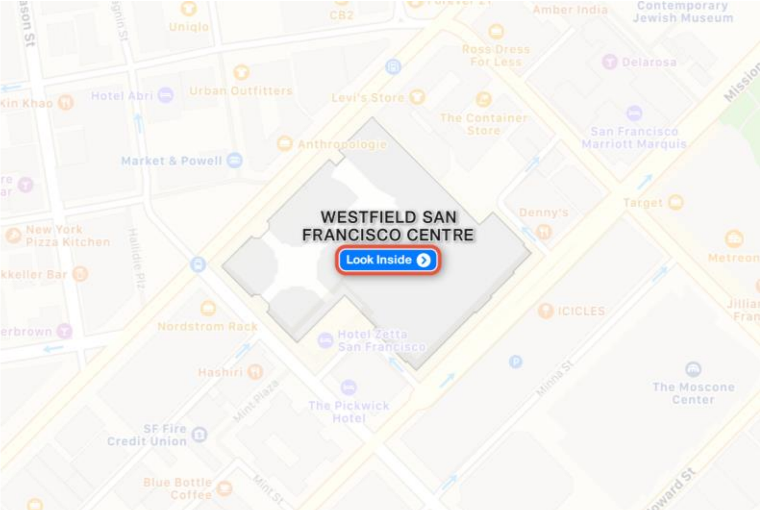


Figure 4.3 The curated location used as the point-based representation of this Venue.

Restrictions to certain areas can be done, as it is a property in the features *Building*, *Geofence*, *Level*, *Section*, *Unit* and *Venue*. *employeesonly* is a category for the property, which can for example describe a space that is only available to employees in a *Venue*. *Geofence* could be described as a separator of areas that have different restrictions, like pre- and post-security in an airport.

Several options exist to create IMDF, depending on the size and type of the venue. For airports and shopping centers, Apple can help create IMDF from CAD drawings, BIM files or GIS files. This requires some details on the occupants of each space inside the building, for example retailers. For other large public venues, such as stadiums, train stations and museums, Apple may provide assistance to create IMDF from provided data. Requests of these types are processed on a case-by-case basis. The third and last option is for organizations of other buildings, facilities or venues, to create IMDF by themselves with the guidelines of the specification. Several third-party platforms and tools are available to make this process easier (Apple Indoor Maps Guidlines 2019).

Feature Manipulation Engine (FME), Safe Software, provides tools for comprehensive data format translation and validation for IMDF, as well as converting IMDF to other indoor mapping formats for further editing or visualization and analysis (Safe Software 2019a). FME also includes a transformer for validation of IMDF, the *IMDFValidator*, which provides detected errors and warnings for the file (Safe Software 2020a).

When the IMDF is complete, it is possible to validate the data through Apple's own validation tool: *Sandbox*. It can visualize the IMDF file and some errors can be corrected directly in the tool. Also, when uploading an IMDF to an account in Apple Business Registrer, a detailed validation is made (Apple Maps Indoor Guidlines 2019).

IMDF is supported by several third parties that provides APIs to display IMDF, and Apple's own APIs (MapKit and MapKit JS) can also be used to display the indoor map on top of Apple Maps. Apple do not provide any APIs for navigation in IMDF, but the data format is supported by several third parties to enable navigation, such as Esri ArcGIS Indoors, Autodesk BIM 360 Ops, VisioGlobe and more (Apple Maps Indoor Guidelines 2019).

4.1.2 IndoorGML

IndoorGML is an Open Geospatial Consortium (OGC) standard with the goal to define a framework of indoor spatial information to locate stationary or mobile features in indoor space, as well as to provide spatial information about their positions in the indoor space. The standard is defined as an application schema of Geographic Markup Language, GML. When no other source is stated, this section is based on the IndoorGML standard version 1.0, see Becker et al. (2018).

In IndoorGML indoor space are defined as a set of cells (rooms) with important properties. Every cell needs an identifier (*c.ID*), which could be a room number. The cell does not overlap with other cells but may have a common boundary. Additional information can be included in cellular space: semantics in form of classification and interpretation of cells, geometry such as solids in 3D or surfaces in 2D and topology, e.g. adjacency or connectivity.

Semantic representation of indoor space in IndoorGML uses indoor space subdivision which represent different criteria of the cell. For example, topography of a building could have the semantics such as '*room*', '*door*', '*window*' etc. and security areas could have '*check-in area'*, '*boarding area'*, '*crew areas'* etc.

The semantics are used for two purposes: to provide classification and determine the connectivity between cells. Cells that are important for navigation are therefore easily detected and defined. The most commonly used classification of cells in topographic space is into navigable and non-navigable cells. The properties on these cells can act as a navigation constrain.

Restrictions in IndoorGML can be set as feature *Constraint.* This feature could describe restrictions for *NavigableSpace* and *NavigableSpaceBoundary* (rooms and doors etc.). The different restriction *Constraints* are *PassRestriction, WalkTypeRestriction, UserRestriction, TimeRestriction* and *OneWayRestriction.* They consist of different types depending on the meaning of the restriction. For example, the *WalkType* for *WalkTypeRestriction* could be normal, wheelchair or vehicle and describes the level of pass ability in a room or through a door.

The geometric representation of indoor space can be defined by ISO 19107 (ISO 19107:2003 2003**)**, CityGML and Industry Foundation Classes (IFC). The ISO 19107 data model defines 3D space as *GM_Solid* and 2D space as *GM_Surface*. This data model describes and models real world objects as features with provided conceptual schemas, where the described cells in indoor space are a type of feature. Through external links in an IndoorGML document, a representation of geometry can be defined by the included geometric information of objects in other data sets, such as CityGML or IFC. Figure 4.4 provides an overview of the different options to represent geometry in IndoorGML, where the option of not including any geometric information in the IndoorGML document is also provided.

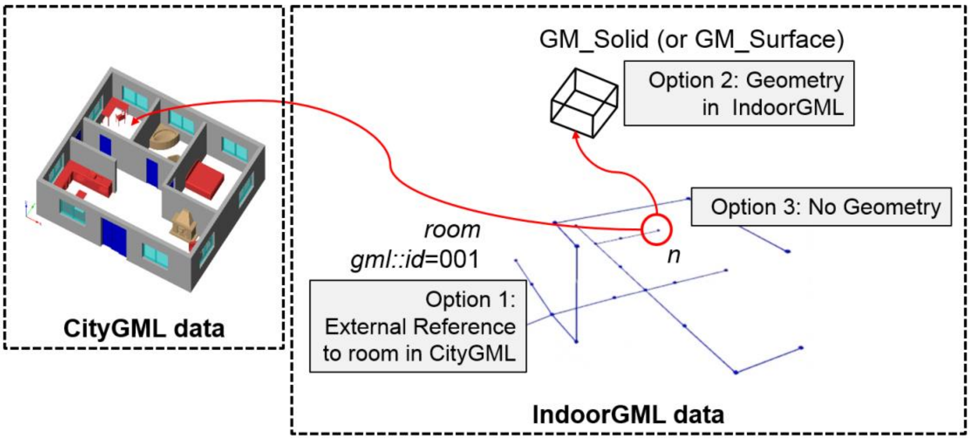


Figure 4.4 Three options to represent geometry in IndoorGML.

A Node-Relation Graph (NRG) provides a solution for representing topological relationships between cells, since it is not included in cellular space. Solid 3D objects (e.g. rooms) in 3D primal space are mapped to nodes (0D object) in a so called dual space. Two rooms (3D objects) may be sharing a 2D surface (e.g. wall), which is transformed into an edge (1D object) linking two nodes in dual space. An adjacency graph is created by these nodes and edges.

Depending on how walls and doors etc. are defined in the original data, the NRG has two ways of being defined: the thick wall model or thin (or paper) wall model. In the thin wall model, the walls and doors are represented as boundaries and are accordingly mapped to edges in dual space. However, in the thick wall model, they are represented as cells with certain thickness which forces the NRG to be differently constructed. Walls and doors are then mapped to nodes of dual space.

From the adjacency graph, other graphs can be created based on semantics or constraints. A connectivity graph can easily be derived if the edges in the adjacency graph contain information of navigability. This is roughly visualized in figure 4.5 below. Using constraints, such as the need of having doors with a certain width, an accessibility graph can be derived from the connectivity graph as seen in figure 4.6.

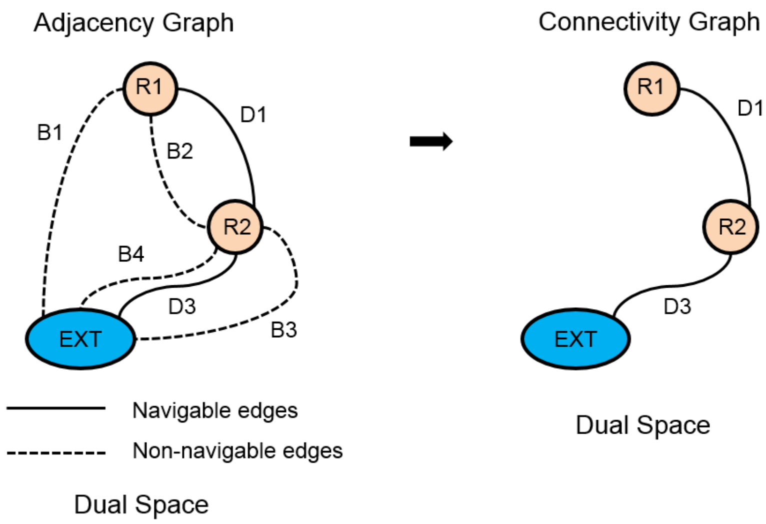


Figure 4.5 Derivation of connectivity graph from adjacency graph.

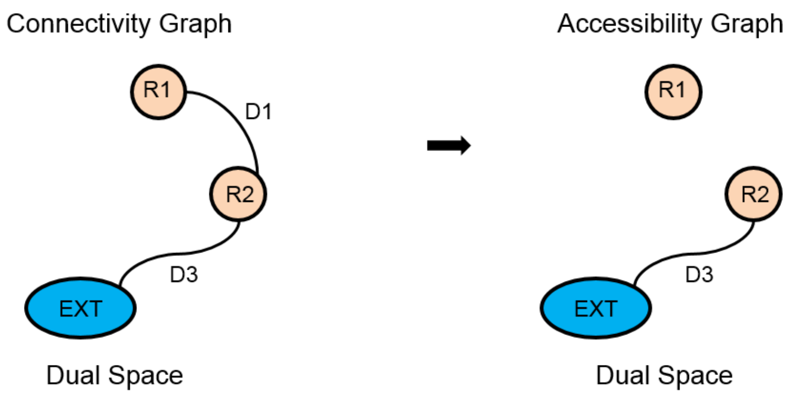


Figure 4.6 Derivation of accessibility graph from connectivity graph.

A NRG can be either geometric or logical, where the geometric NRG contains coordinates of the nodes and edges and the logical NRG does not contain any geometric properties. In the geometric NRG, each node has point coordinates and each edge has the coordinates of starting, ending and intermediate vertices. These are defined as *GM_Point* and *GM_Curve* of ISO 19107, respectively.

IndoorGML supports multiple representation layers, called Multiple Layered Space Representation (MLS representation), as an indoor space is often semantically interpreted into different cellular spaces. A single indoor space can for example be represented as a topographic cellular space, as well as different cellular spaces such as WiFi coverage cells. The MLS representation is useful in many ways: a hierarchical structure of indoor space can be represented where interlayer edges connect two hierarchical layers, and another application example is indoor tracking with topographic cellular space layer and RFID sensor coverage layer.

Two frameworks are the base of IndoorGML: The Structured Space Model and the Multi-Layered Space Model (MLSM). The key concept of the MLSM is to combine several space structures for different interpretations and layers to support different indoor information services, such as indoor navigation. The UML diagram for the Structured Space Model in figure 4.6 below, shows the data model. The NRG is a part of this model: the node of NRG is called *State* and the edge of NRG is called *Transition*. In the same figure it is shown that a *SpaceLayer*, which represents a separate interpretation, is composed of *State* and *Transition* (nodes and edges of NRG in dual space, respectively), which are used in navigation for example.

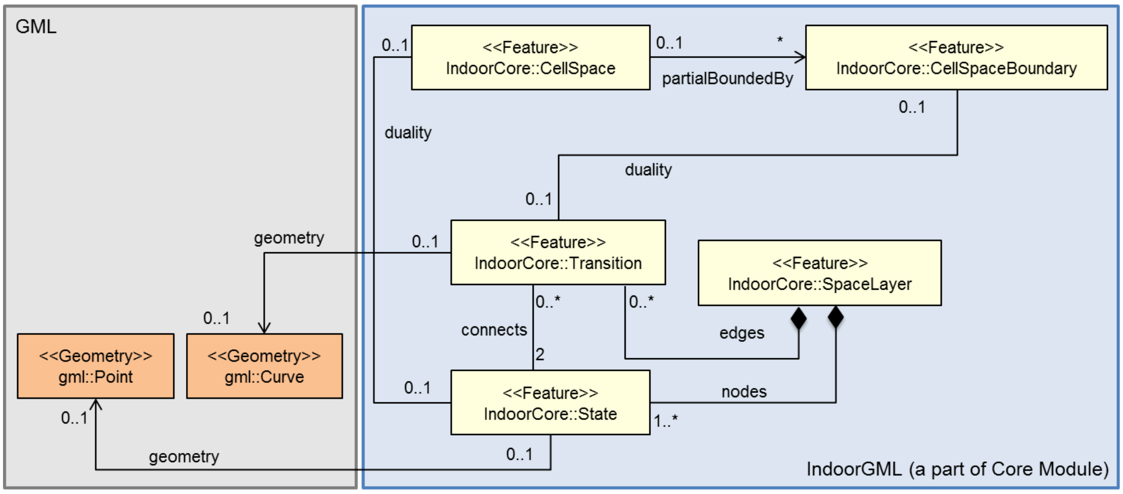


Figure 4.7 Implementation of Structured Space Model in IndoorGML.

In the release for IndoorGML version 1.1, a new attribute *level* for the feature *CellSpace* has been suggested to include floor level information. The value of this attribute is given as a *xs:string* (Becker et al. 2019).

Since IndoorGML is XML-based, it is possible to validate it against the defined XML schemas for all employed IndoorGML modules by using an appropriate software tool or manually check all definitions. FME could work as a validator through the transformer *XMLValidator* (Safe Software 2019b).

No commercial IPS supports IndoorGML at the moment, but as several open source tools are available to create and view IndoorGML, open source IPSs could be developed based on the data format (IndoorGML 2019). FME provides both Reader and Writer for IndoorGML (Safe Software 2020b).

4.1.3 ArcGIS Indoors model

The ArcGIS Indoors model is a part of ArcGIS Indoors (described in section 4.3.2), tools to create and manage indoor data, which consists of two datasets: ArcGIS Indoor information model (AIIM) and Network. The first dataset manages the GIS data defines indoor spaces for use with ArcGIS Indoors applications. There exist Indoors tools in ArcGIS Pro, that creates the hierarchical features for the AIIM. The second dataset manages the network artifacts that are created to support routing between indoor spaces. These features are also created using the Indoors tools. One important aspect of the model is that data and floor plans must be georeferenced to enable use of the ArcGIS Indoors tools. When no other source is stated, this section is based on ArcGIS Indoors Information Model, see ArcGIS Indoors Information Model (2019).

The configuration information of the Indoors model is maintained in four tables: *Categories, DisplayLODs, DisplayScale* and *IndoorsConfig. Categories* describes the category definitions applied to POIs features by the Indoors web and mobile applications. *DisplayLODs* and *DisplayScales* are used in conjunction in the Indoors mobile applications. The first one describes the levels of detail in the final maps created and the second describes the minimum and maximum scales that a feature will be displayed when optionally applied to POI features. Various settings that are required to be configured for the successful use of both the Indoors web and mobile applications are described in *IndoorsConfig.*

The AIIM is represented by two different types of feature classes: features representing the indoors information and features representing tracking and indoor positioning restrictions. The first type is hierarchical with assumed spatial relationships defined in the following descending order: *Units/Detail/PointsOfInterest, Sections/Zones, Facilities* and *Sites.* One important feature also included in the AIIM is *Level.* The second type consists of *DeadZones* and *TrackingZones.*

The feature *Level* describes the level for each floor plan, with elevation, height and area. It is connected to a *Facility* and *Site* through the attributes *FACILITY_ID* and *SITE_ID.* The *VERTICAL_ORDER* defines the order of display and reference to floors in an IPS. The AIIM uses a zero-based ordering system, with ground level represented as zero (0), floor levels above with positive values and below with negative values. The attribute *LEVEL_ID* could in turn be used in other features of the AIIM to connect them to the right floor level.

The Network consists of three feature classes: *Landmarks, Pathways* and *Transitions. Landmarks* describes POIs which can be used as callouts when change of directions occur in routing between locations. *Pathways* are the network pathways used for routing. Last, the *Transitions* describes the transitions between floor levels.

The restriction of access to, or access to path through certain areas can be described in the attribute *ACCESS_TYPE* for some feature types in the AIIM dataset, such as *Unit*, *Section, Level* and *Facilities.* In the Network dataset, there is also an attribute *ACCESS_PEDESTRIAN,* to describe the accessibility for pedestrians in both *Pathways* and *Transitions.*

4.2 POSITIONING TECHNIQUES

Since GPS is not working indoors, other techniques are required. The following sections describes the most common techniques for indoor positioning.

4.2.1 Fingerprinting

The technique of fingerprinting is that each location has its own unique pattern in form of several signals received from access points, for example WiFi. A device receives the signals and compare them to a so-called Radio Map, a database with the pattern of signals, which returns the location where the pattern match to the device.

Received signal strength indicator (RSSI) is a common indicator of location in free space and outdoor scenarios but has its disadvantages in indoor positioning due to the effects of obstructions indoors (e.g. walls). Therefore, a solution could be to connect a certain location with the RSSI of all wireless access points (WAPs) as a kind of fingerprint. A WAP could be a Wi-Fi access point. The RSSI from different WAPs create a unique pattern at each location due to the interference of the signals (dos Santos et al. 2018).

Fingerprinting consists of offline and online phases. The first step of the offline phase is to choose Reference Points (RPs), where multiple copies of RSSI measurements are read and collected from available WAPs throughout a time interval. These measurements provide a Radio Map of the whole area as a database of fingerprints. In the online phase, the device detects RSS measurements at its location and then applies algorithms to associate these measurements to the radio map entries by finding similar fingerprints (Akopian et al. 2017).

Akopian et al. (2017) and Liu et al. (p. 8, 2018), discuss the cause of the increasing attention of using RSS fingerprinting for positioning. They state two main reasons:

1. Wi-Fi or Wireless Local Area Network (WLAN) and their access points are well spread in offices, business buildings, airports, shopping centers etc. Therefore, the areas in these facilities is provided with a broad coverage.

2. Mobile and wireless receivers contain Network Interface Cards (NICs) to provide RSSI measurement. Thus, it is not necessary to install any additional hardware on your device.

Liu et al. (p. 10-11, 2018) state three challenges for fingerprinting which need to be solved for it to become a truly ubiquitous system. Firstly, the procedure of conducting the radio map is heavily time-consuming and labor-intensive, since the survey needs to be done by hand and often over large areas. Secondly, they discuss the sensitiveness of signal strengths. These are easily affected by moving subjects or furniture changes. Realtime RSSI samples could therefore deviate from the ones stored in the radio map, which indicates that it is sensitive to change in the fingerprint pattern. The problem could be solved by doing regular surveys and updating the radio map, but as stated in the first challenge, this is costly in practice. Lastly, the effects on the signal strength can also cause location errors itself, which is a tough problem to solve.

Akopian et al. (2017) claim that their implementation has an success rate of 85% for a position accuracy of 2 meters or less, while Liu et al. (2018) state that fingerprinting positioning are not able to achieve better accuracy than 5 meter.

4.2.2 Trilateration

Trilateration uses distance to surrounding APs to find the relative location of a user. To determine the exact position, the point intersection formed by three circles of APs are used. The approximate accuracy is within 2 meters. The distances are often calculated with measurement techniques such as Received Signal Strength (RSS), Time of Arrival (ToA), Time Difference of Arrival (TDoA) etc. (Ali et al. 2016).

The coordinates of the APs are needed as well as a database, stored with the APs Mac addresses. RSS from all APs are received and then converted into distances. After that, the system can trilaterate the user’s location as shown in Figure 4.7 below. Point B represent the user and P1, P2 and P3 represent the APs (Ali et al. 2016).

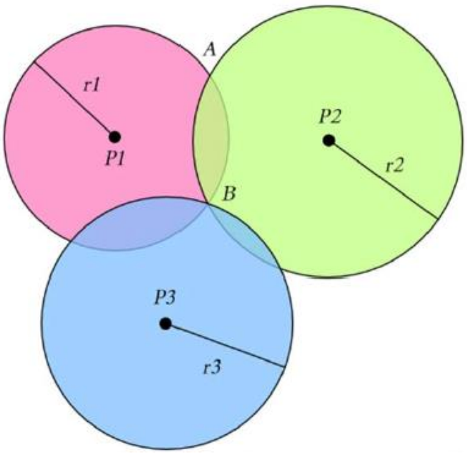


Figure 4.8 Visual overview of location of point B determined by trilateration with three APs (P1, P2, P3) (Ali et al. 2016).

The distance r is calculated with the RSSI as the user's device can obtain the signal strength in dBm and convert it with the following equation:

$$r_i = 10^{((27.55-(20*log10(f))+s)/20)} \quad (1)$$

where,

r = distance in meter, f = frequency in MHz, s = signal level in dBm, i = 1,2,3 ...

As seen in figure 5.6, the position of point B(x, y) is in the intersection of the three circles of the APs. Assuming z=0, this intersection is occurred at Cartesian plane. The distance r is used in the equation for each circle:

$$(x - x_i)^2 + (y - y_i)^2 = r^2 \quad (2)$$

where, (x_i, y_i) is the position of the AP and *i* is the ID for the AP (Ali et al. 2016).

The intersection is obtained by solving systems of linear equations for 2 variables simultaneously. Hence, by solving these linear systems the position of B(x, y) can be determined (Ali et al. 2016).

4.3 INDOOR POSITIONING SYSTEMS

Following sections describes several indoor positioning systems, with the data format used for the map and positioning technique.

4.3.1 Apple Indoor Maps

The Apple Indoor Maps program targets owners or operators of large venues, public or private. For two certain venues, airports and shopping centers, Apple performs necessary work in publicly accessible areas to make indoor positioning available. In other buildings and non-public areas, the organizations are provided with the tools needed to enable indoor positioning by themselves (Apple Indoor Maps Guidelines 2019).

The indoor maps created for the facilities can be made available in two different ways, either through Apple Maps or in your own app and/or website. The first option is only available for airports and shopping centers and is based on data Apple receives from the organization. The data can be of various data formats as CAD, BIM or other GIS data formats which Apple transforms to IMDF. Only publicly accessible areas are shown in Apple Maps. The second option offers organizations to convert floor plans of buildings to IMDF files themselves. Updates and changes to the IMDF are possible to be added by the organization without the need to communicate with Apple. When approved validation of a IMDF file is recieved for both the data format requirements and georeferencing, and the fingerprinting survey is performed, it can be downloaded from *Sandbox* and changes and updates should be done to this file (Apple Indoor Maps Guidelines 2019).

The technology used for positioning in Apple Indoor Maps relies on radio frequency "fingerprints" using the radio frequency (RF) patterns emitted by fixed Wi-Fi access points inside a building. This technique is explained further in section 4.2.1 Fingerprinting. The technique is combined with the sensors in the iOS device to determine direction of travel and speed. The RF patterns are measured and associated with known latitude and longitude locations via the Indoor Survey App. This requires correct geo-referenced floor plans of the building. The positioning using the fingerprinting technology for Apple Indoor Maps provide GPS level accuracy (Apple Indoor Maps Guidelines 2019). This statement is required to be discussed as GPS accuracy can differ a lot depending on surroundings.

For other facilities than airports or shopping centers, the organization of a venue or building must perform a radio frequency survey of the building or area. This is done by using Apple's Indoor Survey App and indoor positioning are then accessible via the Core Location API or via Safari on iOS. The Core Location API uses positioning information from satellites when the device is outside and the Wi-Fi fingerprinting when the device is inside, which makes it easier to deal with indoor/outdoor transitions (Apple Indoor Maps Guidelines 2019).

The Apple Indoor positioning works in all iOS apps as well as websites viewed in Safari or other WebKit compatible browsers on iOS devices. iOS is the mobile operating system developed by Apple which features on all their devices like iPhone and iPad (Apple Indoor Maps Guidelines 2019).

The Apple Indoor Maps program is free of charge, if used and developed by companies themselves, as well as the creation of IMDF to use in the program and the Indoor Survey App (Apple Indoor Maps 2019).

4.3.2 ArcGIS Indoors

ArcGIS Indoors is developed by Esri and enables the user to create and manage data and share authored maps and services, with support of applications like ArcGIS Indoors Web, ArcGIS Indoors for iOS and ArcGIS Indoors for Android. The apps allow a user to find a location or resource within a facility and get directions to that place. To use ArcGIS Indoors, the following software are required: ArcGIS Pro, ArcGIS Indoors for Pro and ArcGIS Enterprice 10.8 (Get started with ArcGIS Indoors 2019).

ArcGIS Indoors provides several geoprocessing tools to create the Indoors data: map and network with transitions. The process of data creation workflow consists of three steps: 1. Create the database. 2. Load the floor plans and POIs. 3. Create the Indoors network (Get started with ArcGIS Indoors 2019). The *Create Indoors Database* tool adds all AIIM feature classes, relationships, and some prepopulated configuration tables to your specified workspace. Section 5.1.3 ArcGIS Indoors Model provides information on what features the model consists of. The user can then load floor plans, dwg files from AutoCAD or dgn files from Microstation for example, layers with POIs and people data to the database with the help of *Floorplans To Indoors* tool. It is also possible to digitize floor plans manually from floor plan images. It is important that the floor plans are accurate georeferenced. Several tools help the user to create the Indoors network, for example Generate Pathways tool which generates a fishnet of pathways and *Create Floor Transitions* tool which connects pathways between levels in facilities. The other tools help making the network as accurate as possible (Esri 2019a).

Positioning in ArcGIS Indoors is not available by the product itself. To enable positioning in the ArcGIS Indoors system, Esri works with Indoo.rs which is an IPS service provider that surveys buildings and creates positioning data from Wi-Fi access points and Bluetooth beacons (Esri 2019b).

4.3.3 Nimway

Nimway is an IPS developed by Sony, especially for office environments. The system handles tasks such as navigation, finding available rooms or desks and locating your colleagues with the help of Bluetooth Low Energy Beacons and occupancy sensors. If necessary, the solution also includes the possibility of reporting problems in the office environment. It is also possible to connect to some standard calendar systems, such as Office 365, Exchange and Google Suite. An overview of the solution and its different parts is provided by figure 4.8 below. When no other source is stated, this section is based on the Nimway system by Sony Europe BV, see Sony Europe BV (2020).

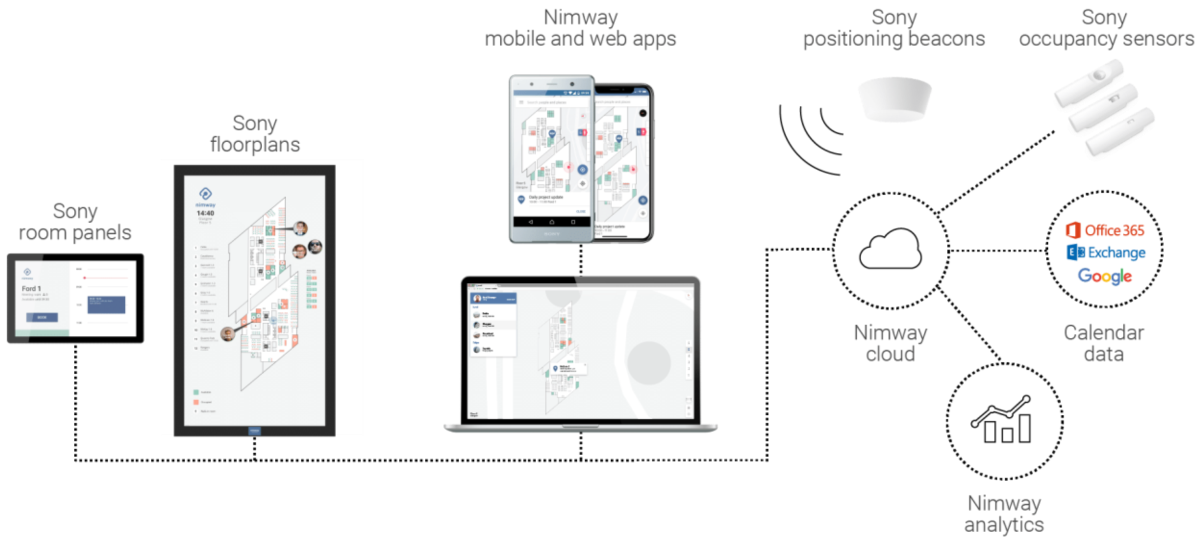


Figure 4.9 An overview of the Nimway solution by Sony.

Two technologies are the main parts of the system: Sony positioning beacons and Sony occupancy sensors. The positioning beacons are used for the positioning of a user, while the occupancy sensors are used for visualization of availability in meeting rooms, desks and so on.

The solution includes Sony floorplans and Sony room panels. The Sony floorplans can be located on each floorplan and provide a quick overview on availability on rooms. If a user is connected to Nimway with a phone, the person can see where he or she is on the digital floorplan and achieve navigations instructions without picking up the phone. The room panels can be fitted outside meeting rooms, with an interface that can show today's schedule, the room name and type, as well as indicate occupancy. If the room is available, it is possible to book the room directly on the room panel or in the mobile app.

The Nimway mobile app provides several areas of application for a user and is compatible with Apple iOS 10 or later, as well as almost all Android devices with Android 6.0 or later operating system. Finding and book available rooms, achieve navigation and finding colleagues within the office space are some of the functions in the app. It is possible to hide your visibility in the app settings if you do not want to be disturbed.

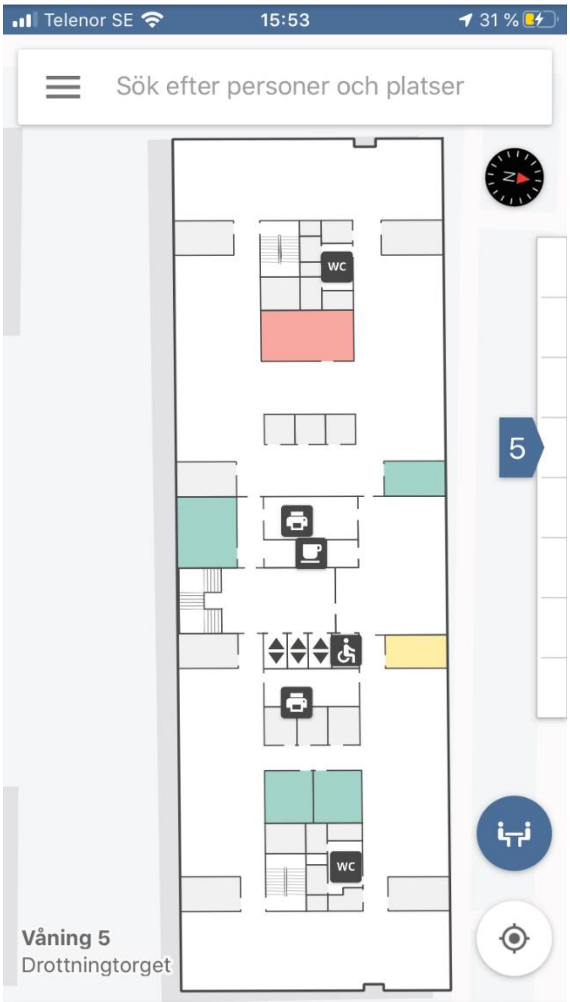


Figure 4.10 Screenshot of a floor level in Sweco's office in the Nimway app.

Figure 4.9 above provides an example on how the app can look like in a smartphone (here, Sweco's office in Malmö), with the color system on bookings and POIs. Green rooms represent available, bookable rooms while red represents booked and occupied rooms. The orange rooms represent rooms that are booked but not used at the moment, which means they could be available if needed.

Nimway Analytics provides tools to help customers make use of the data produced by the Nimway system, which could be of use when changing and optimising the workplace. It is possible to see which rooms are most popular, if there is enough meeting rooms and which type of workspace that is preferred. An example of the data that can be analysed is shown in figure 4.10 below. For example, it is easy to notice which rooms that are often booked but not used, and after that change the configurations in the Nimway system to make sure a suitable room is always available when needed.

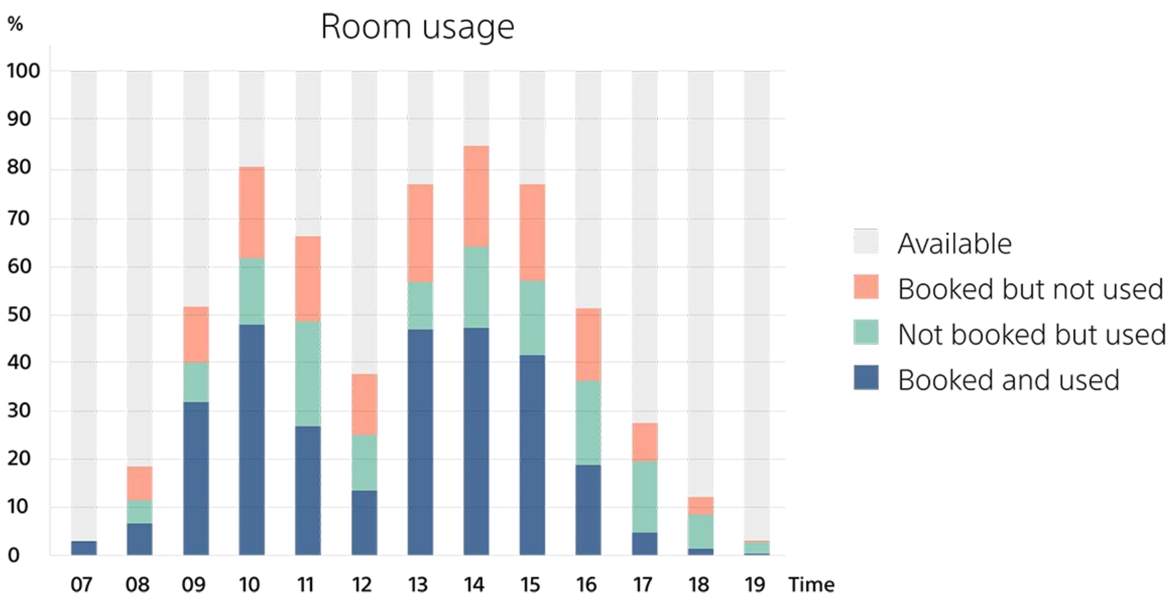


Figure 4.11 Example of how the data can be visualized in Nimway Analytics, here the usage of a room during work hours.

5 ASSESSMENT OF DATA FORMATS AND INDOOR POSITIONING SYSTEMS

In this section the described data formats and IPSs are evaluated against the set requirements.

5.1 DATA FORMATS

Tabell 5.1 Summary of assessment of data formats

Requirements	**IMDF**	**IndoorGML**	**ArcGIS Indoor Model**
DF 1	x	x	x
DF 2	x	x	x
DF 3	x *	x *	x *
DF 4	x	x	
DF 5	x	x	x
DF 6	x	x	x
DF 7	x	x	x
DF 8	x	x	x
DF 9	x	**	x

*manual controls are needed

**used in open source solutions

DF 1 The data format must be well documented.

IMDF, IndoorGML and ArcGIS Indoors are all very well documented. However, the difficulty is in the way to implement them. To make the implementation of IMDF and IndoorGML easier, third-party platforms have been made available, such as FME. ArcGIS has its own tools to convert data to ArcGIS Indoors. Implementation of indoor map data seems to rely on tools to help convert and implement the data in the right way. IMDF could be imported and used in ArcGIS Indoors as well.

DF 2 The data format must be provided by reliable supplier.

Apple (IMDF) and Esri (ArcGIS Indoors model) are reliable suppliers and therefore fulfill DF 2. IndoorGML is an open source standard by OGC and is therefore accessible and reliable to use, hence DF 2 is fulfilled.

DF 3 Importing and transforming data should be partly automatized.

With the help of FME, automatization of a part of the implementing process for the format is possible but not totally fulfilled for IMDF and IndoorGML. Some manual controls are still needed. This applies for the tools for ArcGIS Indoors as well.

DF 4 Validation of imported or created data for the data format should be possible

IMDF has its own validation tool, *Sandbox*, making it easy to validate the data, as well as the IMDF validation tool in FME. IndoorGML is possible to validate against the XML schemas defined for the IndoorGML modules with help of appropriate software like FME, or manually. ArcGIS Indoors does not have a validation tool.

DF 5 The data format must handle multiple floor levels in a building.

All three data formats handle multiple levels in a building: IMDF with *Ordinals* and *Levels,* IndoorGML with attribute *level* in *CellSpace* (this is a suggestion for version 1.1 and not yet released), and ArcGIS Indoors with *Levels*.

DF 6 Transitions between rooms and floor levels and corresponding network, or available APIs must be featured to enable navigation in an IPS.

IMDF is supported by several third-party platforms that provide APIs for navigation. The feature *Unit* contains categories of stairs, elevators, escalators etc which described transitons between floor levels. ArcGIS Indoors consists of Network dataset with *Transitions, Landmarks* and *Pathways. DeadZones* and *TrackingZones* also help enable navigation. The NRG in IndoorGML enables topological relationships between cells (rooms, doors, etc.), and with the help of semantics classification, such as navigable and non-navigable, it can be applied and used in navigation.

DF 7 It must be possible to add restrictions to areas, so accessibility is known if needed in an IPS.

IMDF has the possibility to add restrictions, as *restrictions* is one of the properties of some features. This applies to ArcGIS Indoors as well, with attributes *ACCESS_TYPE* and *ACCESS_PEDESTRIANS.* IndoorGML has the feature *Constrain* which describes several restrictions for other features.

DF 8 POIs must be featured in the data format.

IMDF uses the property *display-point* to represent POIs, and other properties describe the POIs in terms of categories and names. A layer of POIs can be added in ArcGIS Indoors. In IndoorGML POIs are described through the semantic representation.

DF 9 An established and frequently used IPS must support the data format

Both IMDF and ArcGIS Indoors model are supported in IPSs: Apple Indoor Maps and ArcGIS Indoors respectively. FME enables converting ArcGIS Indoors model to IMDF, which makes it possible to use with Apple Indoors Maps as well. The other way around is possible too: importing IMDF in ArcGIS Indoors and transforming it to ArcGIS Indoor model. No commersial IPS is supported by IndoorGML at the moment.

5.2 INDOOR POSITIONING SYSTEMS

Tabell 5.1 Summary of assessment of IPSs

Requirements	**Apple Indoor Maps**	**ArcGIS Indoors**	**Nimway**
IPS 1	x	x	x
IPS 2	x	x	x
IPS 2.1	*	*	*
IPS 2.2	*	*	*
IPS 3	x	x	x
IPS 4	x	x	x
IPS 5	x	x	
IPS 5.1	**	**	**
IPS 5.2	x	x	
IPS 6	x	x	x
IPS 7	x	x	x
IPS 8	x	x	x
IPS 9	x	x***	x***
IPS 10	x****	x	x

* must be tested

** not enough information

*** small installations needed

**** positioning only works on iOS devices

IPS 1 The IPS must consist of a map with accurate information of the building.

Apple Indoor Maps uses IMDF for the map, which is detailed with accurate building information that could be styled as desired when being used in the final IPS. ArcGIS Indoors uses the ArcGIS Indoors model for the map, enriched with building information. It is not stated which data format that is used in the Nimway system, but from the information available (searching for rooms and POIs are available) a conclusion is that the map consists of accurate building information.

IPS 2 The position of the user must be visible in the map.

It is possible to use the fingerprinting technology for positioning in Apple Indoor Maps if Wi-Fi are available. ArcGIS Indoors and Nimway require a third part supplier for positioning and further installations respectively to enable positioning.

> **IPS 2.1** The accuracy of the position must be 2 meters or less.
>
> Must be tested to confirm accuracy. Apple claims that the fingerprinting positioning provide GPS level accuracy or better, which is a topic required to be discussed as it can differ depending on surroundings.
>
> **IPS 2.2** The position must be updated in less than 1 second.
>
> Must be tested for all three, no information available.

IPS 3 Searching for POIs in the IPS must be a featured function.

Since POIs are part of the map in all three IPSs, the function of searching for them should be possible to implement.

IPS 4 Achieve navigation from position to chosen POI must be a featured function.

Navigation are not available in Apple Indoor Maps itself, but through a third part API this could be possible. ArcGIS Indoors and Nimway both have navigation as a feature. This includes that requirement IPS 2 needs to be fulfilled.

IPS 5 The IPS should be independent of supplier.

Nimway is a provider of the whole system and all work with the IPS that are performed within the supplier, hence the requirement is not fulfilled. ArcGIS Indoors and Apple Indoor Maps are independent as developers are able to work with the systems on their own.

> **IPS 5.1** It should be possible to use only updates and changes in the data instead of whole datasets when updating the map data in the IPS.
>
> Not enough information is available to fulfil this requirement. Apple mentions that this could be done, but how it is done practically is not stated.
>
> **IPS 5.2** Updates and changes in the map data should be possible to be done by the developer (from a company developing an IPS, not the supplier of the system).
>
> Fulfilled for both ArcGIS Indoors and Apple Indoor Maps since the development of the systems is in the hands of a developer. Nimway is in charge for all updates and changes in the map.

IPS 6 API or equivalent must exist for further development of the IPS and integration with room booking system.

This is possible for all three IPSs, hence the requirement is fulfilled.

IPS 7 The IPS must be provided by a reliable supplier.

Esri (ArcGIS Indoors) is a service provider for many GIS tools used today. They must implement standard kept in place since they sell their services to customers. One conclusion is they will continue to develop the ArcGIS Indoors product to meet future requirements. Therefore, ArcGIS is a reliable supplier. Apple Indoor Maps is provided by Apple Inc, one of the largest tech-companies worldwide today, making them a reliable supplier as it can be assumed that they will continue developing their products as new requirements are established. Nimway is provided by Sony, and since they provide a final implemented IPS with all deisrable features, including the maintenance on parts.

IPS 8 The degree of security and exchange of personal data must be enough for the usage.

This is fulfilled if the provider is not using the data for any reasons as well as the developer for the system. When a developer is in charge for the whole process instead of the supplier, it is easier to set up the security for both user and developer as desired. For Apple Indoor Maps and ArcGIS Indoors the requirement could be fulfilled. For Nimway, agreement on the safety should be discussed between the supplier and the buyer, but the user also needs to be informed about what data is shared for analysis.

IPS 9 The system should require no or small installations in the building to enable positioning (use what is accessible as far as possible).

For all three IPSs Wi-Fi is used for positioning (if Indoo.rs is used in ArcGIS), and additionally for Nimway Bluetooth beacons need to be installed. Hence, Apple Indoor Maps is the only system that will truly fulfil this requirement.

IPS 10 The IPS should be easily installed on a smartphone, iPhone or Android.

All three IPSs could be installed on iPhone's iOS or Android's software depending on the app developed. For Apple Indoor Maps, the Wi-Fi fingerprinting needs to be performed on an iPhone with the Survey App, and the positioning works only on iOS devices.

6 CASE STUDY

The case study consists of an implementation and evaluation of an IPS with selected techniques and data formats.

6.1 BACKGROUND

The case study is a test for an IPS in an office environment. The process for implementing the IPS is a significant part of the case study, which is described further in section 6.3 Method. This method is evaluated to acknowledge any difficulties or improvements in the process for implementing the IPS. The evaluation of both data formats and IPSs in section 5 are used when choosing which to use in the case study. The requirements are then used in the evaluation of the implemented IPS as well.

At Sweco's office in Malmö, the Nimway system is already implemented, and the case study provides a comparison between the new IPS (including possible functions) and Nimway.

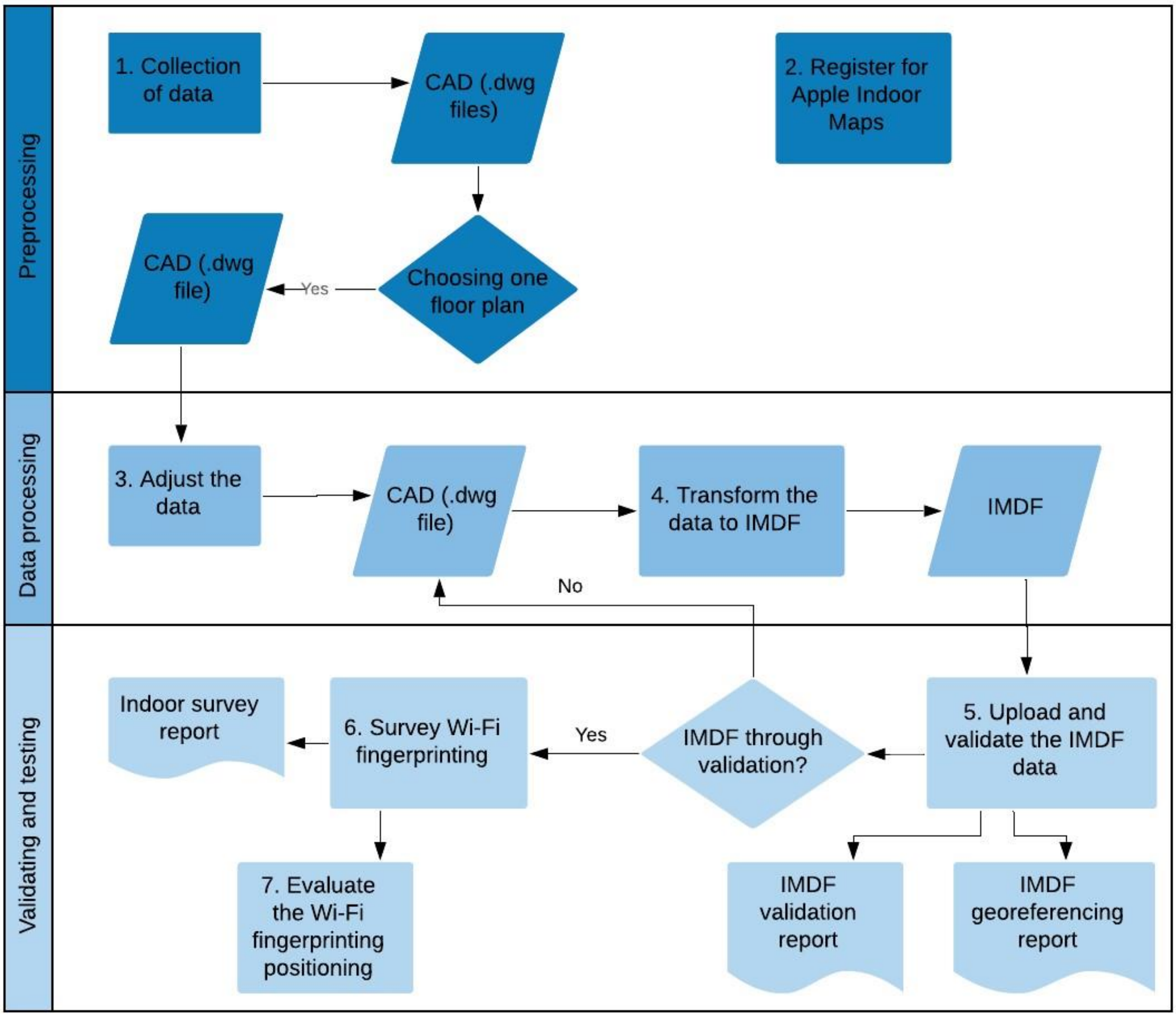
The evaluation of the IPS did not get as exhaustive as originally planned. One major reason for this was that the planned tests in Sweco's office coincided with the COVID-19 outbreak in Sweden. For that reason, the office building was partly closed and there were few persons available for tests.

6.2 Selection of indoor positioning system and data format

The IPS and data format chosen for the case study should fulfill all requirements, which are evaluated in section 5. IMDF fulfills all requirements for the data format, and Apple Indoor Maps meets most of the requirements for IPSs. The ones that are not fully met are the accuracy of positioning (IPS 2.1) and how fast the position are updated (IPS 2.2), which needs to be tested. Also, how changes to a map is added is not declared (IPS 5.1). One important requirement for this case study is IPS 9 which describes that no further installations for positioning should be needed. Apple Indoor Maps positioning use the existing Wi-Fi which makes it available to all. Other data formats and IPSs may fulfill the same requirements as IMDF and Apple Indoor Maps. However, the availability of FME at Sweco to help implement and validate the IMDF and the possibility to use the positioning technique in Apple Indoors without further costs are two aspects that effects the choice of data format and IPSs. Therefore, the data format IMDF and IPS Apple Indoor Maps with Wi-Fi fingerprinting positioning is selected.

6.3 Method to collect data, implement and evaluate indoor positioning system

The method of this case study consists of several steps. Each step is described in the following sections. An overview of the steps, marked with numbers and separated into three sections, is seen in figure 6.1. The first section, preprocessing, consists of preparing steps: collection of data to work with and register in Apple Business Register for Apple Indoor Maps to be able to use the validation tool *Sandbox* and testing indoor positioning. The second section, data processing, is where the source data is adjusted and then transformed to the right data format, IMDF. The third and last section consists of the first two steps where the IMDF is validated. A fingerprinting survey on the mapped area is performed once validation is approved. If validation is not approved, steps 3 and/or 4 are remade to correct errors. The last step in this section is testing the IPS.



Figur 6.1 An overview of the method process in the case study

6.3.1 Collection of data

Sweco's office at Drottningtorget 14 consists of 8 floor plans, where floor plan 1 is the entrance floor with reception, café and larger meeting rooms. The rest of the floors are where the different divisions of Sweco are located, with at least one or more divisions per floor. The floors consist of similar parts: meeting rooms, phone booths, areas for working desks, small kitchen and lounge area, along with other parts. The floor plans are connected with elevators and stairs.

The floor plans are delivered as CAD drawings, dwg files, with one file for each floor. In this case study, one floor (and therefore one CAD file) is chosen to be converted to IMDF.

Some adjustments in the CAD file have already been performed by Jürgen van Tiggelen, Sweco Position, like mapping lines to correct feature (walls to *Room*, building wall to *Footprint*, etc.). This file is the one that is used in the case study. Figure 6.2 below shows the file in AutoCAD, with names and categories for rooms. The different colors represent different features in IMDF, such as pink for rooms (*Unit*), blue for *Fixture*, red for *Kiosk*, yellow for *Venue*, black for both *Level* and *Footprint*, and orange for *Section*. The right part of the drawing consists of features and lacks certain features (due to some censoring), that will not be in the final map. Further work applied on this file, as a part of this case study, is presented in section 6.3.3 Adjust the data.

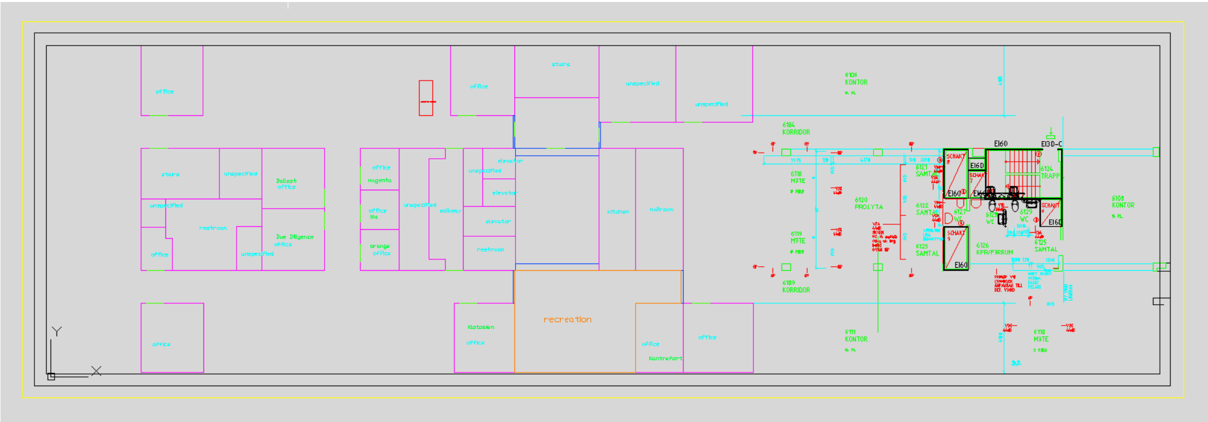


Figure 6.2 The adjusted CAD file by Jürgen van Tiggelen, shown in AutoCAD.

6.3.2 Register for Apple Indoor Maps

After receiving the data, next step is to register in Apple Business Register for the Indoor Maps Program, which allows an organization to upload an IMDF and validate it. The building itself needs to be registered as well, including an approval from the owner to map the building. The building in this case is related to a company, Sweco, which means that the map developer needs to be registered as an Apple Developer of the company to provide access to uploading files that can be validated and performing the survey for positioning. An Apple ID is required for the registration, which in this case is connected to an existing e-mail. In figure 6.3 below, the profile could be seen with roles and permissions for the Apple Indoor Maps Program: Surveyor and Map Maker.

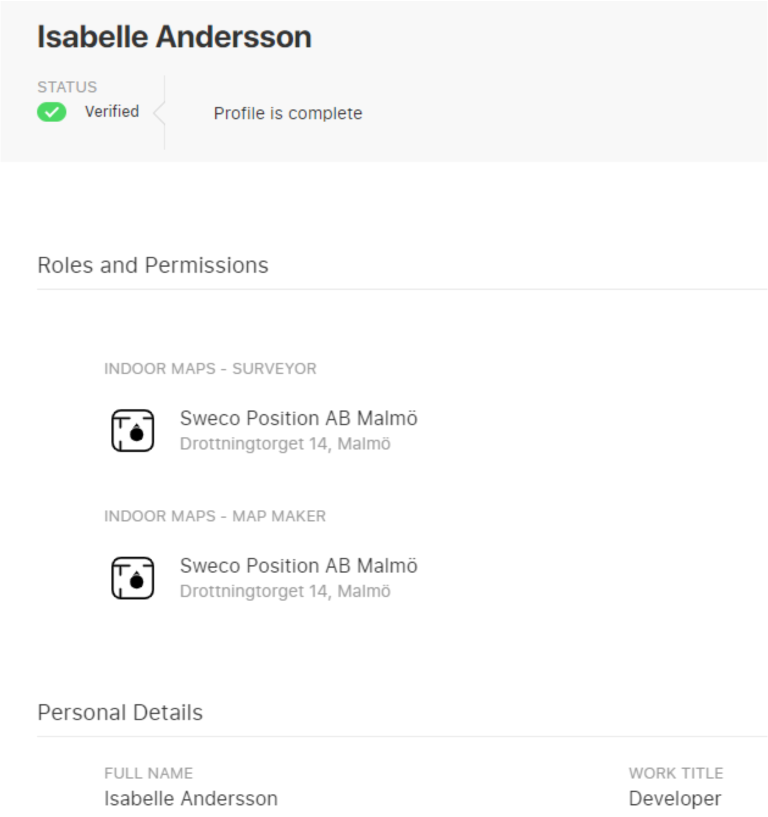


Figure 6.3 The profile in Apple Business Register.

6.3.3 Adjust the data

When the registration in Apple Business Register is done, the next step is to adjust the CAD file in AutoCAD, adding missing features and removing or changing features that are not correct. As mentioned, some adjustments from the original CAD file have been performed by Jürgen van Tiggelen, Sweco Position. The adjusted file is the one used in this case study and further work on it are here described.

An important step of the whole process is to geo-reference the floor plan, which can be done in several ways. In this case study, it is performed in AutoCAD. First, a local plannar coordinate system is assigned to the drawing: SWEREF 99 13 30 (Malmö municipality official coordinate system). Activating a background satellite map enables to rotate, offset and scale the drawing to the right location so it matches the building real world location, and the coordinates are then stored in the drawing.

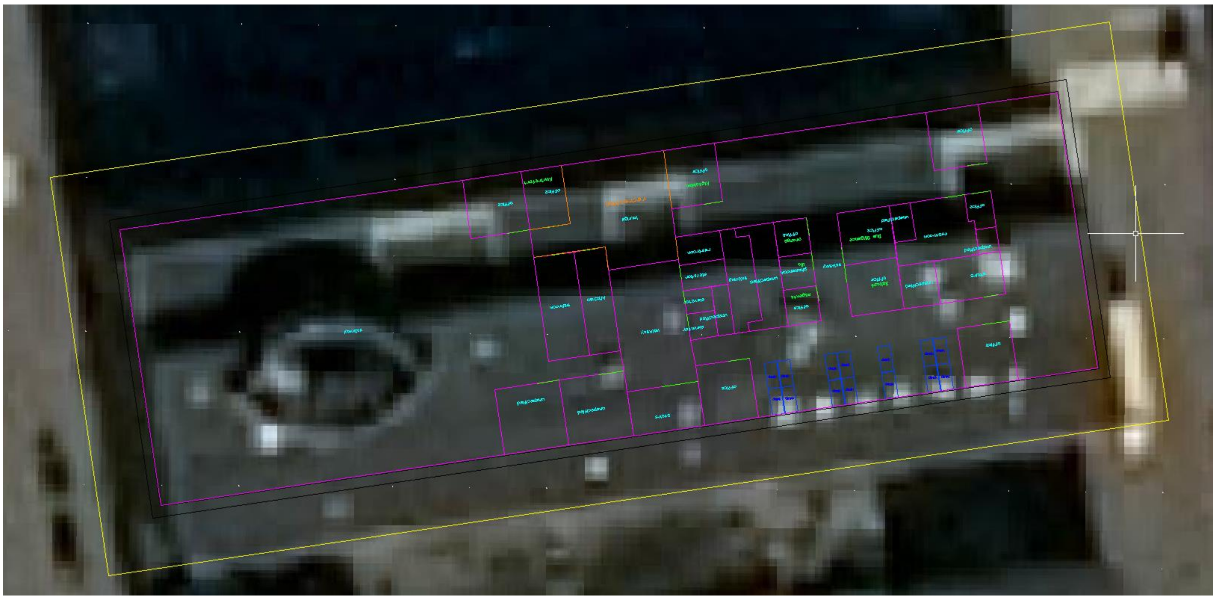


Figure 6.4 Georeferenced drawing with a satellite map background in AutoCAD.

Other things that are done in this step are changing, removing or adding features to the drawing. When comparing figure 6.2 and figure 6.4, it is detected that the yellow line (*Venue*) is scaled to include more space around the building, in the second figure. Doors (green lines, *Opening)* are added at locations where there should exists doors, as well as desks (blue lines, *Fixture*) in the office area. The desks are a bit different from the other features as they do not exist in the drawing from the beginning. This is because they are movable objects and not part of the building's structure and therefore added manually.

6.3.4 Transform the data to IMDF

Cleaning up unnecessary attributes and adding or changing attributes for each feature are done in FME to assure that all features are correct according to the requirements of IMDF. The IMDF writer in FME creates the required metadata JSON-file in addition to the chosen features. All features have writers on their own with pre-decided attributes, so it is easily detected if an attribute is missing. This is shown in figure 6.5 below with the example of feature *Venue*: to the right, the layer is written to the IMDF format, and the green triangles show that all required attributes exist. However, this does not mean that they are accurate. The accuracy is checked in the validation step. A total overview of the whole FME workspace is found in Appendix, included with all readers, writers and transformers.

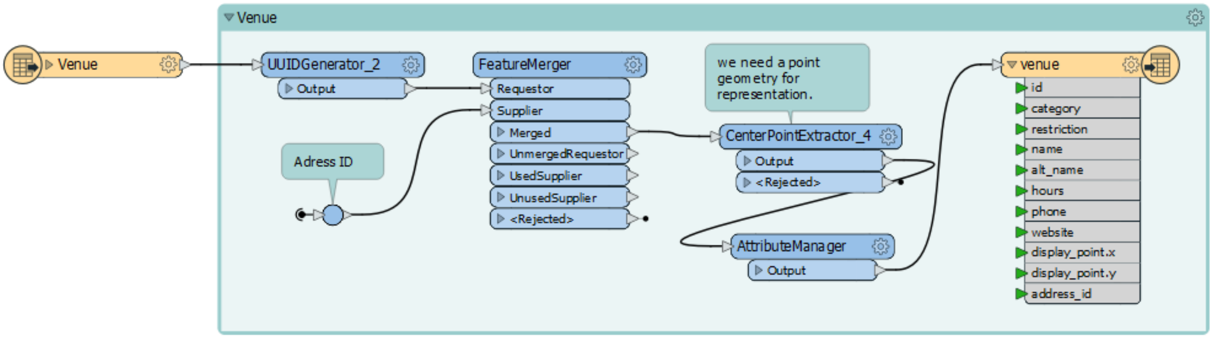


Figure 6.5 Transforming the Venue layer in the AutoCAD file to the feature venue in IMDF, in FME.

One transformer that is used for all features is the *UUIDGenerator*. This transformer generates a UUID (Universally Unique ID) for each feature (Safe Software 2020b), which is one of the requirements for all features in an IMDF. The transformer can be seen in figure x above, the first transformer from the left.

It is a requirement for many of the features to have point coordinates, which is used for visualization of icons or map labels in the map. The geometry is represented by the attributes *display_point.x* and *display_point.* In the writer for the feature *venue,* in figure 6.6 below, these attributes are visible. They are created by the transformer *CenterPointExtractor,* which extracts the x, y and z coordinatesof a features point. The point is either in the center of the feature's bounding box, at the center of mass of the feature or somewhere guaranteed to be inside the feature's area (Safe Software 2020c). In this workspace the center of the bounding box is used, as most features are rectangular.

The geometry for each *Unit* feature is required to have a polygonal value – an area. The geometry of the layer Rooms (*Units*) in the CAD file is inconsequent with both lines and polygones, why *Intersector* and *AreaBuilder* transformers are used. The *Intersector* takes the incoming features and compare them to each other, and each feature is split wherever an intersection occurs. It then creates a node in each intersection as well as intersected segments. Figure 6.6 shows how the features are split where nodes are added (pink points) and intersected segments are lines between every pair of nodes. The segments are input to *AreaBuilder,* which creates polygons where these segments form closed shapes (Safe Software 2020a).

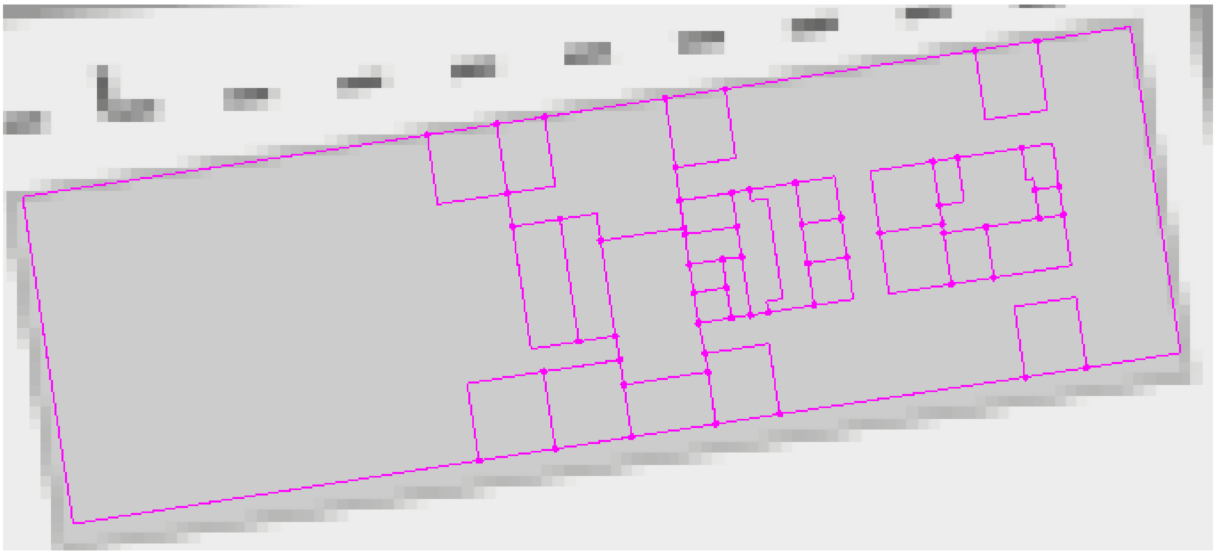


Figure 6.6 Intersected segments (pink lines) and nodes (pink points in intersections) visualized in FME.

The transformer *AttributeManager* is used to change attribute names, set values, deleting unnecessary attributes or adding attributes (Safe Software 2020a). An example of how the transformer is used is seen in figure 6.7 below. The attributes *name*, *alt_name*, *category* and *restriction* are added and given set values. The attribute *building_id* is renamed to *id*. These changes are done to match the required output attributes in the writer for the feature *building*. In this step it is also important to be aware of that some attributes only can have restricted values. As *name* is the name of the building or company that occupies the building, it does not have any restrictions, but the attributes *category* and *restriction* are only allowed to have values given in the IMDF specification.

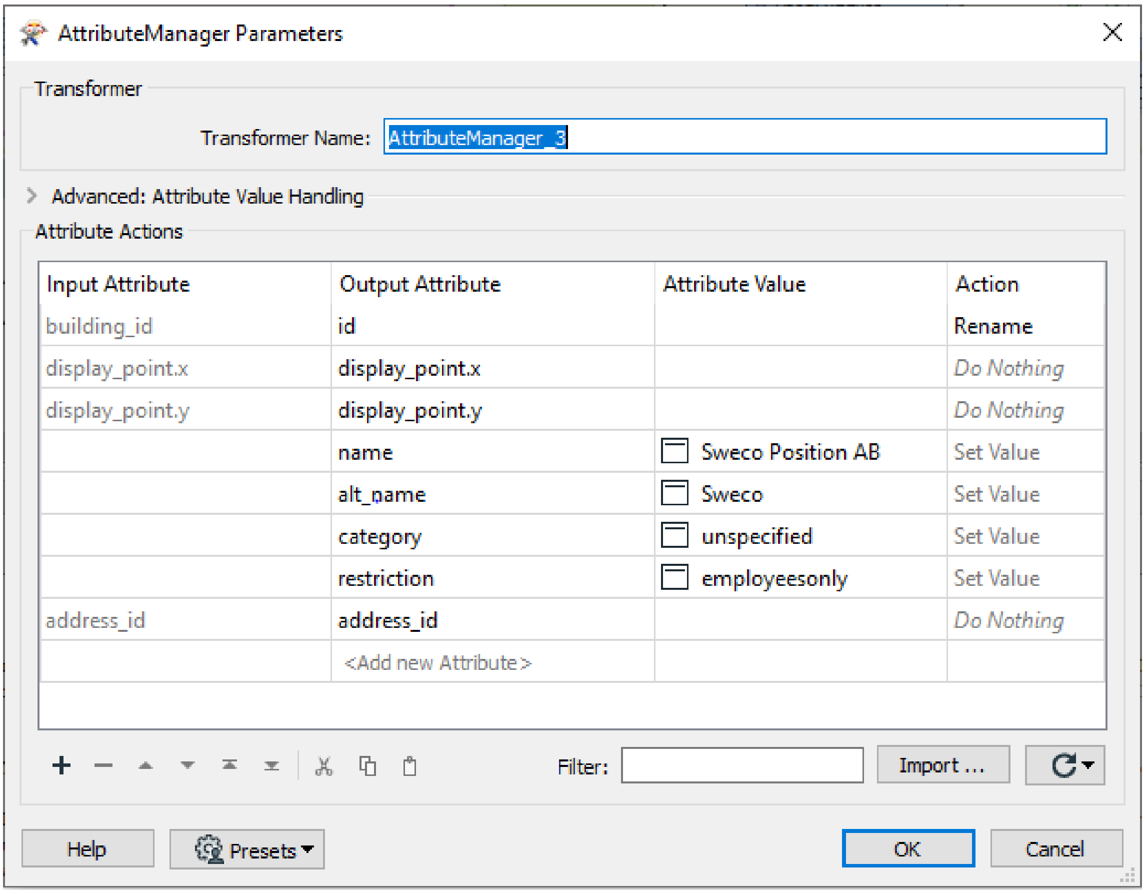


Figure 6.7 Example of how the AttributeManager is used for the feature building.

The transformer *IMDFValidator* is used in FME to detect errors or warnings before validating the IMDF in *Sandbox*, making it possible to correct errors at an early stage. The transformer reads an IMDF file directly, a zip-file of all the features that are required to be validated. The output features from the transformer consist of message with error level (error or warning) and the type of warning (Safe Software 2020a).

The result from this step is a zip-file (IMDF file) containing the required files as well as additional files for chosen features.

6.3.5 Upload and validate the IMDF data

The next step in the process is to upload the zipped IMDF file to the account in Apple Business Register where validation is performed. There are two parts of the validation process: that the IMDF is valid due to the requirements of both GeoJSON and IMDF, and that the building is georeferenced correctly. The tool *Sandbox* in Apple Business Register is used to visualize the IMDF, displaying any errors or warnings, and for correcting minor errors or warnings.

The first step of validation takes about 24 hours before the file is accepted or rejected, and a validation report is available where errors are listed. During this time, it is possible to examine the file in *Sandbox* if it not contains of too many errors. If the IMDF file is rejected and failed validation, several options are available to correct the errors. They are corrected in Sandbox (minor warnings or errors), FME (mostly attributes but other changes too) or CAD (adding, removing or changing features), which means some steps in the method are done more than once.

Below in figure 6.8 is an example of a warning for the IMDF, a display point is located outside of the geometry of a feature. In figure 6.9 shows the feature with its geometry visualized. This kind of warning is fixed in *Sandbox*, as the point can be moved to a more suitable location with only a click.

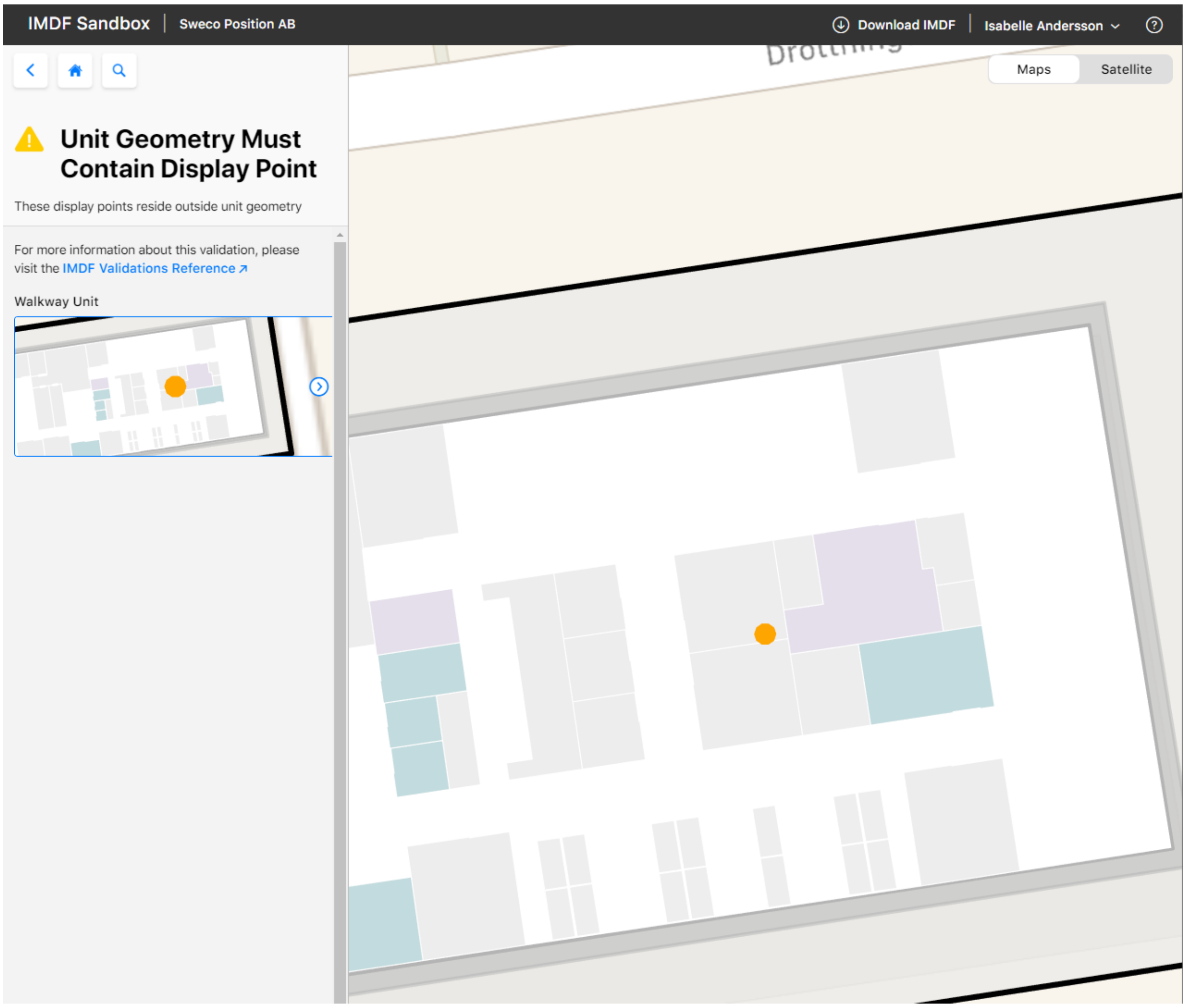


Figure 6.8 An example of warning in Sandbox tool where a display point lies outside the features geometry, which is shown in figure 6.9 below.

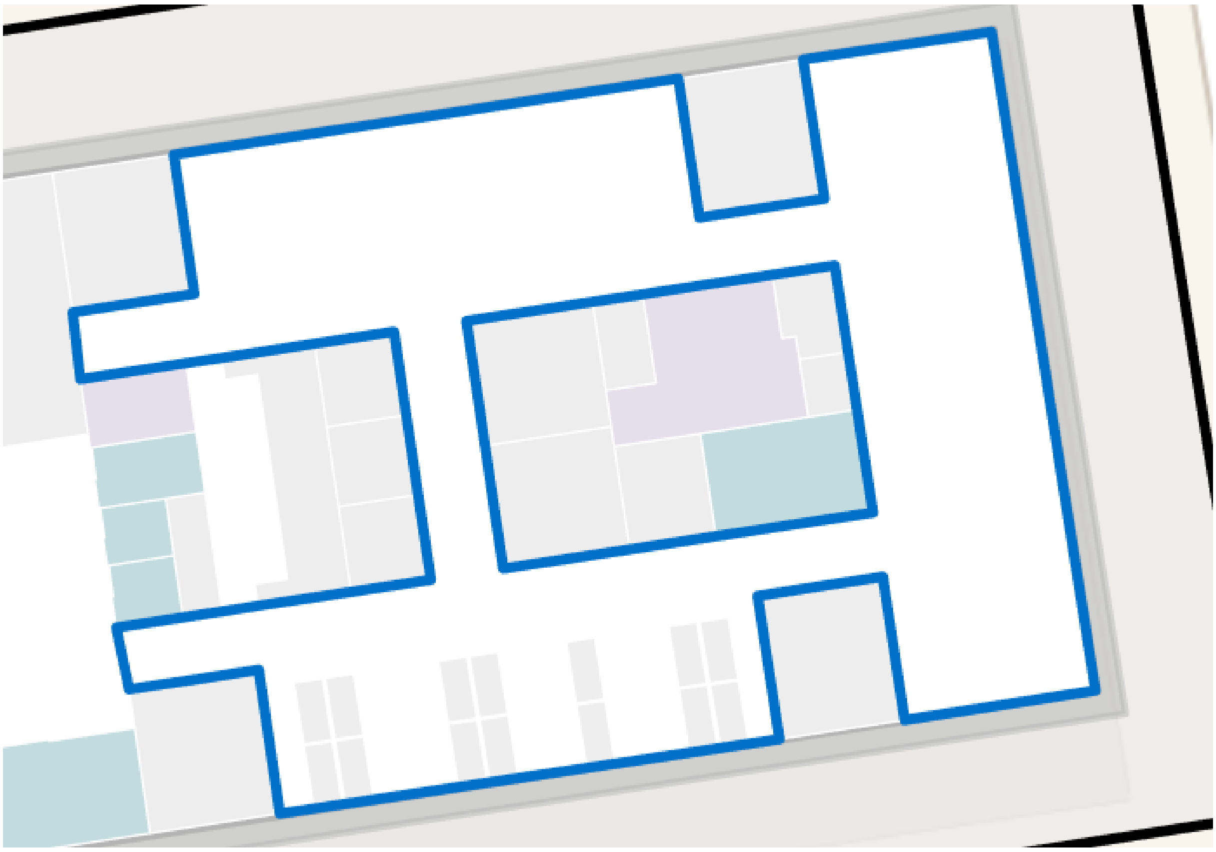


Figure 6.9 The walkway unit feature that the warning in figure 6.8 visualizes.

When the first step of validation is succeeded, it is time for the next step: validation of the georeferencing. This takes a couple of days and results in a georeference report if failed. The errors presented in this report needs to be corrected. The errors could be incorrect scale of features, that the features are skewed, wrong rotation of features or that the features have wrong location.

6.3.6 Survey Wi-Fi fingerprinting

When the IMDF has gone through the validation the Wi-Fi fingerprinting survey is conducted. The survey is performed with the Survey App, which requires an iPhone. In the app, the Apple ID used in Apple Business Register is used for logging in to enable performing the survey on the correct IMDF. In this case study an Apple iPhone 7 is used.

After choosing the building on which to perform the survey, the screen below in figure 6.10 is presented to the user. As seen, the app is in Swedish but are available in English as well. In the Survey app, three steps are present where the first two are part of this step in the method: 1.

Kartlägg (Mapping) and 2. Överför (Submit). The last step, 3. Testa inomhuspositionering (Testing indoor positioning) is described in section 6.3.7 Testing.

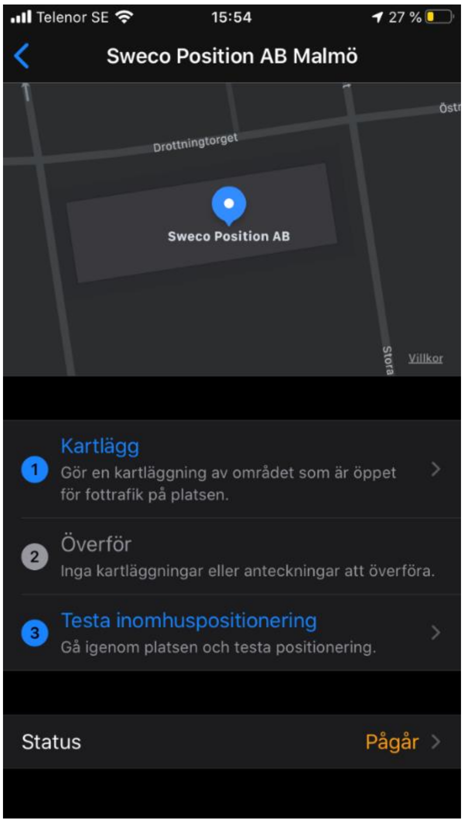


Figure 6.10 The interface of the Survey app after choosing a building to perform a survey on..

Step one, mapping, is done manually as the user holds the phone and moves the dot on the map to his or her approximate location as seen in figure 6.11 A below. The user clicks on the screen which starts the mapping and walks about 5 meters in a direction that is walkable. Then the dot is moved again to the new location as seen in figure 6.11 B. The user clicks on the screen which completes the mapping between the two first points. This is visualized as the orange area in figure 6.11 C. Then the user walks another 5 meter and move the dot. This is repeated until the whole map is walked through and mapped with the Wi-Fi fingerprints. The time can also be seen in the top of the figures, which could indicate on a sense

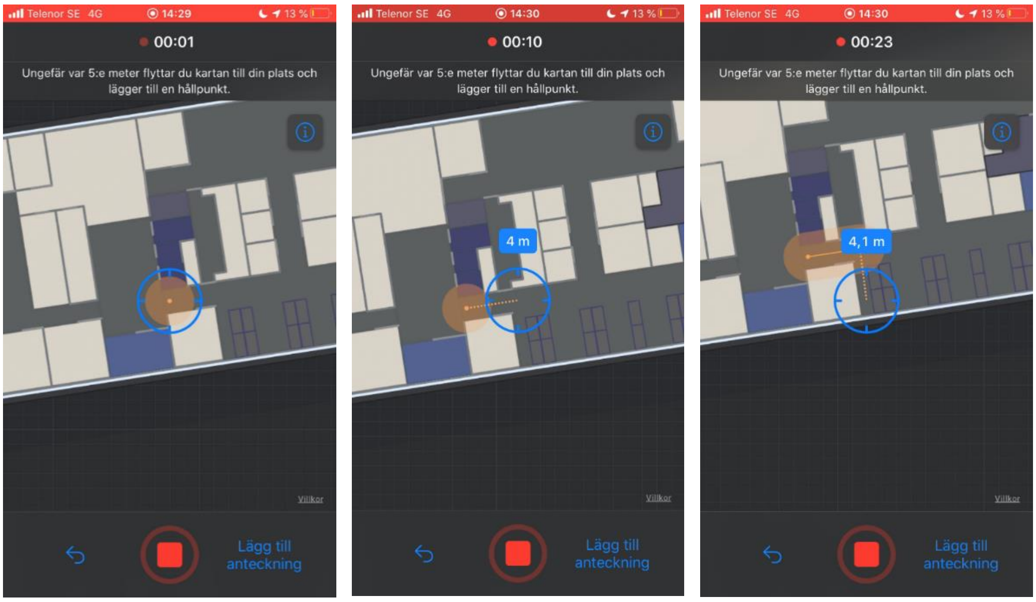


Figure 6.11 From left: A. Moving the dot to approximate position in map. B. Walking to a new position and moving the dot to that position in map. C. Walking to a third position and moving the dot.

When a part of the map is completed (the orange area covers a larger part of map), it can be submitted to the map in Apple Business Register and then verified. This takes a couple of hours up to one day depending on how much is covered and submitted. In both Apple Business Register and the Survey app, the area turns green when it is confirmed that the mapping is correct (as in the fingerprinting data is available where the map is covered). This is seen in figure 6.12 below, where almost the whole area is covered. A large part of the map consists of a large open space, which is in real life covered with rooms etc. This part of the map is chosen not to be mapped for positioning since the part that is mapped in the figure will suffice for further testing.

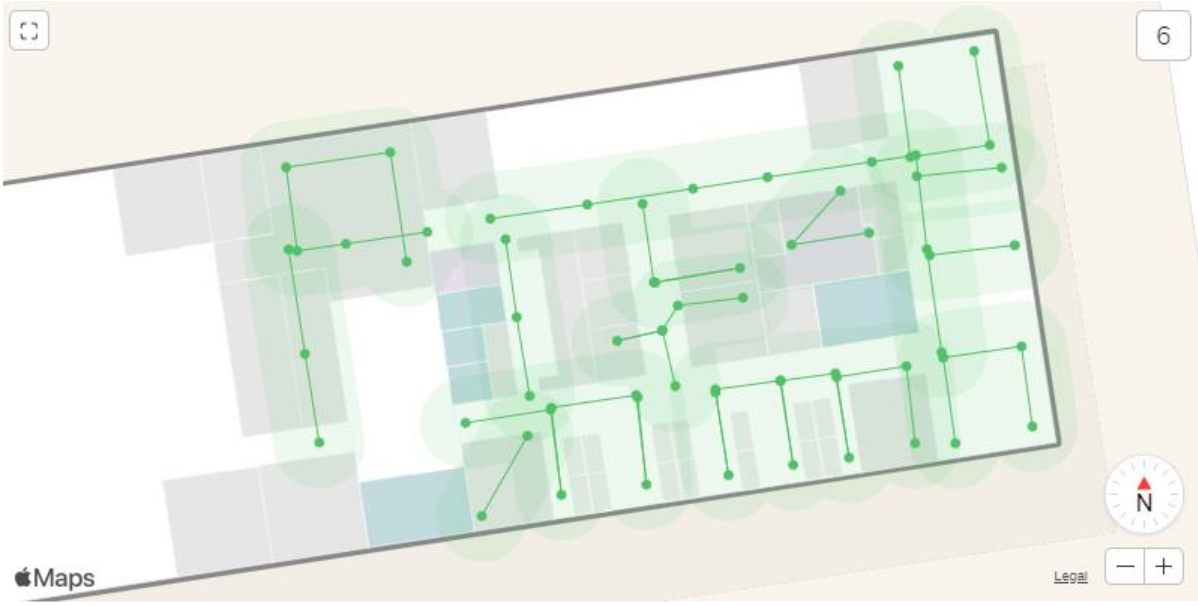


Figure 6.12 The verified green areas in the map ready to be used for positioning, seen in Apple Business Register.

6.3.7 Evaluate the Wi-Fi fingerprinting positioning

As mentioned in section 6.3.6 Survey app, the third and last step in the app is testing the positioning. This is done by walking through the building and checking that the position (blue dot) follows the user in the map. This is the testing functionality built in the app, implementaions are required if other tests are desired, such as numerical testing of positions. If something seems to be wrong, a new mapping of a certain area may be needed. In figure 6.13 below, a screenshot while walking through the building is shown. The position of the user is the blue dot, located in a walkway between office rooms.

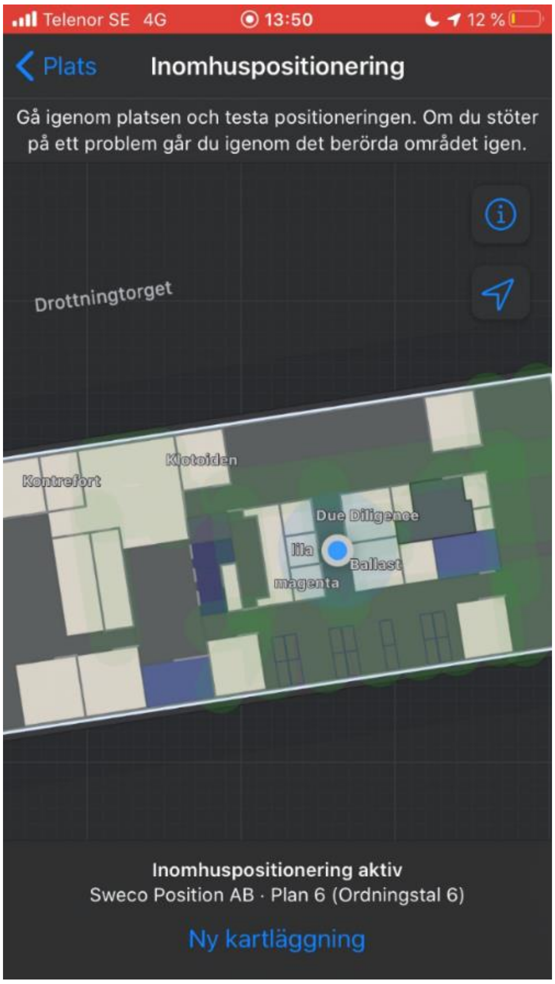


Figure 6.13 Testing positioning in the Survey App, the blue dot is the position of the user.

6.4 RESULT

6.4.1 IMDF

DF 1 The data format must be well documented.

This requirements facilitates the transformation of the source data, in particular what adjustments is required of the source data before transforming it. In FME the attributes are predefined, but any ambiguities are solvable since the data format is well documented.

DF 2 The data format must be provided by reliable supplier.

This requirement is important to ensure the future development of a data format and for a well functioning IPS, high demands are on the data format for the indoor map.

DF 3 Importing and transforming data should be partly automatized.

In this case study, a lot of manual steps are done to prepare the source data for the IPS and FME facilitates some of these steps. How much the automatization could vary is depending on source data, chosen data format and the platforms used for adjusting and transforming the data. In this case study, using ArcGIS Indoors to adjust the source data might be easier than AutoCAD, but for other source data a third platform might suit better. This is a topic for further discussion.

DF 4 Validation of imported or created data for the data format should be possible.

For an accurate map and easy visualization in an IPS, the data must meet the requirement of the data format. By using some kind of validation, the accuracy is therefore ensured for the structure which helps other requirements to be met.

DF 5 The data format must handle multiple floor levels in a building.

A requirement that can not be deducted, and should be included for all data formats for indoor maps. With no representation of different floors, the indoor map would not be useful. In IMDF this is clearly a large part of the data format.

DF 6 Transitions between rooms and floor levels and corresponding network, or available APIs must be featured to enable navigation in an IPS.

This requirement is important if navigation is a functionality that is demanded of the IPS. For IPSs with other main functionalities, this may not be as important and instead other requirements are set.

DF 7 It must be possible to add restrictions to areas, so accessibility is known if needed in an IPS.

As mentioned in DF 6 above, some functionalities may be more important for some IPSs than others. This requirement may not reply or be as important to all kinds of IPSs, but often larger buildings (where an IPS could be useful) contain of areas where not everybody should have access.

DF 8 POIs must be featured in the data format.

This is a requirements that somehow needs to be fulfilled of all IPSs, to ensure the accuracy and understanding of the indoor map.

DF 9 An established and frequently used IPS must support the data format.

This requirement does not respond to all data formats for IPSs, as in other projects open source implementations could be an option. Commercial IPSs are of more interest in this case study, why this requirement is set. IMDF is strongly connected to and supported by Apple Indoor Maps, thus this requirement is well met for the case study.

6.4.2 Apple Indoor Maps

IPS 1 The IPS must consist of a map with accurate information of the building.

The map is based on the IMDF with both movable features (desks) and features that is based on the buildings structure. The resulting map in the IPS is accurate for all features in it, but some details that would enrich the whole map are excluded like more desks with information of the owner of a certain desk. However, this requirement is important as a map without accurate information and structure could confuse a user.

IPS 2 The position of the user must be visible in the map.

> **IPS 2.1** The accuracy of the position must be 2 meters or less.
>
> **IPS 2.2** The position must be updated in less than 1 second.

In the Survey app, the position of a user was enabled to be shown after the survey had been performed. The testing that was performed for the positioning resulted in sufficient accuracy, concluded by the fact that the blue dot was never on the wrong side of a wall. If the accuracy was 2 meters or less (requirement IPS 2.1) could not be stated by calculation. However, since the position always was on the right side of walls, a conclusion is that the accuracy determined with provided testing would suffice in this certain building but can not be numerically stated. A negative aspect is that the positioning only works on iOS platforms.

IPS 3 Searching for POIs in the IPS must be a featured function.

This is available with further development, but should be included in a complete IPS, to meet the type of usage required from it.

IPS 4 Achieve navigation from position to chosen POI must be a featured function.

This is available after further development. That the positioning works in a sufficient way is a requirement for this to work. bIf navigation is required in this type of building could be discussed – it may suffice with only positioning of a user and highlighting POIs.

IPS 5 The IPS should be independent of supplier.

> **IPS 5.1** It should be possible to use only updates and changes in the data instead of whole datasets when updating the map data in the IPS.

> **IPS 5.2** Updates and changes in the map data should be possible to be done by the developer (from a company developing an IPS, not the supplier of the system).

In this case study, the developer is in charge of the whole process. Further analyses on how to use only updates and changes when updating data are needed as no changes were added after validation due to time limits. The developer can perform updates and changes in the map. It is important to ensure the accuracy of the map, why this requirement should be considered for implementation in similar projects as well. Otherwise, great demands are placed on effective communication between supplier and customer.

IPS 6 API or equivalent must exist for further development of the IPS and integration with room booking system.

Should be available with further development. This is a requirement and function that would improve the IPS. In other user cases, integration with room booking system might not be as important, but integration with other services could be considered.

IPS 7 The IPS must be provided by a reliable supplier.

As stated earlier in section 5, Apple Inc. is a reliable supplier of both data format and IPS. This requirement is important for further implementations and development of both data format and IPS, so that it continues to work properly.

IPS 8 The degree of security and exchange of personal data must be enough for the usage.

Not tested, but a conclusion for this requirement is that if the developer instead of supplier is responsible for developing the IPS, the desirable degree of security and exchange of personal data could be costumized. This requirement should be considered, whenever personal data or positioning is used to ensure the users safety and privacy.

IPS 9 The system should require no or small installations in the building to enable positioning (use what is accessible as far as possible).

No installations were done as to this case study as the Wi-Fi fingerprinting positioning uses the existing Wi-Fi in the building. The requirements itself just accounts for this thesis and case study, even though it is positive to use the existing possibilities from a sustainable point of view.

IPS 10 The IPS should be easily installed on a smartphone, iPhone or Android, or require no installation.

The Survey app used for the fingerprinting survey and testing positioning was the only app installed and downloaded on an iPhone, and visualizes how the map with positioning would function. No actual IPS-app was developed. However, the IMDF file with positioning enabled is possible to use in such an app, but only on an iPhone or other iOS device. This requirement could have been stated differently with the addition that the IPS must work on all smartphones to make it available for all.

6.4.3 Apple Indoor Maps vs Nimway

Both Apple Indoor Maps and Nimway could include the required main features for office environments – finding POIs and navigation. This was not tested for Apple Indoor Maps as further implementations of an app with these features would be necessary. Nimway has the possibility of including navigation in its IPS, however, this is not included for the system at Sweco and therefore not tested.

One large aspect of Nimway is that it is fully reliable on the supplier, which in this case study was not desirable. For a smaller venue like an office building, Apple Indoor Maps sets the full responsibility of implementing the IPS to the developer. Thus, the developer is in full charge of desired features as well as the layout of the map. It is then possible to use it in own apps or websites.

Nimway at Sweco integrates with the booking system for meeting rooms, which is easy to use when needing a room instantly. With a click on a free room, the room could be booked for a certain amount of time and meeting partners could be invited as well. Apple Indoor Maps could include a similar function as well, which would need to be implemented. However, the Nimway app can only be used for employees at Sweco. When implementing a similar app using Apple Indoor Maps, a feature could be to choose if user is a guest or an employee and receive different features in the app, and even different detailed maps (censured in some way for a guest for example).

The positioning would need further testing for both IPSs to be able to compare them. Based on the small test performed, the achieved accuracy suffice for this kind of building in both IPSs. The IPSs use two different kinds of positioning techniques, which both are sensitive to changes in the building structure in separate ways. The Wi-Fi fingerprinting of Apple Indoor Maps depends on the Wi-Fi signals, which are disturbed if the structure changes. If changes occur, the Wi-Fi fingerprinting survey of an affected area requires to be re-done. For Nimway, changes in the structure may indicate that new positioning beacons are required to be installed, or that existing beacons must move to a more suitable location. Thus, for Apple Indoor Maps it is more time consuming when changes in the structure occurs, while for Nimway it could be a cost issue.

Showing the occupancy of meeting rooms, like in the maps Nimway provides, is a great feature when needing a meeting room instantly: fast detecting which rooms are booked, but not used (no one is in the room), or free rooms. This should be able to be featured in Apple Indoor Maps as well, when integrating with a room booking system. If meeting rooms are often booked and not used, the occupancy feature is helpful. However, for offices where the competition for meeting rooms is not too high, it would suffice with a feature showing if a room is booked or not booked. This is usually not a problem in Sweco’s office in Malmö, and therefore no further installations would be required if Apple Indoor Maps would replace the current Nimway system.

One aspect of security degree and exchange of personal data in Nimway is that some data is used for analysis of room usage for example. An important question is if the users know that data are used for these purposes and if that knowledge could affect the usage of the app.

6.5 DISCUSSION

6.5.1 Method to collect data, implement and evaluate indoor positioning system

The method is discussed and evaluated, and some improvements of the method are provided. The discussion of the method highlights limitations and difficulties in both the method itself, as well as for the data format (IMDF) and IPS (Apple Indoor Maps).

Collection of data

This part of the method could vary depending on the source data, if any is available, and also affects the rest of the implementation as noticed in other parts of the method. Transforming source data to meet the requirements of the data format could be hard if the source data are lacking important information or features, or if it contains unnecessary features. In this case, some cleaning up had already been done in the data which made the transformation easier.

Register for Apple Indoors

For this part, the building was already confirmed to be used in Apple Indoors which made it a simple step. As long as the owner of the building or the company that holds the building have accepted that it will be mapped for Apple Indoors, this step should not be an obstacle. Sweco already had a developing team in Apple, which led to some problems when trying to add a new developer, and it was unclear how to solve it until suddenly the inquiry was accepted. It is difficult to know what went wrong and why, as insufficient information was available for this step.

Adjusting the data

If adjustments had not been performe to the existing CAD file prior this case study, this step would have been more extensive. Also, if more than one floor was to be used for the map, this step would be even more extensive as the floors would need to align and making additional features present. To ease the work in the next step, this step requires precision for the features and how they are layered which were identified while validating the data.

In this step, the georeferencing was performed as well. This affects the final map and IPS in many ways: the scale, placement and rotation which in turn affect the positioning system if the features are not accurate georeferenced. The georeferencing, adjusting the drawing with the help of a satellite map, had to be done several times as the validating step in *Sandbox* did not approve the georeferencing: the IMDF did not align geographically with the building on the map in different ways. This could be avoided if known coordinates for the building were available, and therefor also increase the accuracy of the map. This is an example of how the source data could affect the method and result.

Some detailing features were removed from the in the CAD file since they were not necessary for the indoor map. Those details would not improve the readability of the map. Detailing in the source data is an aspect to consider: what is required in a map, what will be excessively and how will insufficient or excessive source data affect the process when implementing an indoor map.

One aspect that could enrich the case study is to include more than one floor. This was not implemented due to time limits as some steps were too time consuming.

Transform the data to IMDF

This step was more straight forward than other steps. If the case study would include more than one floor, this would increase the work made in this step. One of the difficulties was to ensure that attributes with restricted values had only allowed values. If the geometry of features was wrong, this could be corrected in FME for some features. Geometry that could have been wrong is due to lack of knowledge in AutoCAD, eventhough some erros could have been avoided with greater knowledge of the system.

The result from the *IMDFValidator* seemed to be more thorough than the validation in *Sandbox*. Considerably more warnings occurred in FME, which were not shown in *Sandbox.* Some warnings were easily fixed in FME right away as many were connected to attributes, and some were ignored as they were not to affect the final IMDF. The errors on the other hand gave some advance on what needed to be adjusted before going through validation in *Sandbox.* It is a great time saving tool as it is used to determine, detect and correct these errors during an early stage of the process before validating in *Sandbox.* Although it was great to find these warnings and errors, the overall result was a bit overwhelming and hard to interpret due to the extensive content and that the warnings and errors were described in text.

Upload and validate the IMDF data

Every time an IMDF file was uploaded and did not get through validation (i.e. errors occurred), necessary changes and adjustments had to be done in earlier steps, and then the whole file had to be uploaded again. Thus, if changes were made in AutoCAD, all features had to be run through the FME workspace again. Each time a new IMDF is uploaded, it has to be validated first and then the georeferencing validation is done only if the IMDF is approved. So these two validation steps are repeated each time a new file is uploaded, even if the georeferencing validation fails. The first validation takes about 24 hours while the georeferencing validation takes a couple of days, resulting in a time consuming process just waiting for it to be done. No adjustments can be done to the IMDF while it is validated. When and if there are new improvements or changes performed, it will stop the current validation file which adds a considerable amount of time waiting for validation.

The validation tool *Sandbox* was helpful with visualization of the map, warnings and some errors. The overview made it easier to understand the errors and that some warnings could be corrected instantly was a great feature. It is positive to know that some properties could easily be added or changed for different features without having to change it in the CAD file or in FME.

Survey Wi-Fi fingerprinting

This step was very time consuming, even though it was only made for one part of a floor level. A building like Sweco’s office may not change to much which is positive for the positioning and indicates that it does not have to be performed often. Still, small changes in the building’s structure could affect the fingerprinting map, which is why this is a negative aspect of fingerprinting positioning.

The app itself was easy to use and straightforward. The map noticeably may not have acurrately been georeferenced in terms of rotation, scale and placement while walking through the building and mapping the fingerprints. When walking 5 meters and trying to adjust the location in the app, it could differ up to 1 meter to the length in the app. Because the original file was not georeferenced, the scale of the original drawing could also be faulty, resulting in that full accuracy for georeferencing is hard to achieve with the georeferencing method used in this case study.

Evaluate the Wi-Fi fingerprint positioning

The testing step in the Survey App could have been more developed. To only walk through the building and checking that the blue dot is following the user can not result in anything that could be used to check accuracy or updating time. To achieve this, further implementations for testing the positioning would be needed, such as receiving coordinates for the position in the map, which could be compared to the real coordinates of that position.

7 CONCLUSIONS

The thesis aims to provide an overview of indoor data formats, some positioning techniques and various IPSs. This is fulfilled, with information provided based on the set requirements. More detailed information is available, but the most relevant information for this thesis is provided. A conclusion from the literature study is that, especially for the data formats and IPSs, studies on the chosen data formats and IPSs has barely been performed. This could be explained with the fact that they all were released within a couple of years prior to this thesis. One aspect is also that improvements and new features are added to the data formats during this thesis (for example, the attribute *level* has been added to IndoorGML), proving that this is a new area of techniques and standards still under development. Hence, requirements DF 2 and IPS 7 are concluded to ensure that further development and adaptation take place.

Two requirements of functionality of an IPS in an office environment (IPS 3, 4) are concluded to work as a base functionality for IPS with navigation, whereas requirement IPS 6 could improve the usage of IPS in office environments. Thus, a conclusion is that requirements set for a certain IPS have to be adapted to the applications and essential functionalities of that IPS. Moreover, as some requirements could be responding to IPSs overall or the certain environment, others are adapted due to this thesis, such as DF 9 and IPS 5, 9.

Furthermore, implementing an IPS demands properly set requirements for both the system and the data format based on applications and functionalities for the IPS. That an IPS should be available to anyone who wants to use it (IPS 10) is a significant requirement that unfortunately is not met by Apple Indoor Maps in the case study. Consequently, it is not proposed to recommend the system until the possibility of using positioning works for all smartphones or in case other technology is used for positioning, although the IPS could meet all the other requirements.

One aim of the thesis is to evaluate the process for implementing an IPS in an office environment, detecting limitations or difficulties. One main conclusion from this evaluation is as IPSs will get more common with increased usage, a higher level of easy integration between source data and chosen indoor map data format is required. When source data is created, the fact that it might be used for an indoor map should be taken into consideration. On one hand, the accuracy of structures and details in the source data are of great importance if it is later transformed to a data format for indoor mapping. On the other hand, the source data could be too detailed, making it more difficult to distinguish which features are significant for the indoor map when transforming the data. The balance between the accuracy, enough details, and how the source data is created for the easiest transformation are all aspects that requires further discussion for optimization. This responds well to many of the requirements set for both data formats (DF 1, 3, 4, 5, 6, 7, 8) and IPSs (IPS 1, 5.1 and 5.2), which are not only responsive to IPSs in office environments but for IPSs overall.

Another conclusion while implementing the IPS was the fact that the georeferencing affects the positioning of a user in a map depending on the accuracy of scale, rotation and offset. Knowing the coordinates for a drawing of a building's structure or that the drawing is georeferenced from the beginning will increase the accuracy of the final map and therefore indirect the positioning. Requirements for positioning (IPS 2, 2.1, 2.2) are thus dependent on requirement IPS 1 to be fulfilled, which is again proven important.

A conclusion from comparing the implemented IPS and the current IPS at Sweco, is that both work in the office environment and can include all desired functions. However, Apple Indoor Maps is more adaptable, and fulfills that the system should be independent of the supplier.

Finally, further tests and developments are proposed to the implemented IPS to fully evaluate its potential, including navigation and integration with desired service and also adding floor levels. These proposals are due to limited implementations and tests in the case study as a consequence of the COVID-19 outbreak, with a result in a heavier focus on the litterature part in this thesis than originally planned. Similar implementations and studies as in the case study for other data formats and IPSs, mentioned in this thesis, are proposed as well.

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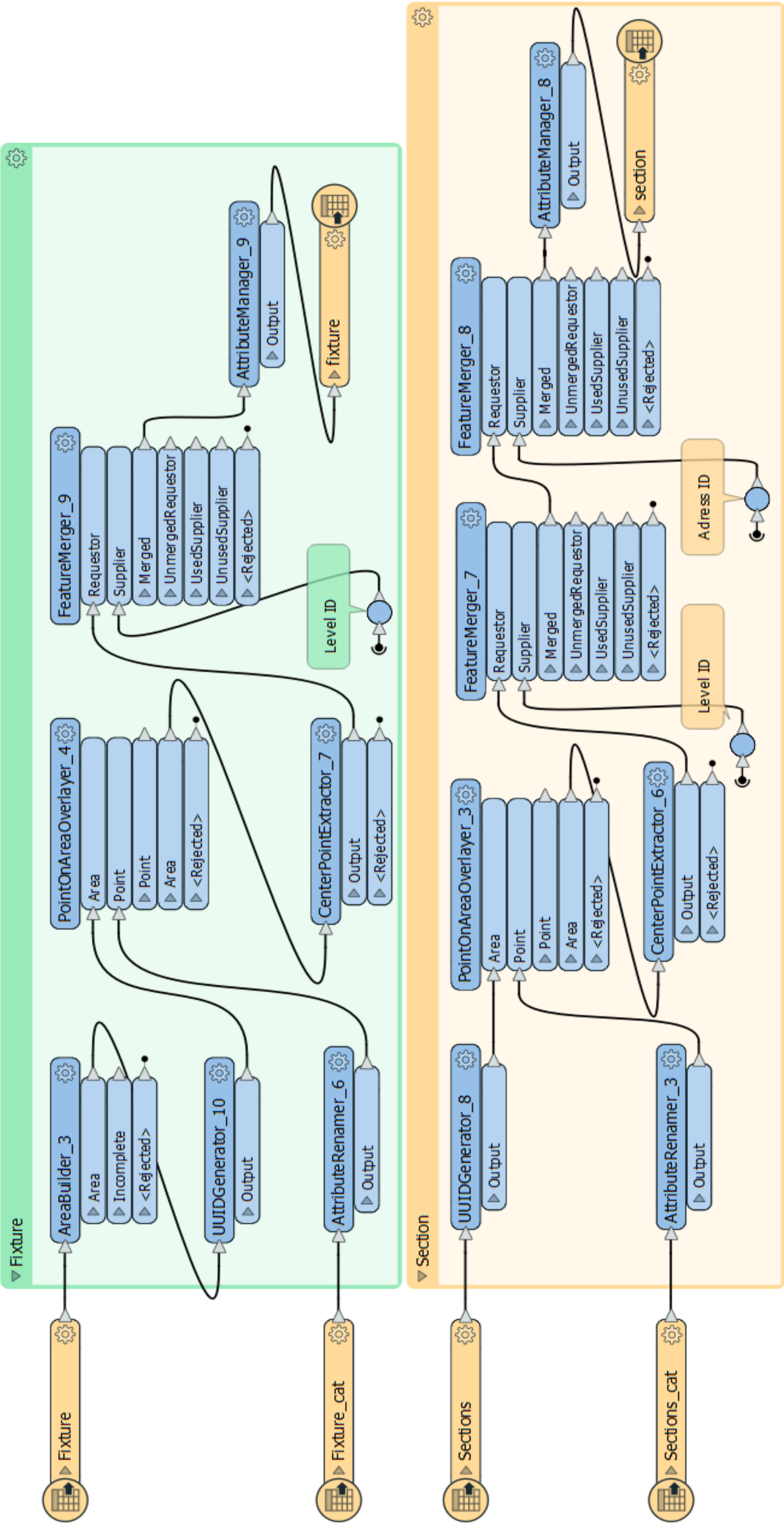
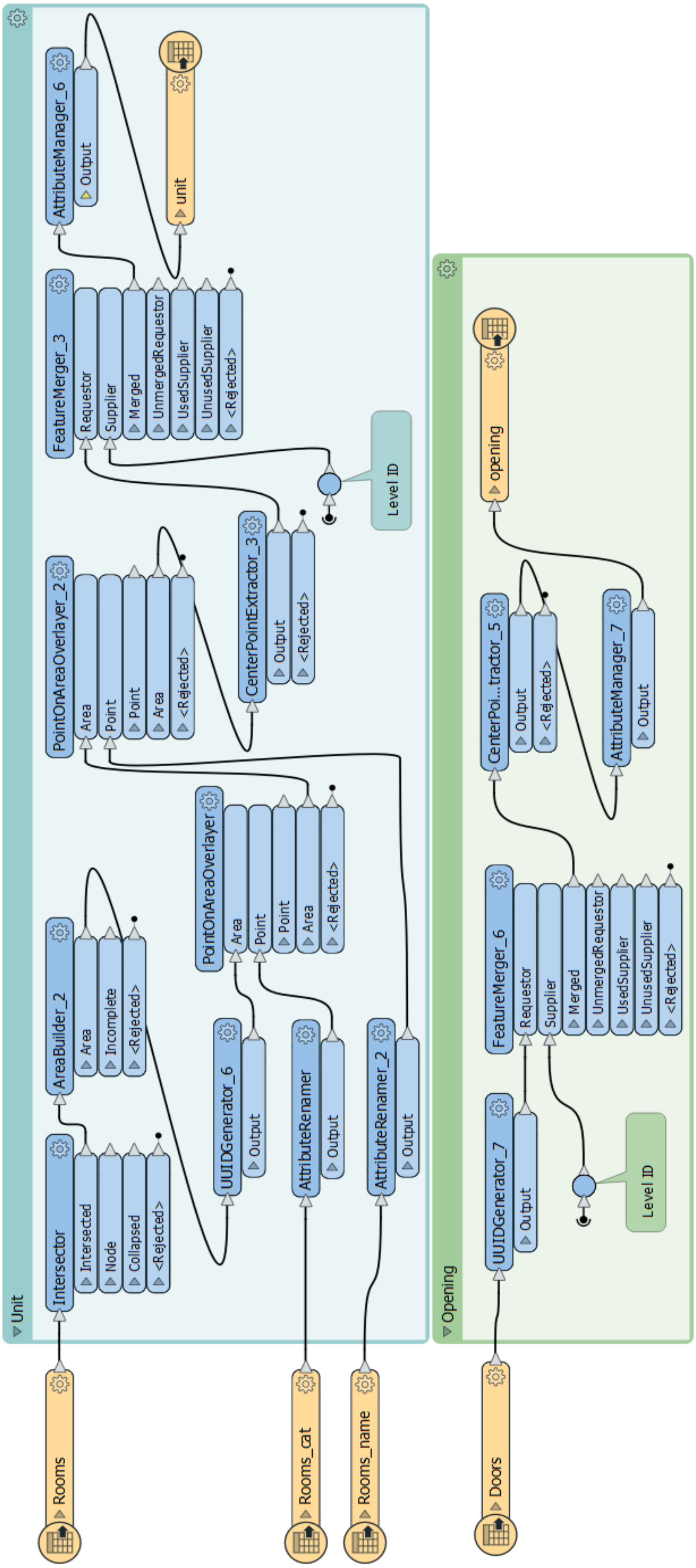
APPENDIX

The FME Workspace used for transforming CAD data to IMDF in section 6.3.4 Transforming the data to IMDF. The layers from the CAD file map to responding feature in IMDF and required attributes are added to each feature.

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Rooms_cat
Rooms_name
Intersector
Intersected
Node
Collapsed
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Area
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UUIDGenerator_6
Output
AttributeRenamer
Output
AttributeRenamer_2
Output
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Area
Point
Point
Area
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PointOnAreaOverlayer_2
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Supplier
Merged
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Output
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Output
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FeatureMerger_6
Requestor
Supplier
Merged
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UsedSupplier
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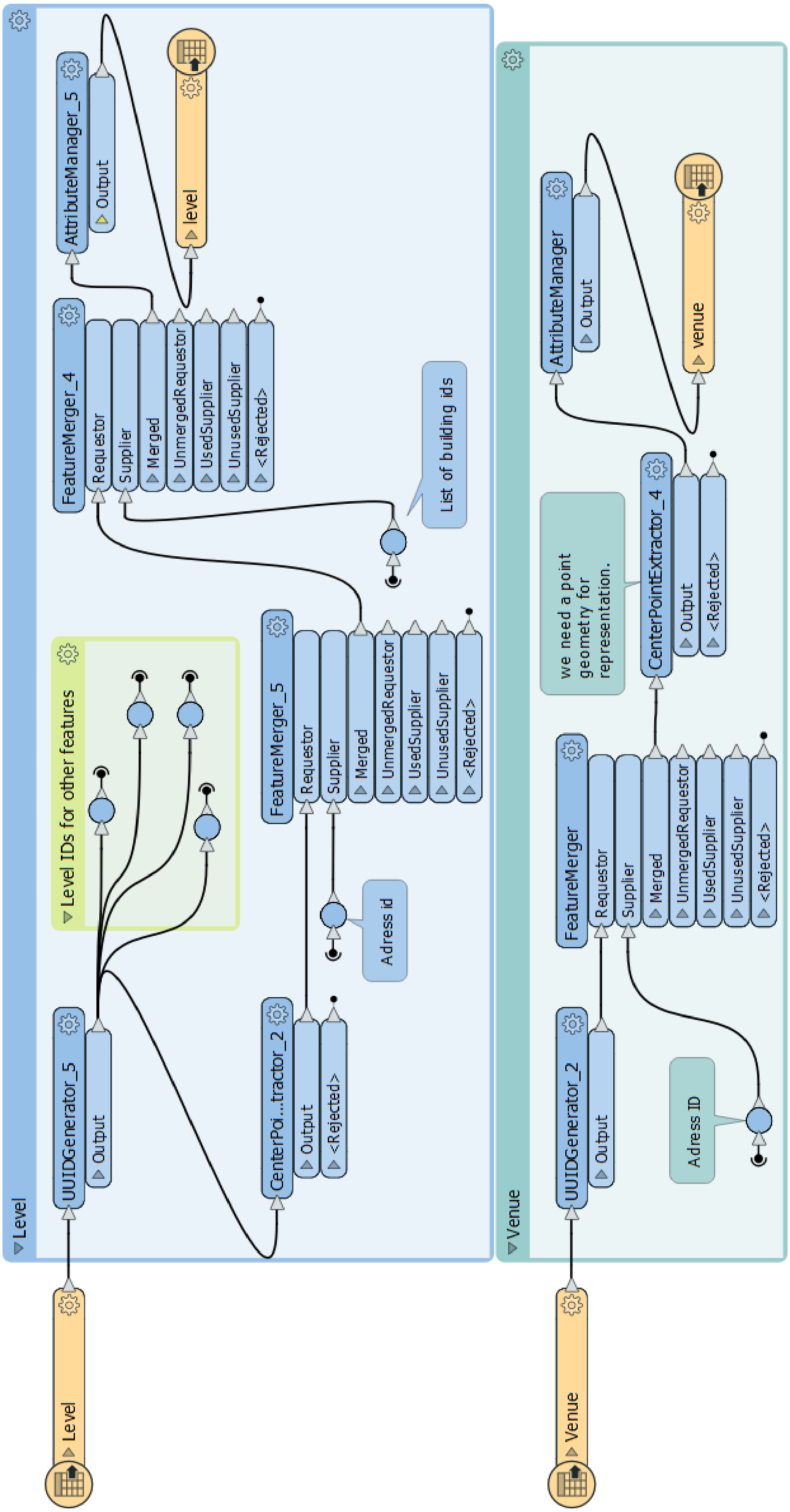
Output
opening


Level
Level
UUIDGenerator_5
Output
Level IDs for other features
FeatureMerger_4
Requestor
Supplier
Merged
UnmergedRequestor
UsedSupplier
UnusedSupplier
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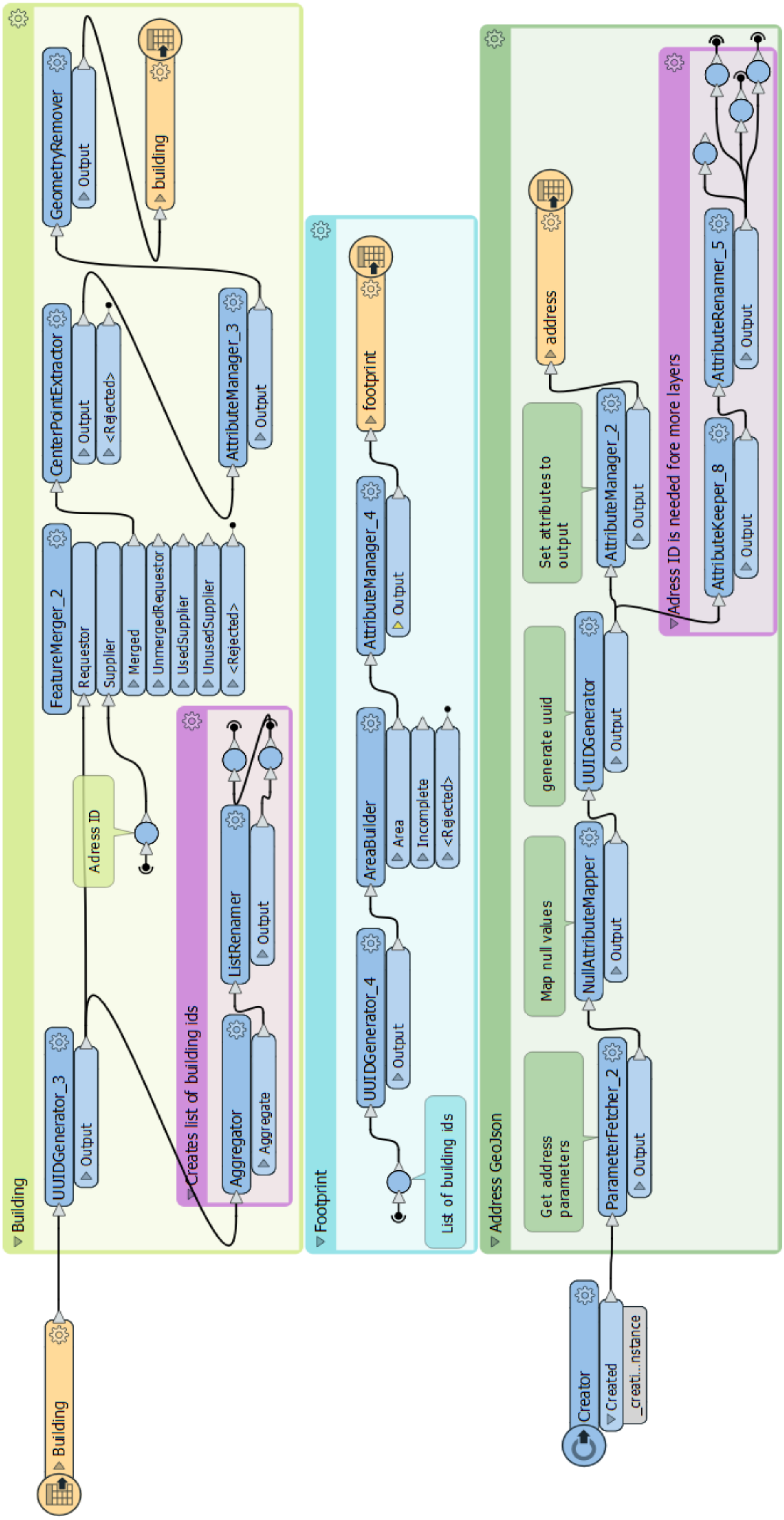
AttributeManager_5
Output
level
List of building ids
CenterPoi...tractor_2
Output
<Rejected>
FeatureMerger_5
Requestor
Supplier
Merged
UnmergedRequestor
UsedSupplier
UnusedSupplier
<Rejected>
Adress id
Venue
Venue
UUIDGenerator_2
Output
FeatureMerger
Requestor
Supplier
Merged
UnmergedRequestor
UsedSupplier
UnusedSupplier
<Rejected>
Adress ID
we need a point geometry for representation.
CenterPointExtractor_4
Output
<Rejected>
AttributeManager
Output
venue


Building
Building
UUIDGenerator_3
Output
Creates list of building ids
Aggregator
Aggregate
ListRenamer
Output
Adress ID
FeatureMerger_2
Requestor
Supplier
Merged
UnmergedRequestor
UsedSupplier
UnusedSupplier
<Rejected>
CenterPointExtractor
Output
<Rejected>
AttributeManager_3
Output
GeometryRemover
Output
building
Footprint
List of building ids
UUIDGenerator_4
Output
AreaBuilder
Area
Incomplete
<Rejected>
AttributeManager_4
Output
footprint
Address GeoJson
Creator
Created
_creati...nstance
Get address parameters
ParameterFetcher_2
Output
Map null values
NullAttributeMapper
Output
generate uuid
UUIDGenerator
Output
Set attributes to output
AttributeManager_2
Output
address
Adress ID is needed fore more layers
AttributeKeeper_8
Output
AttributeRenamer_5
Output

Institutionen av naturgeografi och ekosystemvetenskap, Lunds Universitet

Student-examensarbete (seminarieuppsatser) i geografisk informationsteknik.

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