NTNU
Norwegian University of
Science and Technology

Smart Hospital

Combining BIM and Indoor Position System

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Abstract

This thesis aimed to investigate how to improve the accuracy of indoor positioning systems in large building complexes. Especially considered in this work, was a case where a wireless local area network infrastructure was already in place, and using this technology in combination with building information models to track asset tags placed on objects and persons. The work was done in collaboration with St. Olav's Hospital, where a prototype system integrated in an enterprise BIM strategy was developed by Jotne EPM Technology for St. Olav Eiendom.

The thesis was based on a previous master thesis at IDI, NTNU, where it was unveiled that a location system featuring BIM was promising. Therefore, this current thesis was supposed to do an implementation and more extensive testing phase, but this was unfortunately not possible. Instead, data was gathered by doing a literature study of technologies and methods and by researching other state-of-the-art indoor positioning systems. Potential use of BIM was found, as these models contain lots of useful semantic information for improving accuracy. Several positioning techniques were found promising, most prominent being map matching algorithms. Combination of technologies and methods also holds potential, bringing out the best advantages in each of them.

Sammendrag

Denne masteroppgaven hadde som mål å undersøke hvordan nøyaktigheten til innendørs posisjoneringssystemer i store bygningskomplekser kan forbedres. Arbeidet ble spesielt vurdert i et tilfelle der en trådløs nettverksinfrastruktur allerede var på plass, og ved hjelp av denne teknologien i kombinasjon med bygningsmodeller, kunne en spore aktivitetsmerker plassert på objekter og personer. Arbeidet ble utført i samarbeid med St. Olavs sykehus, hvor en prototype integrert i en BIM-strategi for virksomheten ble utviklet av Jotne EPM Technology for St. Olav Eiendom.

Avhandlingen var basert på en tidligere masteroppgave ved IDI, NTNU, der det ble avdekket at et lokaliseringssystem med BIM var lovende. Derav var det ment at denne oppfølgeren skulle gjøre en implementering og en mer omfattende testfase, men dette ble dessverre ikke mulig. I stedet ble data samlet ved å gjøre en litteraturstudie av teknologier og metoder og ved å undersøke andre toppmoderne innendørs posisjoneringssystemer. Potensiell bruk av BIM ble avduket, da disse modellene inneholder mange nyttige semantiske opplysninger for å forbedre nøyaktigheten. Flere lovende posisjoneringsteknikker ble funnet, mest fremtredende som ble beskrevet var map matching algoritmer. Kombinasjon av teknologier og metoder har også potensial, og kan produsere de beste fordelene i hver av dem.

Acknowledgment

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F.K.J.

Preface

This thesis concludes my master thesis within my track Master of Science at the Norwegian University of Science and Technology (NTNU). The thesis was supervised by professor John Krogstie, and carried out in collaboration with Jotne EPM Technology and St. Olav Eiendom. The thesis was submitted to the Department of Computer and Information Science (IDI), at the Faculty of Information Technology, Mathematics and Electrical Engineering (IE), at NTNU.

Assumed background of readers are scientists, professors, students and others interested in the Informatics and Communication Technology (ICT) area.

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Introduction

This chapter introduces the topic of the thesis and gives it a context. Then problems in current systems are explained, and why it is important to address and find better solutions for this field in computer science and information technology.

1.1 Context

Indoor Positioning Systems (IPS) are more and more in focus. This is because people spend a great portion of their time indoors, due to the increased number of large buildings like shopping malls and universities. In addition, the business benefit of indoor location is significant because it increases the value of your assets - when you can locate equipment and facilities easily, you will use them more. In the case of hospitals, it can be a matter of life and death to find the "crash cart" in seconds rather than minutes.

In the outdoor environment, there exists the Global Positioning System (GPS), which does very well for tracking and path finding in urban and more rural areas. However, the GPS does not work or just barely works inside buildings. For this reason, a new research area emerges, figuring out new technologies to use in this environment. Currently, there exist many different IPS, but most of them are unsatisfying, or they only fulfill a part of the company's criteria. A substantial reason is due to low accuracy in the localization. Different techniques are being proposed and tested, such as Bluetooth, Infrared, Wireless Local Area Network (WLAN), Ultrasound and so on. Drawbacks exist for all the indoor techniques, like range and distortions. Wi-Fi holds great promise as it is generally already installed as a WLAN infrastructure in large buildings, reducing the deployment cost massively.

Building Information Models (BIM) contain detailed information about large buildings and complexes, like hospitals and universities. BIM is a big help in the construction phase, but less applied in later stages for tasks such as maintenance and support of business processes.

The research in this thesis is built upon a previous master thesis from spring 2016 at NTNU, where it was made clear that BIM holds a great potential for use in IPS. A next step to making the services more reliable and useful would be to improve the systems's accuracy.

1.2 Problem Description and Contributions

St. Olavs Hospital has a need to locate medical equipment. Larger equipment like AGV robots, wheelchairs and beds tends to move quite a lot. Though these are easy to spot, it still takes time to locate them across a building. Smaller medical equipment is often borrowed from one department within the hospital to another, and sometimes it is not returned. This causes the facility manager of the former department to go and look for it, wasting valuable time and effort. A system for locating the equipment faster is much appreciated from the departments of the hospital. Facility managers and hospital architects are also interested in the historical data from the positioning system, as they can use it to check if maintenance for the equipment is required or improvements of the buildings are necessary.

At later stages, there is possible to track doctors and their patients, for instance, to check if they were in the same room. This would require a more real-time system; in contrast to locating medical equipment, specially in case of an emergency. Tracking persons is also a privacy concern, which halts the development of this system.

It is important for the solution to be cost-efficient. Positioning systems are expensive and must cover a huge indoor area. Wi-Fi is normally installed in large building complexes before engaging in developing an IPS. This is also the case at the hospital, where the managers are eager to continue using this technology as much as possible. Additional technologies can require new hardware upgrades, but if they improve the system they should be considered.

An Ultrasound option, described in detail in the background section, is supposed to be tested and used in critical areas of the hospital. Questions arise on how to achieve best result when combining the Wi-Fi and ultrasound systems, and they are further researched in this thesis. As of today, the system developed at St. Olavs has not fully satisfied their need. The main reason for this is low and unreliable accuracy. For instance, if a tag (placed on some medical equipment) is located inside one room, but the system displays it in the adjacent room, it will require the staff to work more figuring out where the tag is located. For this and similar reasons, the stakeholders want room-level accuracy.

The contribution of this thesis is to present how the accuracy of indoor positions system can be improved by using a BIM model, along with an existing WLAN infrastructure, thereby making a more usable positioning system. In addition, other technologies are researched, to see if they hold promise to improved IPS. Since St. Olavs Hospital consider an ultrasound solution, this thesis also discusses how a combination of especially Wi-Fi, ultrasound, as well as the map data from BIM can together achieve best possible result. The work has been done in connection to Wireless Trondheim Living Lab [Andresen et al., 2007 [2]] , and the project Smart Hospital Architecture.

1.3 Limitations

There exists a dependency to the system developed by Jotne EPM Technology, which only has been running for a very short time. Also, the access rights to the computer and the infrastructure of the hospital was never given by the IT department, reducing the ability to contribute and test implementations.

1.4 Structure of the Report

The rest of the thesis is organized as follows. A Background part is presented, describing relevant theory for the project and relevant work. Then the methodology and process is described, before the results are presented in the next chapter. A discussion part follows, and the thesis ends with and conclusion of the research and notes on further work.

2

Background

This chapter describes the background theory required to understand the topic of thesis. First part explains Building Information Models, and the way they are used at St. Olav's Hospital. An overview of the system developed by Jotne is also presented. Then, positioning systems in general and related indoor technologies is described, followed by a section about location engines. Thereafter, is a description of an ultrasound solution which is considered at the hospital, followed by a part which presents some successful systems for indoor localization. Last part is a literature study of relevant techniques for improving the accuracy indoors.

2.1 BIM

Building Information Model (BIM) is a process and methodology by which a team of architects, engineers and contractors work collaboratively to design and build a commercial building utilizing the same database and computer model. This allows the team to analyze and visualize design decisions long before a project even breaks ground. At its core, BIM offers a digital representation of the real facility, including functional systems (pipes, electric) and aesthetics (walls, roof, windows). It integrates the geometric properties of the 3D model of a building with all the building objects and attributes.

A description of spatial data is presented first. Spatial data is information about an object in the physical world, such as buildings, towns or mountains. This information can be mapped in geographic coordinate system by numerical values. The data represents the location, size and shape of such object, and in some cases, provides more information by including attributes to the data. Specialized software applications, like Geographic Information Systems, are utilized to visualize, manipulate and analyze the (geo)spatial data [53]. BIM is a tool that contains a rich selection of this type of information.

BIM provides two important pieces of spatial information: 1) The coordinates of objects needed for localization. 2) The topology and geometry needed to navigate the building. The semantic information (thickness, material, direction of opening), can especially be useful as navigation-oriented information for indoor positioning systems [14]. An example of BIM used in a software program is seen in figure 2.1.

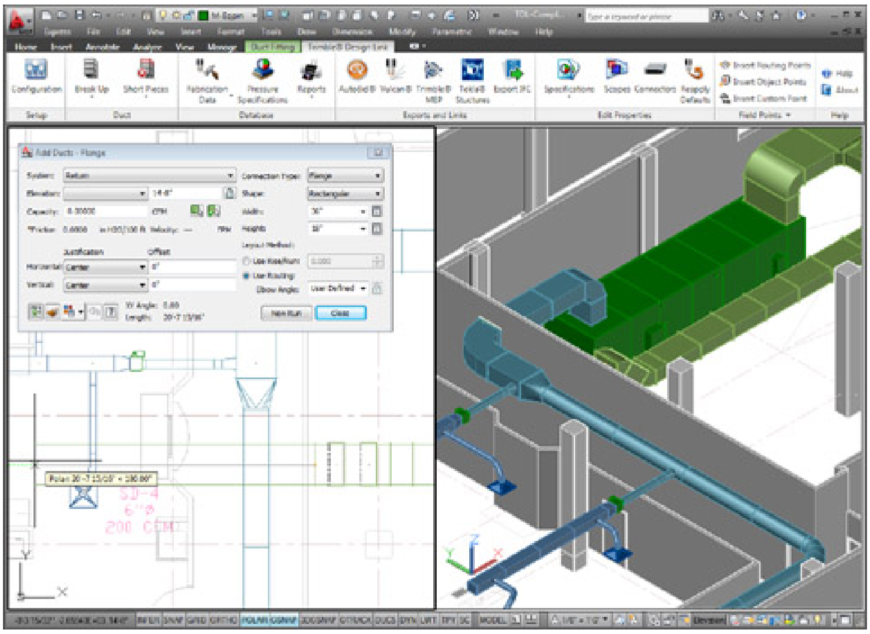

Fig. 2.1: Image from software AutoCAD by AutoDesk, presenting details of the pipe system in a building [45]

A strong benefit is the convenience of a central 3D model. This leads to a more cost and time-efficient process, as well as a significant reduction in errors, which can be discovered much earlier. In addition, since BIM is a shared resource from start to finish across multiple disciplines within both the design and build, it creates one communication channel to push a project forward efficiently and collaboratively [3].

2.1.1 openBIM

OpenBIM is a universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows. It is an initiative of buildingSMART and several leading software vendors using the open buildingSMART Data Model, allowing the different actors to share information. The open format used is called Industry Foundation Classes (IFC) [34].

IFC is an open, neutral data format developed by buildingSMART. The format specifies a conceptual data schema and an exchange file format for BIM data. The conceptual schema is defined in EXPRESS data specification language. The standard exchange file format for exchanging and sharing data according to the conceptual schema is using the clear text encoding of the exchange structure [21]. Further description and usage is explained in the results chapter.

2.1.2 Enterprise BIM

Enterprise BIM (EBIM) is a virtual representation of buildings adapted for an optimized business administration. The platform incorporates processes and business of St. Olav's Hospital by integrating all old and new buildings in the same portfolio.

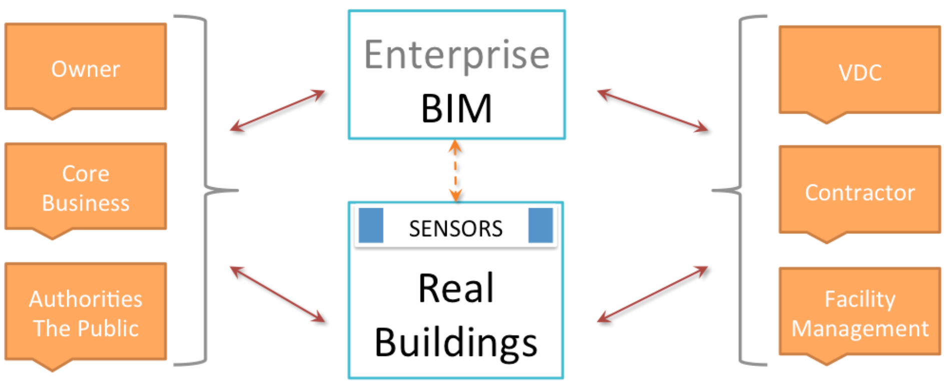

Fig. 2.2: St. Olavs Hospital Enterprise BIM architecture [59]

The beneficiaries include the owner and management, users of buildings, operation and maintenance management, authorities and the crowd. Figure 2.2 illustrate the purpose of EBIM, which is to support important actors and functions and become a tool for analysis.

2.2 Model Server Manager

Jotne EPM Technology has developed an application for visualization and management of St. Olavs Hospitals EBIM, called Model Server Manager (MSM). The application is object-oriented and based on open standards. It uses STEP/EXPRESS language including the buildingSMART family like IFC [18]. Because it uses the IFC standard, converting between other systems is not necessary. The application is particularly developed and useful for facility management (FM), with tasks consisting of administration, leasing, work orders and reconstruction projects.

The MSM is an openBIM model server where BIM models are stored and administrated. All of St. Olavs Hospital's building models are stored in a database on a BIM server and the MSM can retrieve and update these models. The application allows a display of multiple models in the same view. Each object has attributes depending on its type, like measurements, placements and connected systems. The models have several classification systems, one being "Tverrfaglig Merkesystem" for categorizing the components. It consists of three parts; the location (as in coordinates), associated discipline and type of component.

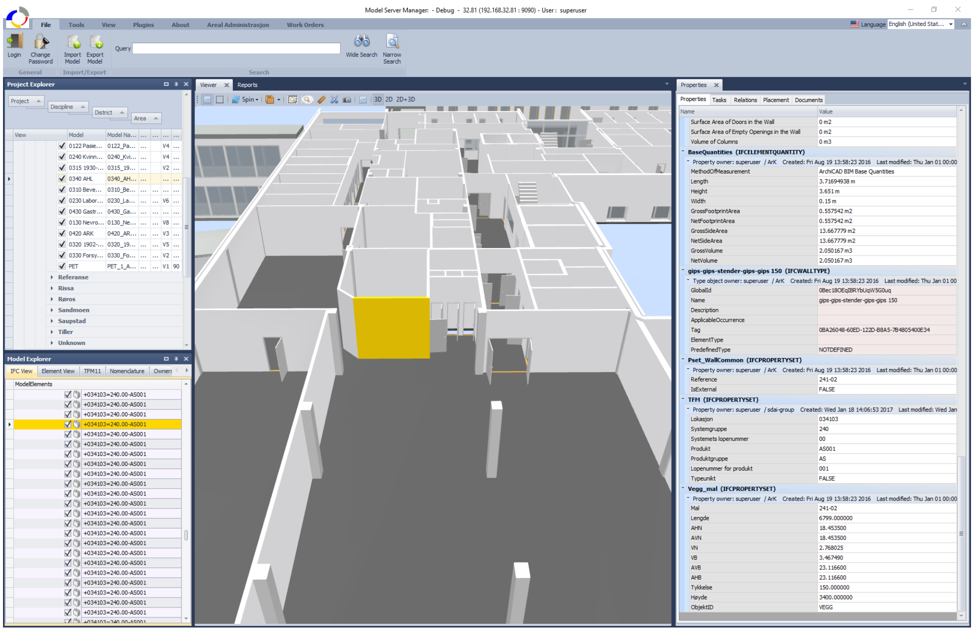

Fig. 2.3: Screenshot a selected wall in the Model Server Manager

Figure 2.3 displays a view of selected wall in the model of the building called Nevrosenteret. The current wall slab is highlighted, and all the containing information like id, size and materials is shown in the right pane. This is information collected from the IFC files in the database. The left panes are an overview of models on the top and the elements in them, being floors, walls etc. on the bottom pane. It is therefore easy to select different buildings and see exactly what type of elements which is of interest. Additional images for illustrating different views are presented in Appendix B.

2.3 The Implemented System of Jotne

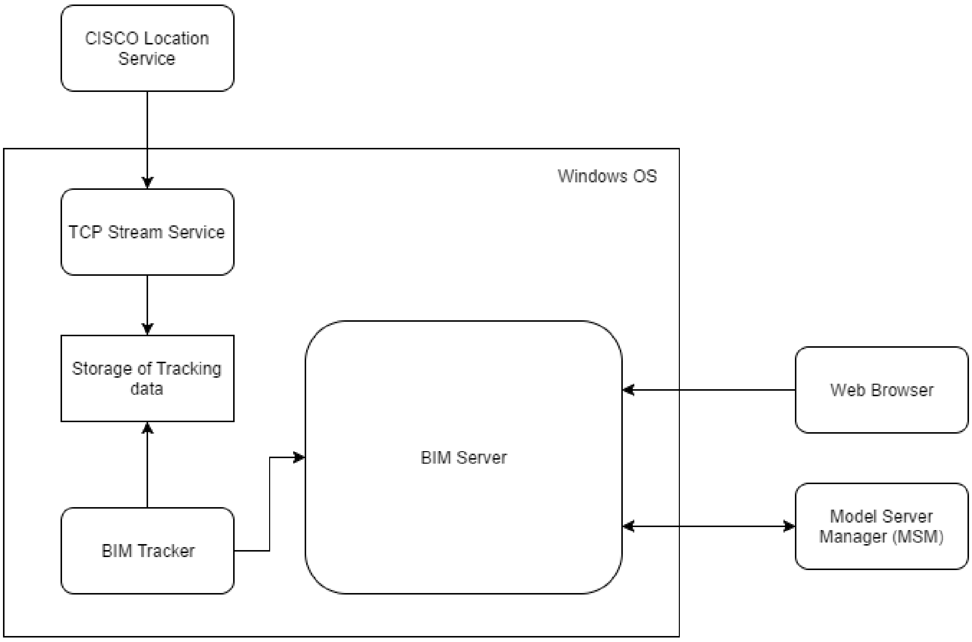

Fig. 2.4: Simplified model of Jotne's implementation of the BIM server

This section explains in more detail how the system developed by Jotne is using the BIM models and tracking data. This helps the readers by understanding how the BIM are being used in practice. Figure 2.4 displays an overview of the implementation.

The TCP Stream Service establishes a connection to the CISCO location service and collects a stream of data gathered from the asset tags. Then the service writes the necessary data to an .xml file, containing attributes like current position and time, and saves this in a designated folder.

Next, the BIM Tracker is a service for reading, rewriting and store the CISCO-data into the BIM models. This is to create an IFC object of the tracker and put it in the correct IFC model. It continuously updates the tracker in the BIM models, finding geo-references, current floor and the time. The service also registers all position data in a history folder, keeping track of all preexisting read tracking data.

The BIM server is where all the models are stored. It is where the tracker put its data from CISCO. In the MSM application, a user can import, export and view the IFC models. Based on the permissions, the user can also do modifications to model values. Therefore, the MSM are mostly being used by architects, developers and others core stakeholders.

Lastly, a Web browser application is created to display the models along with the tracking data in a more user friendly environment. The user can access the BIM server and show all tracking devices stored here will be visualized in a 2D map. The map is generated using the BIM models. The web client can also retrieve history of locations to the tag and draw the path lines.

2.4 Outdoor positioning

GNSS stands for Global Navigation Satellite System, and is the standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. This term includes for instance the Global Positioning System (GPS). GPS uses orbit satellites in different orbital planes to estimate a location. Operational since 1978 and globally available since 1994, GPS is currently the world's most utilized satellite navigation system [54]. The location is calculated by gathering data from at least three different satellites. Usually, this is done by calculating the angles from each satellite to the current position of the device, called triangulation, described in section the next section.

In the outdoor environment, GNS effectively provides accurate user position and is widely used in personal navigation devices, like the smartphone or as a GPS device mounted in a car. In indoor situation applications, however, it is difficult for GPS to provide reliable positioning information due to the additional signal attenuation and blocking caused by buildings and construction materials [29].

2.5 Indoor Positioning Systems

GPS has difficulties indoors; therefore, other technologies and systems are developed. Indoor Positioning System (IPS) is a system for locating objects or person inside buildings using different technologies, methods and information, like radio waves or sensor information from mobile devices. Several technologies are explained in the next section, since IPSs can use a wide range of technologies that varies and apply for different scenarios. An IPS has the following performance metrics for estimating the potential: [1]

- **Accuracy:** "The closeness of agreement between a measured quantity value and a true quantity value of a measure."
- **Availability:** The availability of the positioning system in terms of time percentage.
- **Coverage Area:** The area covered by an IPS.
- **Scalability:** The degree to which the system ensures the normal positioning function when it scales in geography and number of users.
- **Cost:** Can be measured in different dimensions; money, time, space, and energy which can be affected at different levels of the system.
- **Privacy:** Strong access control over how users' personal information is collected and used.

A term related to IPS is called Real-Time Locating Systems (RTLS). Centrak defines RTLS as "any solution that is used to automatically identify and track the location of an asset, individual or other objects in real time" [5]. RTLS solutions consist of various tags and badges, platforms (ex. WLAN), network appliances (readers) as well as other components like servers, middleware and end-user software. The system can track and monitor real-time movement on a computer application. An example is finding medical equipment in a hospital with the use of RTLS tags attached to the objects.

2.6 Technologies

This section presents several technologies for localization indoors, along with their benefits and drawbacks.

2.6.1 WirelessLAN

The IEEE 802.11 WLAN standard (the term Wi-Fi is also used, and is the preferable term used in this thesis) is defined as *"the protocol and compatible interconnection of data communication equipment via the air in a local area network (LAN) using the carrier sense multiple access protocol with collision avoidance (CSMA/CA) medium sharing mechanism"* [50]

WLAN can be configured to an infrastructure mode. In this mode, access points bridge mobile stations and the wired network. The radio range and the surrounding environment of an access point determine the coverage area, or cell size, for that access point. By placing the access points so that their coverage areas overlap, the mobile stations can seamlessly move between the access points without losing network contact, called roaming. Using Wi-Fi in indoor positioning and navigation systems depends on knowing a list of wireless routers that are available in an area in which the system operates.

The use of WLAN signals is a valuable approach, since WLAN access points are readily available in many indoor environments and it is possible to use standard mobile hardware devices, reducing cost of deployment. The range being typically 50 m to 100 m outreaches other radio technologies like Bluetooth and Radio Frequency Identification. Another advantage of using WLAN is that line of sight is not required. Time of arrival (ToA), time difference of arrival (TDoA) or angle of arrival (AoA) methods are less common in WLAN due to the complexity of time delay and angular measurements. The most popular WLAN positioning method is to make use of Received Signal Strength Indicators (RSSI) which are easy to extract, bringing the accuracy of WLAN positioning systems to around 3 to 30 m [25].

2.6.2 Radio frequency Identification

Radio Frequency Identification (RFID) uses radio waves to transmit the identity of an object (or person) wirelessly. RFID technology is most commonly used to automatically identify objects in large systems. It is based on exchanging different frequencies of radio signals between two main components: readers and tags. Tags are attached to all the objects that need to be tracked. They consist of a microchip and a radio antenna. The distance is dependent on the frequency operation of the RFID system. It is most commonly classified as: [3]

- Low frequency (LF), operating within a range of 10 cm.
- High frequency (HF), reading within 1 m.
- Ultra-high frequency (UHF), which can read as far as 12 m.

There are two types of tags; active tags and passive tags [1].
Passive tags are read as they pass fixed points. They are cheap and simple. However, they require specialized scanners and more effort to get a read at a limited range. The tags do not transmit power, but reflects it back to the antenna. The reader must provide the operating energy to the tag through radio frequency waves. When reflecting, some of this energy is consumed by the tag. A measurement of how much power is received by the reader from the tag, in comparison to the original signal, is done. This is called the RSSI. Since the signal strength propagates and reduces as the distance increases, the RSSI will be lower the further away the tag is. The max is known as the power output from the reader and the min strength the signal strength required to operate the tag. These are known, and make the approximation of the tag location possible [15]. Passive tags are for instance used in the alarm chips on clothing.

Active tags are equipped with a battery, making it possible to send out a signal to a reader every few seconds on its own, like cell phones [5]. Advantages consist of having a smaller antenna and a significantly increased range. An estimate of location can also be computed by triangulation of sensors within a designated proximity. However, this can lead to the case where it can be difficult to determine if an object is one side of a wall or another, because radio frequency signals can penetrate floors and walls.

2.6.3 Bluetooth

Bluetooth is designed to be a low power technology for peer-to-peer communications, operating in Wireless Personal Area Networks (WPANs). It is a standard for connecting handheld wireless devices with other similar devices and with desktop computers. Positioning is commonly estimated using proximity and Received Signal Strength methods [44]. In indoor environments, the Bluetooth technology is often linked to the use of beacons, which are devices that broadcast signals at a certain interval. Bluetooth Low Energy (BLE) is the new standard, supported in the newer devices, providing reduced power consumption rates and low cost, which are the key factors in the practical perspectives [7]. Since Bluetooth has a limited range and poor prediction, the tags or beacons would have to be placed very close to each other in order for the technology to function as a standalone IPS. However, Bluetooth is still useful as a supplementary technology.

2.6.4 Ultra-wideband

Ultra-Wideband (UWB) is a wireless technology for transmitting digital data over a wide spectrum of radio frequency bands. Benefits include transmission of large amounts of data with low power and less influenced by metals, high humidity and background noise. UWB can carry signals through doors and other obstacles that tend to be reflected by other technologies. The accuracy is also an advantage, with an approximate precision of 5-10 cm [17]. However, some disadvantages of UWB regarding navigation are that it requires installation of readers in specified locations and it cannot store timestamps. In addition, it has a short transmitting distance, like Bluetooth [40].

2.6.5 Infrared

Infrared Radiation (IR) are lights with wider wavelengths than visible light, making it invisible to human eye under most conditions. IR is used in WPAN since it is a short-range narrow-transmission-angle beam suitable for aiming and selective reception of signals. Most of the infrared systems are based on the LOS mode and they provide the benefit of high room accuracy of the IR location [25].

The spectral region of infrared has been used in various ways for detection or tracking of objects or persons. Systems based on high resolution infrared sensors can detect artificial IR light sources at a millimeter accuracy, whereas systems based on active beacons or those using natural radiation are mainly used for rough positional estimation or detecting the presence of a person in a room [30].

2.6.6 Ultrasound

Ultrasound is an ultrasonic wave, that is, an oscillating mechanical wave of pressure through a medium. It does not interfere with electromagnetic waves. For indoor positioning systems, the ultrasound waves can benefit from building material and the air as propagation medium.

The waves have a relatively short range, about maximum 10 meters, but scalable by adding further nodes. Distance between devices can be measured using ToA of the pulses travelling from emitters to receivers. The position is then estimated by multilateration from three or more receivers at fixed and known locations [30]. Precision down to 1 cm is reported from several ultrasound systems, using passive device systems [37] [43].

2.6.7 SLAM

The term SLAM is an acronym for Simultaneous Localization and Mapping. This technique is concerned with the problem of building a map of an unknown environment by a mobile robot or a vehicle, while at the same time navigating the environment using the map, rendering a system autonomous. SLAM is advantageous for environments where detailed indoor maps are not readily available. It is a concept that can involve many steps being implemented as different algorithms [39]. The vehicle is typically equipped with a combination of laser range scanners, cameras, and inertial measurement units. More advanced visual algorithms have led to camera-based approaches and using stereo camera setups makes more applicable for calibration indoor environments [28].

SLAM can help reduce time, cost and expertise when recording fingerprints in buildings to create electronic maps using the SLAM Engine smart algorithm. The map will be automatically generated from radio data resulting in improving efficiency of the mapping process significantly. The measures after a walk-through in the building will be corrected afterwards, making it easier to use in the initial phase [36].

Landmarks are defined as certain locations in building and indoor environments which have signatures making them easier to sense for various sensing techniques. For instance, an elevator will display a distinct pattern on devices that has accelerometers, as it moves in a constant way vertically through floor. A large angle can be measured by gyroscopes where there is a sizable corner of a corridor. Specific spots may have magnetic fluctuations, and there may exist blind spots where wireless signals cannot reach. Such landmarks can aid SLAM techniques to improve the positioning and generation of map, because they make the fingerprinting algorithm more autonomous and therefore faster.

2.6.8 Overview of technologies

An overview of the described technologies is presented in table 2.1. The most relevant differences are mentioned. Signal influence and complexity are not close equals, but they describe how techniques using these technologies must be handled. Further categories are cost, accuracy and range.

The Wi-Fi is supreme regarding range, but lack in accuracy compared to the other low-range technlogies. For improved precision in a system, the cost tend do also rise. A compromise is therefore discussed further in the thesis.

Technology	**Signal influence and complexity**	**Cost**	**Accuracy**	**Range**
Wi-Fi	Signal is influenced by obstacles	Most buildings already have a WLAN infrastructure	Medium/Low	Long (around 50 meters)
RFID	Same as Wi-Fi	Requires additional hardware	Medium/Low	Short - Long
Bluetooth	Poor predictability, simple	Requires additional hardware	Medium/Low (depends on distance to device)	Short (up to 10 meters)
Ultra-wideband	High data throughput, less influenced by materials and noise,	Requires installation of readers in specified locations, no timestamps, low power	High (5-10 cm)	Short (around 10 meters)
Infrared	Requires line of sight	Requires additional hardware	High (mm precision)	Short
Ultrasound	Enclosed by building structure	Requires additional hardware	High (cm precision)	Short (up to 10 meters)
SLAM	Computational heavy and advanced algorithms	No floor plan required, less manual work	Depends on environment, possibly high (mm)	Medium, dependent on methods.

Tab. 2.1: Properties of indoor technologies

2.7 Location Engines

Location engines are used to calculate and estimate the location of a tracked object. We need at least three transmitters (access points) to calculate the position, and the more of them usually leads to better accuracy. There can be different techniques. These are the following:

Triangulation allows an observer to calculate their position by measuring two directions towards two reference points. Since the positions of the reference points are known, it is possible to construct a triangle where one of the sides and two of the angles are known, with the observer at the third point. With this information is a triangle can be defined and give the position of the observer. The keyword is angle.

Trilateration is a technique that requires the distance between the receiver and transmitter to be measured, by using for instance using the RSSI or the TOA of the signal. The receiver and the transmitter need to be synchronized. Keyword here is distance.

Multilateration is using a single receiver listening to the signals, for instance pulses, from two synchronized transmitters. It is possible to measure the difference between the arrival times (which is TDoA) of the two signals at the receiver. It is similar to trilateration, but calculations are based on a hyperbola (2D) or hyperboloid (3D). The advantage is that synchronization is not needed here and the keyword is time. [48]

Afterwards, filters are applied for smoothing, to correct errors in the data and fitting it for improved visualization. A popular algorithm for this is the Extended Kalman Filter, calculating state and measurements equations over a period using matrices.

Regarding the placement of access points, CISCO describes that they should not be placed in line pattern in the middle of the hallway or room, but rather to the edges and in a more distributed matter. The access points should also cover the edges of the floor, so proper placement will be in each corner and along the perimeter, which is displayed in figure 2.5. This will create a finer triangles, resulting in a higher potential for better positioning estimates. Additionalyy, recommended practice for distance between each AP for best location estimate is between 25 to 70 feet. [8].

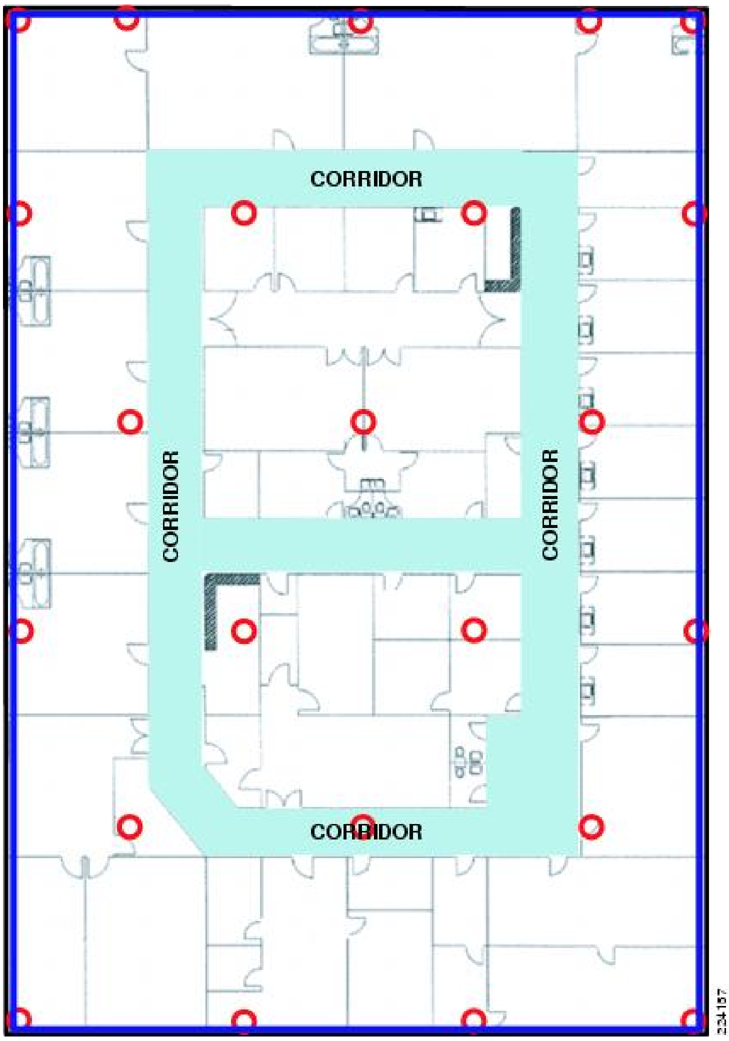

Fig. 2.5: Recommended placement of access points as stated by Cisco [8]

2.7.1 CISCO MSE

Installed in the buildings at St. Olavs Hospital and used in the implementation of Jotne's servers is the CISCO Mobility Service Engine (MSE) location engine. Two main services are provided. The first, Context Aware Services (CAS), can locate devices and tags connected to the Wi-Fi network using their access points. The information is gathered and location is estimated using the different access points. CAS can then provide the location database for CMX applications and services (introduced in the next subsection). Afterwards, the position can be sent to third party application or through a RESTful (Representational State Transfer) API (Application Program Interface) set. In the current system by Jotne, only third party applications are developed. [11] [32]

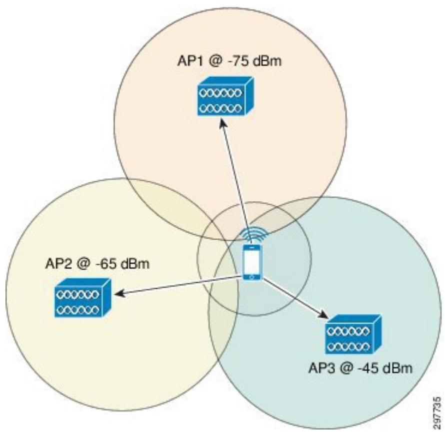

Fig. 2.6: Three APs can hear the client probe requests at different RSSI. However, none of the APs can determine the direction of where the client is. (Cisco, 2015) [10]

The MSE knows the location of APs on the Maps. Using the location of APS on the maps and RSSI at which client has been detected by APs; the MSE can triangulate the approximate location of the client, as displayed in figure 2.6. The MSE provides a 90% confidence level that a client will be within 10 meters of its actual location. Access point placement is important to achieve this accuracy. [10]

2.7.2 CISCO CMX

CISCO's Connected Mobile Experiences (CMX) is a suite of applications that are hosted on the Mobility Services Engine and use its ability to locate Wi-Fi devices. The applications include tools such as; CMX Analytics to gain insight into end-user behavior while inside a venue. Also, CMX Connect to provide a venue-specific, location-based mobile guest access experience. The Cisco CMX solution relies on a Wi-Fi infrastructure within the facility. At the center are location-based services for understanding a mobile user's context and help the organization engage them in a relevant way. The CMX solution is tested to provide faster, more reliable and more predictable user deployments, and it can also integrate third-party products [9]. For simplicity, the MSE is the hardware solution, while the CMX is the software solution running on top of the MSE. St. Olav's Hospital has recently (autumn 2016) upgraded to the CMX 10.0 system, previously using the MSE 8.0.

Location accuracy is improved in several ways using the CMX. The solution uses four techniques for this purpose. First, the access point triangulates position based on Received Signal Strength Indicator (RSSI). Then, by using the Hyperlocation antennae located around the access point, the angle where the Wi-Fi signal appears from can be determined, in turn improving the accuracy of triangulation. Furthermore, Cisco has included their FastLocate technology, which can capture Wi-Fi signals in seconds to create more data points. This does not directly impact the location accuracy, but the solution will provide more real-time location data. Lastly, the CMX provides Bluetooth Low Energy (BLE) visibility, which is useful if the customers decide to add BLE proximity to gain better location information for the Wi-Fi. [9]

2.8 Sonitor RTLS

The Sonitor Sense RTLS System is an open RTLS platform that combines ultrasound technology with Wi-Fi and Low Frequency waves, delivering a fully scalable solution to support and integrate with a broad range of applications. The Ultrasound is the core positioning technology, providing consistent and reliable location data, most importantly a 100% room-level or sub-room level location accuracy. The system includes three main components; active RFID tags, location transmitters as receivers and a location engine, as shown in figure 2.7.

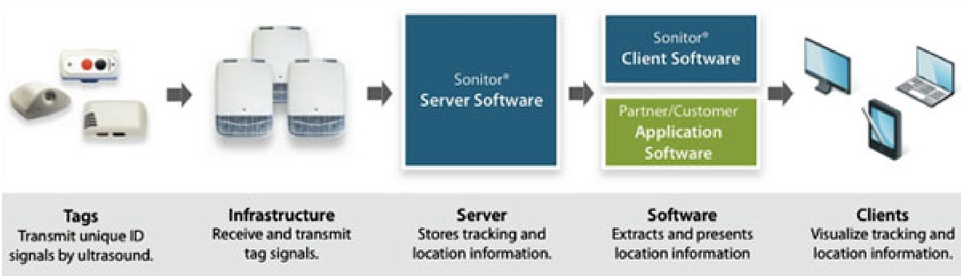

Fig. 2.7: The Sonitor infrastructure and its information flow. Some of the tags come with two programmable buttons to send notifications when pushed. (Sonitor, 2017) [46]

2.8.1 Location Engine

The Sonitor Sence Location Engine is located on the server side software which communicates with the tags, the Sonitor infrastructure and the existing Wi-Fi network and receives the data communicated in the system. It works as the link to applications which want to use the positioning data, making this available for distribution. Third-party application software must interface with the Sonitor software and present the location of the tags to the user. The location engine calculates the position of the tags based on the received Wi-Fi signals of the access points.

2.8.2 Location Transmitter

The Sonitor Sense Ultrasound Location Transmitter combines both ultrasound and low frequency transmitters in a single unit to enhance the positioning accuracy and update rate of the tags. It is battery powered and wire-free, to provide flexible placement and simple deployment. This receiver contains microphones which detect ultrasound messages from the Sonitor Tags. These messages, containing the unique Tag-ID, are processed by the transmitter using patented Digital Signal Processing (DSP) algorithms. The processed information is then transferred to the Sonitor server and the location engine over an existing Wi-Fi network or a local area network, where the tag's location and time-stamp information are stored in the database. It can operate standalone or be integrated in an existing WIFI-network.

The transmitter creates an RTLS location zone. This can be an entire room or the transmitter can split the room in four areas by deploying virtual walls, in turn reducing the number of transmitters needed. In hallways, the zones can function as choke points at a defined exit in an area. The transmitter also supports low frequency signals for designated exit zones.

2.8.3 Tags

The Sonitor Sense SmartTags uses Sonitor's own ultrasound technology, but can also be combined with and handle Wi-Fi and Low Frequency technologies. These active tags have the advantage over previously used tags because they have lower maintenance and cost. The SmartTags are embedded with logic to know their location and to communicate over the Wi-Fi network when their position changes within 1-3 seconds. The tags also send contextual information, like battery life. The tag transmits its identity, status and location using ultrasound. [47]

2.9 Existing solutions

This section presents a few other developed systems which showed promising results in the area of IPS. However, they did not focus solely on the combination of integrating BIM with WLAN infrastructure.

2.9.1 Redpoint

A Cambridge based company called Redpoint has developed a high-precision system for indoor positioning. The system is offering asset tracking, geo-fencing for safety and security, indoor navigation, staff or visitor tracking, and location enabled sensor data communication. The RTLS is claimed to be easy to deploy, high precision and less cost than other similar systems. Currently, it is used for safety applications, alerting workers when entering restricted areas, a few construction companies and in retail stores for workforce management.

The system focuses on an Ultra-wideband technology, and they developed patented software solutions for the positioning algorithms, featuring a precision down to 20 cm. An advantage is easy deployment, because the solution does not require a pre-existing Wi-Fi infrastructure. The company has developed battery-powered or power-over-Ethernet anchors to be installed in area of positioning, which will locate the active RFID tag components. Other technologies, like Bluetooth for connection to smart-phones and laptops, are also included in the anchors. In addition, the system comes with a "dual-API" to program both at the tag end and the server end. Lastly, The Redpoint software can be linked to BIM models of the construction companies for visualization and setting up zones [51], [16].

2.9.2 Q-Track

Q-Track's system differs from Wi-Fi localization in a fundamental way. It doesn't use signal strength to estimate the distance between transmitter and receiver. Neither does it measure the time it takes for the signal to travel from transmitter to receiver, as GPS does. Instead, it exploits the fact that at frequencies of about 1 megahertz, and at building-size distances (for instance, up to 100 meters), the receiver operates in what is called the near field of the transmitter. The system can provide sub meter accuracy using this near field frequencies. It uses frequencies of about 1 megahertz, which is considerably lower than Wi-Fi. The advantage of using low frequencies able signals to more easily go through the different barriers existing indoors. They diffract less around obstacles, and they don't have the multipath problem, which is the problem of the different waves interfering with one another. The disadvantage is the Q-Track's receiving equipment is bulky, and have power hungry tags. So, while the system works well in some scenarios, it's hard to see it going into multiple cellphones, RFID tags, and wireless access points, which is what is required for a truly ubiquitous indoor positioning [42] [41].

2.9.3 Indoor Atlas

IndoorAtlas was born in Finland in 2012. It uses magnetic positioning, a technology that has received less attention. It uses the Earth's two geomagnetic fields to enable the smartphone's compass to precisely locate individuals within indoor spaces. The solution requires no hardware installation and is compatible with iOS devices as well as Android [49]. The positioning accuracy depends on the building's magnetic field information. IndoorAtlas can achieve an accuracy of less than 3 meters using off-the-shelf handsets.

The distortions in the magnetic field caused by building materials such as steel and concrete, is what enables IndoorAtlas to locate people indoors. Founder and CEO Janne Harveninen said from a demonstration, "The more steel the better." More steel improves the building's "signal" and thus the technology's ability to accurately locate users." [49]

As the company explains, steel and concrete help create the unique magnetic fingerprints or signatures of buildings. The company holds multiple patents for magnetic positioning. IndoorAtlas location technology uses a patented sensor fusion algorithm combining every source of position-related data with a basis in magnetic field sensing for universal, accurate positioning. Wi-Fi and other radio signals are used for rough position sensing as well when platform limitations allow that. "IndoorAtlas' technology won't work outdoors; it only works inside", stated in their report.[19]. The reason for this is the requirement of steel and iron in buildings, bringing the magnetic property more present. However, other magnetic systems can work outside. For instance, Wilson et al. [57] developed a magnetically-aided dead reckoning system to provide navigation for aircraft. IndoorAtlas has been tested at St. Olavs Hospital, however with no satisfactory results and with reasons yet to be discovered.

2.10 Current approaches

A presentation of relevant literature study is presented here. All papers try in some way to improve the accuracy of indoor localization, either it is using BIM, several algorithms or combining technologies.

2.10.1 Passive RFID and BIM

Costin, Pradhanga and Teizer (2014) [13] demonstrated in their research how the integration of passive RFID technology and a BIM model can assist in facility maintenance management. The scope was on the Operation and Maintenance phase of the lifecycle of a facility. The contribution of this paper was the integration of passive RFID technology and a BIM model for effective real-time indoor visualization and location tracking without relying on existing building or wireless infrastructure. A challenge to the 3-meter goal [52] was to determine precisely which room the user was located in. The error was small enough to guide the personnel to the general area, but was also too large to guarantee the correct room. Integrating passive RFID technology and BIM for visualization would enable users to localize themselves in a model. The system successfully resulted in an accuracy desired for Operation and Maintenance. This integration holds potential for an increase in safety and productivity.

2.10.2 Bluetooth and BIM

Park, Kim and Cho (2016) [35] studied a Bluetooth Low Energy based tracking system that integrated and used geometric information from BIM. The geometric information was first identified. Then an extraction tool was developed to get the properties of geometric constraints, into a usable format, including coordinates of starting, ending and intermediate point. An interaction algorithm was used to make use of the geometric information, where the algorithm would reject positions that violate the geometric constraint conditions. It then checks for nearby movement or else compute a new position. The tests showed successful results, where the geometric information had a positive effect for detecting incorrect movement. Average error was approximately 0.5 meters and the maximum error at 1.4 meters.

2.10.3 EASBL algorithm

Li, Becerik-Gerber, Krishnamachari, and Soibelman (2014) [23] presented details of an algorithm, namely the EASBL algorithm, that aimed to provide first responders with the ability to set up a fast network and locate trapped occupants in buildings. The EASBL algorithm has the advantages of the SBL schema, including the ability of providing a high coordinate-level accuracy, requiring low number of reference nodes, free of pre-data collection, and providing partial mitigation to multipath and fading effects. Furthermore, the EASBL algorithm was designed to improve room-level localization accuracy and reduce the deployment effort of an ad-hoc sensor network. Building information models were integrated to extract geometric information of the sensing area, to support the computation of space division quality, and to provide a GUI for user interaction. Meta-heuristics were integrated to efficiently search for a solution that, although not necessarily global optima, provided a satisfactory solution within reduced computational time compared to a complete search. Room accuracies were tested from scenarios and evaluated to be around 87 % and error distances at 1,5-1,8 meters. The proposal succesfully proved that the algorithm provided an effective deployment and improved accuracy to a satisfactory level.

2.10.4 Indoor Navigation Space Model

A two-level approach for navigation, was proposed by phd Liu and supervisor Zlatanova at the Delft University of Technology [26]. This research investigated the contribution of semantic modeling for indoor navigation, especially in complex indoor environments. They proposed a semantic modeling method called Indoor Navigation Space Model (INSM). This method can conceptualize all the necessary building elements for navigation purposes, while also attach to geometric parts of buildings, like doors and stairs. One of the advantages of INSM is that it can be employed to almost all kinds of geometric models. Basic semantics of INSM include Navigable Space Cell (any room or space), Openings, (doors or windows) and

Obstacles (desks, columns or other furniture). The method can extract path pattern, and use it to its advantage in the pattern for path finding from the INSM semantics. Further, it also provides a transformation from some semantics data formats, like BIM IFC, see figure 2.8. The INSM semantics are commonly not a feature of many existing data formats, and therefore the system regarded for instance semantic data from BIM IFC as input and enrich the data with INSM semantics. This transformation also worked on digital floor plans with necessary category information (e.g. notifying Stair and Elevator).

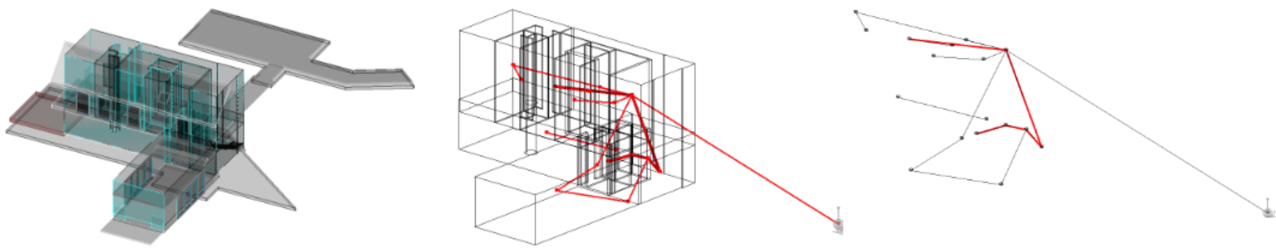

Fig. 2.8: Connectivity Graph derived from an IFC Model [27]

Based on INSM a two-level indoor routing strategy was developed for indoor path planning. There were two levels. On the coarse level, meaningful logical paths were generated in the connectivity graph derived from INSM. On the detailed level, the system can compute detailed geometric paths which were free of obstacles inside rooms, displayed in figure 2.9. By combining indoor semantic modeling and two-level strategy, the system can also conduct user-dependent indoor routing. User profiles and preferences were important criteria on the selection of multiple paths.

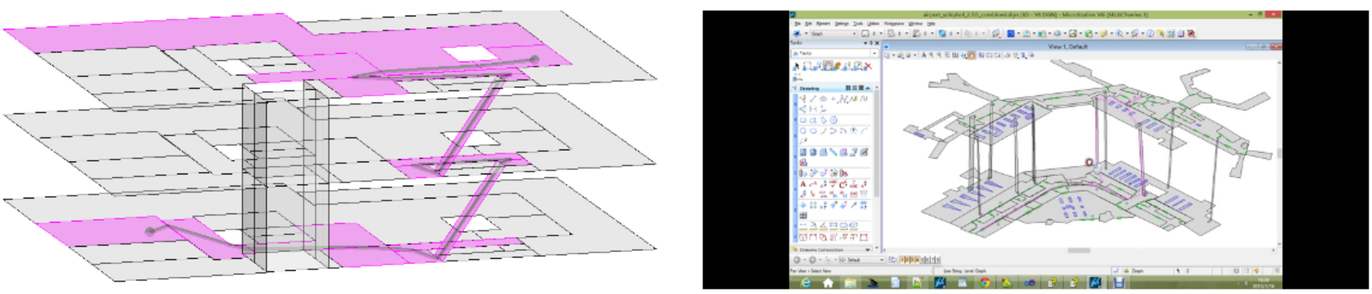

Fig. 2.9: Path on the detailed level

2.10.5 *Radianse*

The company Radianse has developed a RLTS at Brigham and Women's hospital (BWH) for tracking devices throughout the hospital [55]. Tags were placed on certain devices in the hospital, and receivers picked up the signals transmitted by tags. The tracking system was important for making hospital operations more efficient. Hospital personnel used Radianse's web-based software to find medical devices. The Radianse tags are active tags because they have internal battery power and ping receivers periodically. The receivers use both infrared and radio frequency to locate Radianse tags. This multi-media wireless solution saves the Wi-Fi network for other hospital uses. The use of RF allows coarse-grain positioning, like floors, while the IR signals provide additional resolution, typical rooms. Infrared signals do not go through walls and there are two infrared sensors on each receiver. Testing showed one hundred percent room accuracy. The system was not without issues, those most prominent were misplacement of floor, bouncing of the tag and dead batteries.

2.10.6 BO-IDM

At last was a proposal of a new BIM Oriented information model, named BO-IDM, compliant with ISO standards and IFC models. This was developed to fit requirements of IPS, by making it less complex. BO-IDM preserves only useful semantics and relationships. They built a model schema of classes of properties from the semantics of the BIM. For instance, one class was stairs, which was a representation of a connection between two floors, consisting of attributes state, material and geometry. The types of relationship between elements were explicit, meaning they were easy to reach and query. Take this query: "find a wall that separates two room spaces", which can be translated to "Provide the distinct Wall ID of the Wall Parts that separates Space (n) and Space (m)" [20].

3

Methodology

This chapter presents how the thesis was conducted. First, an outline of the process is given. Then, the chosen strategy is described, and how the data was collected. The next section presents the research questions and detailed explanations. Participants for the thesis and the research paradigm are also described. Last section presents user stories and scenarios regarding the proposed system. This will give an overview of how the positioning system can help achieve better result when performing daily tasks at the hospital.

3.1 Research Method and Data Gathering

This section presents the process for my research. To guide and structure the thesis, a research process presented in Oasis J [33] was adopted and followed, which can be seen in figure 3.1. This is to give the work during the thesis a general structure. A background of current literature combined with motivation factor constructs research questions. A conceptual framework is also a possible outcome from this work, where the purpose is to structure the thinking and approach. The thesis should revolve around a chosen strategy. However, multiple can be chosen, which results in more iterations of the methodology in the thesis. To give the thesis empirical evidence, data must be gathered from one or several various sources. Depending on the methods, the analysis of the data will be either quantitative (numeric) or qualitative (words, images and all other types). At the end of the process, there should be some outcomes, in form of knowledge and possibly some artifact like a computer-based product or a development method.

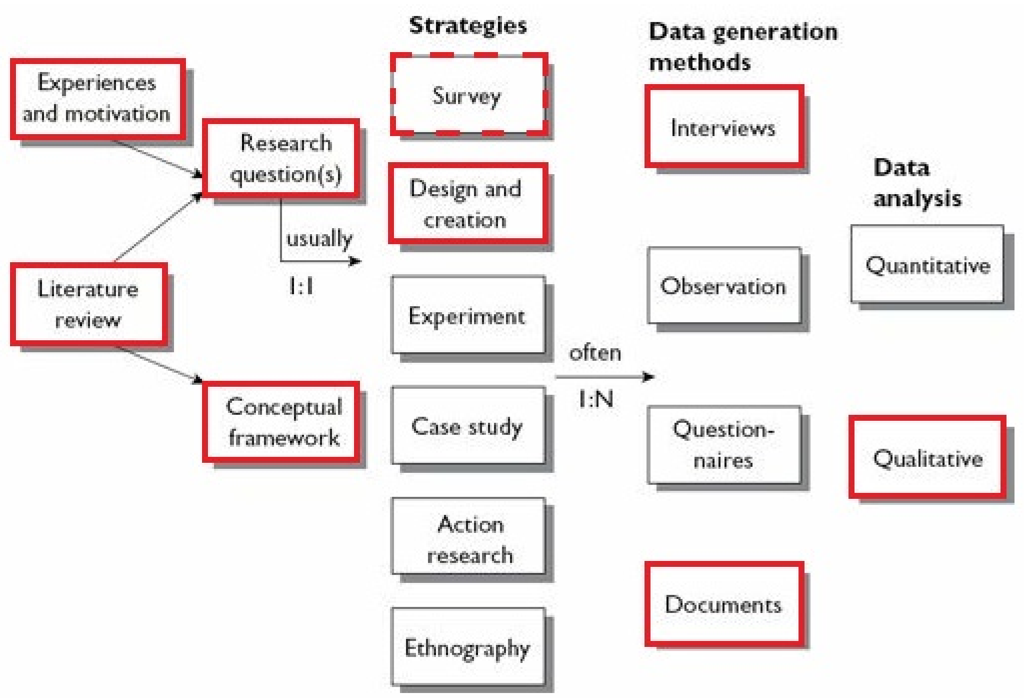

Fig. 3.1: Model of the research process. Red lines highlight the chosen path.

The thesis follows from a specialization project of the topic. Here an understanding of the topic was achieved through a literature review. The review contains research papers from the topic of indoor positioning, location technologies and BIM. In addition, a preliminary study of the current system developed by Jotne was conducted, which identified possible issues and further work. Lastly, my supervisor gave his thought of the topic. All this provided a good basis for picking out research questions, to guide the research.

The initial idea was to do a design and creation strategy for this thesis. However, as the company this research is collaborating with and contribute for could not hand out access to respective parts of their system, I was restricted to do a simpler proposal of improved designs and analysis of these. A more thorough literature study was performed to discover more qualitative data of approaches to enhance indoor positioning. The strategy was mostly a survey with a possible design phase at the end. Research was gathered through talks and research documents on state-of-the-art systems and technologies, where principles and algorithms were discovered. The data produced a qualitative analysis to answer the research questions.

3.2 Research Questions

This lead to the research questions to guide the research. The main one was:

⇒ *RQ1: How is it possible to use WLAN infrastructure and BIM-models to position persons and objects indoor in distinct rooms in a large building complex?*

By distinct we meant to distinguish if a person is in one room or the adjacent room, or said differently; how can we be sure a person or object is in a certain room? Can the information given in a BIM help with this problem? Large building complex are buildings like shopping malls, universities and hospital. The latter is the type of building the system is implemented and tested on in this thesis. To be able to distinguish rooms, an improvement in accuracy was vital. Therefore, an additional sub question to guide the research was;

⇒ *RQ1.1: How is it possible to increase the accuracy of an IPS?*

A goal here was a threshold below at least 5 meter to be able to have a sufficient and reliable system, but a maximum of 2 meter was encouraged. For the stakeholders, the important question was to solve was how to achieve room-level accuracy. If this could be solved with the Wi-Fi technology, a huge investment could be saved. However, combination of two or several techniques has potential to be a viable solution. This was also researched during the thesis, as to how can we achieve the best result when combining WIFI and Ultrasound system. The reasoning is collected in this paragraph to three topics of study to improve accuracy of the IPS:

⇒ Wi-Fi techniques and algorithms

⇒ Adding the BIM data

⇒ Combining technologies, especially Wi-Fi with ultrasound

3.3 Participants

My supervisor on the thesis, John Krogstie, was the main participant and he was contributing with guidance and experience of the topic. Additionally, he provided a network of other professors at NTNU eager to help from their own interests.

The research was conducted with cooperation from St. Olavs Eiendom (The building department of St Olavs Hospital), as I will help improve their system, and they will give me knowledge about the current one and research opportunities. Their resources are therefore the development environment developed by Jotne EPM Technology and an office space. Developers from Jotne also contributed at some extent with knowledge and help regarding their system.

3.4 Research paradigm

Since the selected strategy was a mixed survey and design process, the research sought technologies and knowledge with a belief it existed or at least should be possible to find a viable solution. This made the direction of the research in the thesis closer to a positivist paradigm. The research was based on empirical study of statements, with a goal to confirm or refuse the proposed questions. It was based on facts which is the quantitative data gathered.

3.5 User stories and scenarios

User stories are simple cases for describing some functionality of a system through a user's perspective. They are presented here to give more insight at the current situation in the hospital, displaying scenarios where tracking different objects are necessary or useful.

Firstly, relevant details are presented. These are the most important factors for the use case of the IPS at St Olavs hospital:

- Roles:
  - Facility Manager: Maintains overview of equipment at the hospital, and installs new tags on the objects.
  - Doctor and nurse: Hospital staff who uses the objects being tagged.
  - Patient: Sick or disabled person in need of aid, where the objects are necessary.
  - Architect: A person working on improving the building structure or facilitate for more effectiveness in the workflow.
- Typical Objects to locate:

  - Medical equipment
  - AGV robots
  - Wheelchairs
  - Beds

- Each department has their own budget and equipment
- Employees do not return borrowed objects every time

A question to who should pick up lost objects also arose. Most times it would be the facility manager of the respective department, but regular hospital workers, like nurses, might have time if the object is close.

3.5.1 Scenario 1: Medical equipment

A nurse from the department of gastro and endocrine surgery (DepGES) borrows some medical equipment from the department of breast and endocrine surgery clinic (DepBESC). After use, the equipment is not being returned. An employee in DepBESC notices it is missing, but do not know where it could have gone. She asks around in nearby departments, and on the web-portal (kilden), but no luck. Since the equipment is yet to be found, it is not in use, and therefore has a low usage ratio, which in turn drops the value of the item.

With a tracking system for medical equipment, the departments owning the objects can retrieve and make use of equipment more easily and quickly. In this scenario, the employee of DepBESC logs into the system on a desktop machine via a user interface. She moves on to search for the missing equipment by typing in its name. A list of items will show, and she can select the appropriate one, belonging to her department. She will then see the tag displayed on a floor map, showing the current location of the selected tag, which in this case most likely is in DepGES. The equipment can then be found and transferred back by either department.

3.5.2 Scenario 2: AGV robots

AGV (Alene Gaaende Vogner) robots are mobile, self-operating trolleys carrying stocks of medicines, food and equipment, as seen in figure 3.2. They are often on the move, also in common areas, and as they are of decent size, there is a chance they can block hallways in case of emergencies. A proposed algorithm is to check when a wagon has been stationary for a certain time (ex 4 hours), in addition to check if there are more wagons in the same defined zone (group of rooms). If so, there should be sent a notification to the department or zone operating there, to check if the wagons should be returned. Architects can here look at how and where the robots move, to facilitate for better construction to reduce travelling time or in case they get stuck. Same applies to the cases below.

Fig. 3.2: AGV robot carrying a container of supplies at St. Olavs Hospital. (St Olavs, 2017) [22]

3.5.3 Scenario 3: Wheelchair

A disabled patient should be moved to a different room due to logistics, for instance the patient does not need to occupy a whole room alone. The nurses bring a nearby wheelchair to the room and help the patient to sit. The wheelchair is then taken along with the patient past several departments, before ending up in the department at the end of the building. The patient is after some time healthy enough to leave, but still struggles to walk. The patient uses the wheelchair to get to the exit where the family picks him up and leave. The wheelchair remains empty at the entrance, and the nurses forgets to bring it back along with them. The staff at the entrance notice several wheelchairs, but have no knowledge which department it belongs to or if there is any need of it.

Wheelchairs are moved around a lot, all over the hospital. They tend to end up at entrances, making them easier to track. Still, the staff need to figure out which department each of the wheelchair belongs to. The positioning system can help solve this case, by putting a tag on each wheelchair. The facility manager must link the tag to the respective department's chair in the system before use. After, the system can help the department find its location through its user interface.

3.5.4 Scenario 4: Bed

A bed with a patient moves from one room to an operation hall. It is then brought to a different room for the patient to have isolation. Finally, it ends up back at the first room. At the same time, bed sheets are being changed, the wheels and the structure of the bed slowly but steady after a long time takes its toll. In general, beds, like all equipment, have a certain expiration date. While this duration is usually over several years, there are many beds at the hospital, which needs from time to time to be controlled.

By tracking beds, how much they have moved and being used, proper support can be followed up in case they need fixes. This would be easier to track from the positioning system, by analyzing data regarding distance travelled. The system will gather and store all positioning data for historical purposes. The Enterprise BIM at St Olavs is part of what can integrate the business plans and maintenance schedule to overcome a more robust and reliable solution for the staff at the hospital.

3.6 Deliverable

The end results are presented in a thesis as a paper report. This is the only deliverable, as some software code could not be developed. The report presents the topic and findings which explains and answers the proposed research questions in this chapter. This could be a first step to improve the system at St. Olavs Hospital and thereby improving everyday life at the hospital. The findings should also apply to similar facilities with the need of a precise positioning system.

4

Results

This chapter presents results from the gathered data. The results were from documentations by St. Olavs, Jotne and Cisco, and also from other research papers proposing improved indoor positioning techniques. In addition, some data were noted after talks about 30 to 60 minutes with developers and stakeholders at St Olav, where the names are mentioned in the acknowledgment. From this, different approaches were explored as to figure out what methods and technologies were available and could fit the case at St. Olavs Hospital. The research questions were targeted along the way. First, a brief definition of the scope is given. Then, a research case is reviewed, where an unexpected problem occurs. Indoor positioning methods follows, with theory about them, as to give both a general description and a more applied one. Lastly, an ultrasound solution is presented.

4.1 Scope

An important factor in this specific case at the hospital, was the fact that the Cisco solution was already delivering an estimated position of the tag. The most appropriate task would be to extend this, by adding additional methods and data for filtering, which in the end could improve the accuracy of the estimate given.

Moreover, in most cases from the literature, the research proposed their own location engine which calculated the initial location. Many of the techniques used, were beneficial for accuracy improvement. Some of the most relevant ones are presented in this chapter.

4.2 A case of precision

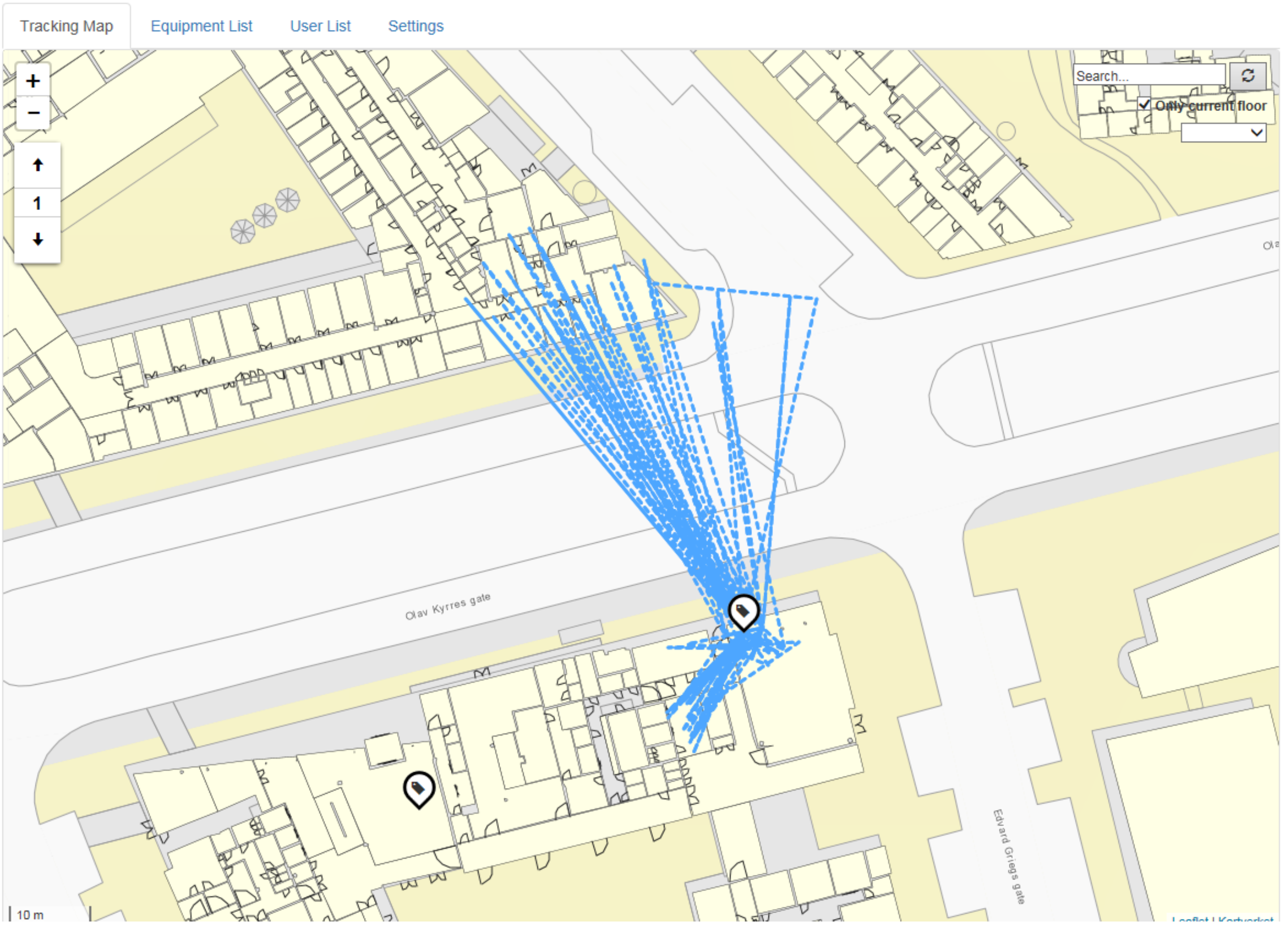

Fig. 4.1: Overview from the interface of the web application developed by Jotne, showing a selected tag and its trajectory over a specified period. (St Olavs, 2017)

This section presents a case, where a tag was tracked over a certain period. It was located at a corner in a building, being stationary the whole time. In the user interface, the selected tag was found in a floor plan provided by the BIM server, as figure 4.1 displays. The blue lines are drawn at each position the tag emitted during the specified period. From the figure the signal from the tag was picked up at several access points, even from the building across the street. Though it was mostly positioned by closely located APs, the fact that the system said the tag has moved to another building was unreasonable in this case, and therefore unacceptable. Possible solutions were discussed further in this thesis.

4.3 Map matching

Map matching algorithms combine the positioning data with spatial road network data. The general purpose is to identify the correct road segment a vehicle is travelling on and determine the location on that road segment. These algorithms are therefore used as a navigation support to improve performances of intelligent positioning and transport systems. Several different techniques have been developed such as topological analysis of spatial road network data, probabilistic theory, Kalman filter and belief theory [38]. A potential final result from map matching algorithm is displayed in figure 4.2.

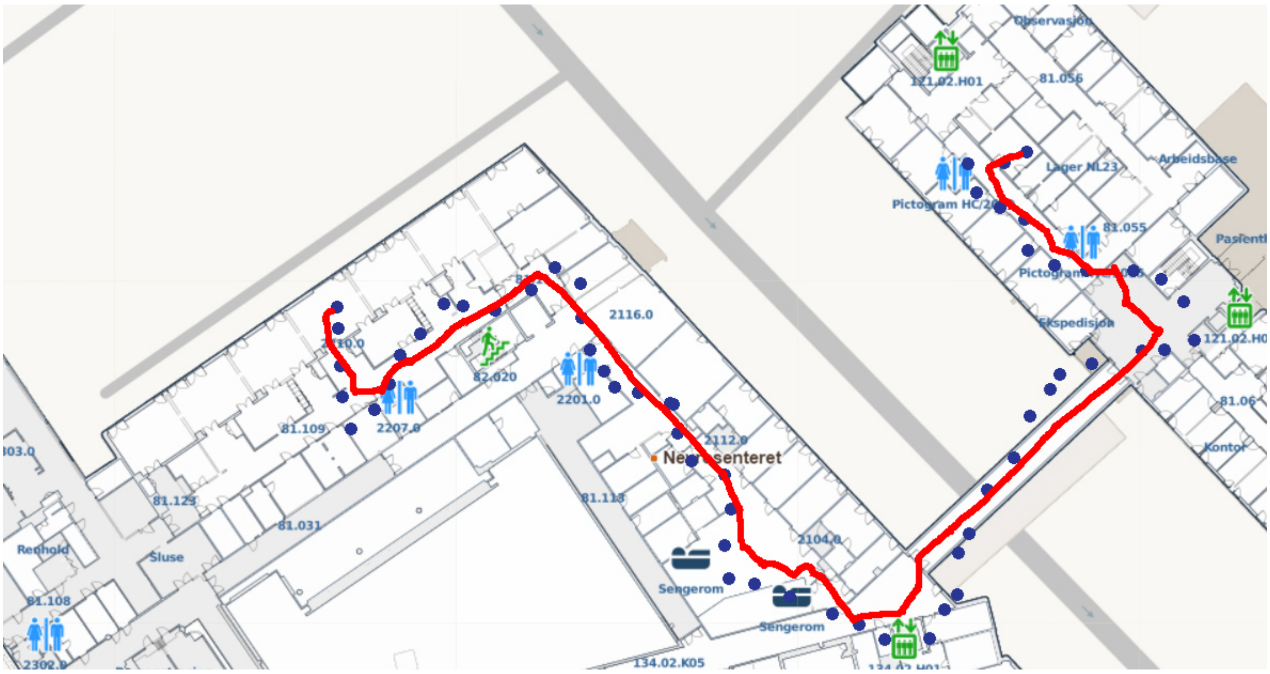

Fig. 4.2: Illustration of a possible trajectory after using map matching. Blue dots display estimated position from the location engine, while the red line is the trajectory after a map matching process combined with the map information. The dots and the path are not real data, but drawn corresponding to a reasonable path. The floor map shows Nevrosenteret acquired from MazeMap [31].

Map matching approaches can be categorized into four groups: geometric, topological, probabilistic and other advanced techniques. The categories are not strict rules, as they borrow techniques and information from each other, but an indication of each is given here.

4.3.1 Geometric

Algorithms that makes use of geometric information on the road network, by examining the position of the nodes and the shapes of the network links (roads). There are three methods within this category of algorithms:

- Point-to-point matching: The position from algorithm input is assigned to nearest node from the network, shown as the stippled arrow in figure 4.3. It is simple and fast, but sensitive to spatial road network data
- Point-to-curve approach: The position is snapped to the curve. This curve is usually built of similar linear segments. The method calculates the distance from input position to neighbouring segments and selects closest link in the network. After, the position is projected on that link, as shown as the plain arrow in figure 4.3.
- Curve to curve method: Matches users' trajectory against path network.

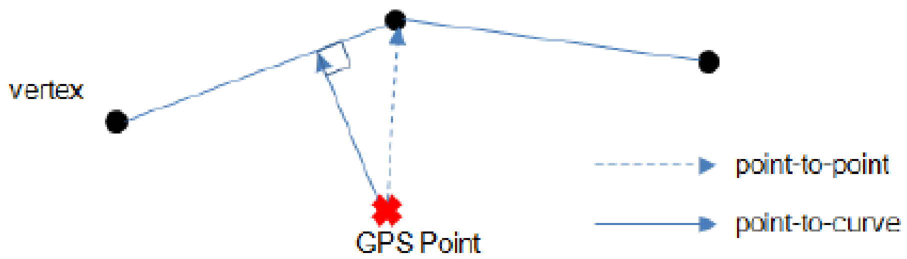

Fig. 4.3: Illustration of how a initial estimated position, here from GPS, is projected onto either a known point or a curve (line) depending on approach [6].

4.3.2 Topological

Topological algorithms make use of the relationships between map objects, which are lines, points and polygons. The relationships, also called topology, can be defined by adjacency between points, connectivity between line or containment of polygons. These algorithms can then refer to the geometry of these links and relationships.

4.3.3 Probabilistic

Probabilistic uses probability theory, often methods involving or extending the Bayes Theorem, in addition to other filter methods. These techniques look for the most likely paths to take. It uses methods to find paths, adding information about previous steps to associate each path with a probability, in the end, finding the one true path.

4.3.4 Advanced

A popular type of advanced map matching algorithms, is the particle filtering technique. The technique implements recursive Bayesian filter using a method known as sequential Monte Carlo [56]. This method requires floor plans like BIM for information about obstacles. The basic principle is to use random samples, called particles, to represent a set of prior positions. Each set of particles is given a weight using a probability density, which in turn models a dynamic state including the information from floor maps.

4.4 IFC structure

Firstly, a detailed explanation of the IFC files, which could be input for map data in a positioning algorithm.

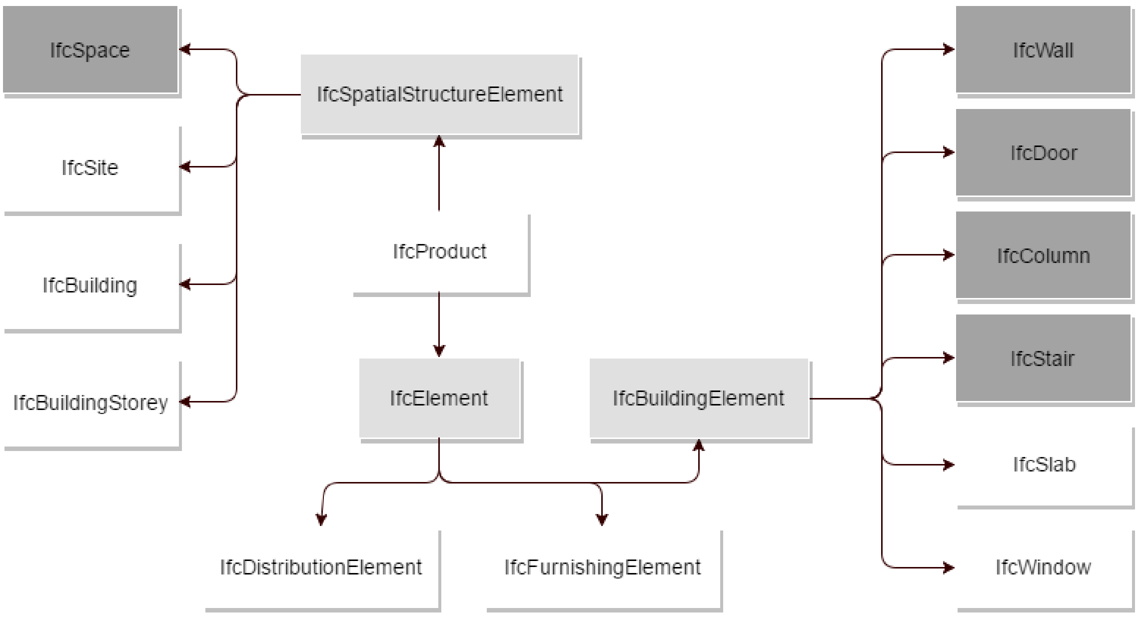

Fig. 4.4: Hierarchy structure of part of defined elements in IFC files. All objects inherit from ifcProduct. The highlighted elements in grey color are the ones most relevant to use in a map matching algorithm or other methods incorporating BIM. Image is inspired by [24].

In the IFC specification, all components like space and columns inherit from the entity IfcProduct, as shown in figure 4.4. There are entities classifying objects above, but they are unimportant for this purpose. The IfcProduct contain all common information about building products.

The IfcSpace element is part of the structure in a building. It represents and area, most commonly a room or a corridor, in a building story. In the BIM, these spaces are usually assigned a function. Figure B.7 in Appendix B, shows the functions in a building at St. Olavs hospital. A map matching algorithm can extract these functions to guide the system in knowing where it is more likely to be positioned. For instance, a room can have certain access restrictions, or it can be closed off in case of hazard. The algorithm can then assign less weight on this room, because it is less likely the tag has moved to this space.

On the other side, there are the building elements. Walls and columns are the most common types encountered, which are treated as obstacles in a path. Doors are the link for objects and tags to move from room to room. Attributes to know if the door is locked or not, can be assigned to this element, making the algorithm consider if the room is accessible or not. This is often referred to as semantic information, as the elements are given meaning. Two snippets from an IFC-file are shown below, where the first one is the generic ifcElement and the second show defines the wall element. The parent IfcProduct can be spotted from the substitutionGroup attribute, as well as other attributes and definitions within the element. The definitions at this stage are the most common and generic ones.

```xml
<xs:element name="IfcElement" type="ifc:IfcElement" abstract="true"
    substitutionGroup="ifc:IfcProduct" nillable="true"/>
<xs:complexType name="IfcElement" abstract="true">
    <xs:complexContent>
        <xs:extension base="ifc:IfcProduct">
            <xs:attribute name="Tag" type="ifc:IfcIdentifier" use="optional"/>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
```

```xml
<xs:element name="IfcWall" type="ifc:IfcWall"
    substitutionGroup="ifc:IfcBuildingElement" nillable="true"/>
<xs:complexType name="IfcWall">
    <xs:complexContent>
        <xs:extension base="ifc:IfcBuildingElement">
            <xs:attribute name="PredefinedType" type="ifc:IfcWallTypeEnum"
```

```
                    use="optional"/>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
```

Within the subtypes of each element we can usually find the geometric representation and placement of a component, which is defined in two entities. The first, IfcObjectPlacement, describes the placement of the product in space. The second is IfcProductRepresentation which describes the component's geometric or topological representation. There exist several geometric representations. For instance, BoundingBox describes the product as a simplistic 3D model, to avoid handling complex shapes, while the SolidModel describes the product using solids and swept solids, Boolean results and boundary representation solids. For a map matching algorithm and other positioning techniques incorporating IFC information, it is important to choose representations that are representative for the product while also being efficient. This will depend on the complexity of the shapes, where straight walls are simpler than curved ones.

4.5 Algorithm using Map matching with BIM data

How can the extracted information from BIM and the IFC files be used? For best and simplest implementation in the existing system, the data will be used in a post-process. The system does not have to be exact real-time, not regarding tracking an object at just a specific instant. Therefore, the method will start by looking at previous positions, and make a path. The specified period or amount of location points (interval) will be discussed further. When a path has been drawn, the algorithm can compare it to path rules defined from the BIM data. The path rules will use the geometric and semantic data from BIM to create a table of constraints for a tag's possible movement. From the IFC files in the BIM, appropriate and relevant information will be collected. Certain elements are more relevant than others, and this must be determined first. Instances like space, walls and doors are some of the most important because they shape the foundation of the building. First and foremost, it is crucial that the tag is placed within the correct building. This means the IfcBuilding element is required. After extraction, possible movements will be defined. A table of rules can be constructed, as shown in table 4.1.

Element	Attribute
Space	Public/private
Wall	Obstacle
Door	Open/locked
Story	Number (ground floor, second etc.)

Tab. 4.1: A representative collection of IFC constraints, linking element to an attribute.

The purpose is to give the algorithm guidelines that will help decide which path lines and locations should be considered accessible or infeasible. Tags are obviously not able to pass through walls, meaning this element is considered an obstacle. Further, the functionality of each room can be useful at this stage. A room can have the attribute restricted access, and should therefore be considered an obstacle. Additionally, some rooms have a higher chance of being visited. A weight factor can be added for each room, to define the probability of moving to that specific room.

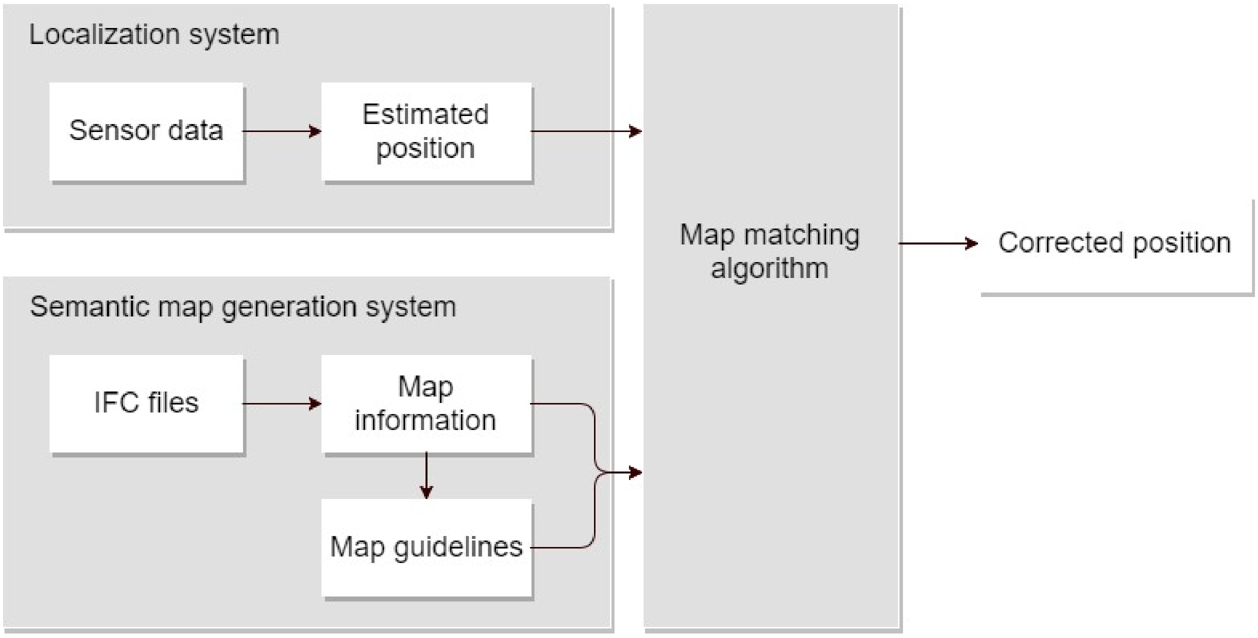

Fig. 4.5: General flow of a system which corrects an estimated position using BIM data and map matching algorithm. Image based on [4]

An overall flow of a map matching system, is shown in figure 4.5. The localization system, in this case Cisco, provides the algorithm with initial positions of the tags. The positions are received at a given interval, which Cisco has set to 30 seconds. The accuracy of these estimates varies because of Wi-Fi fluctuations. The other main input to the map matching algorithm would be information from the IFC files. Relevant data will be extracted. This data will also be used to form map guidelines or a set of movement rules. The algorithm uses this map information to find possible paths, making sure the positions follows the rules, to define a reasonable path. This will improve the position estimates and give a corrected position as output.

Further work on BIM data map can be done by creating a grid layout of the floor map, as shown in figure 4.6

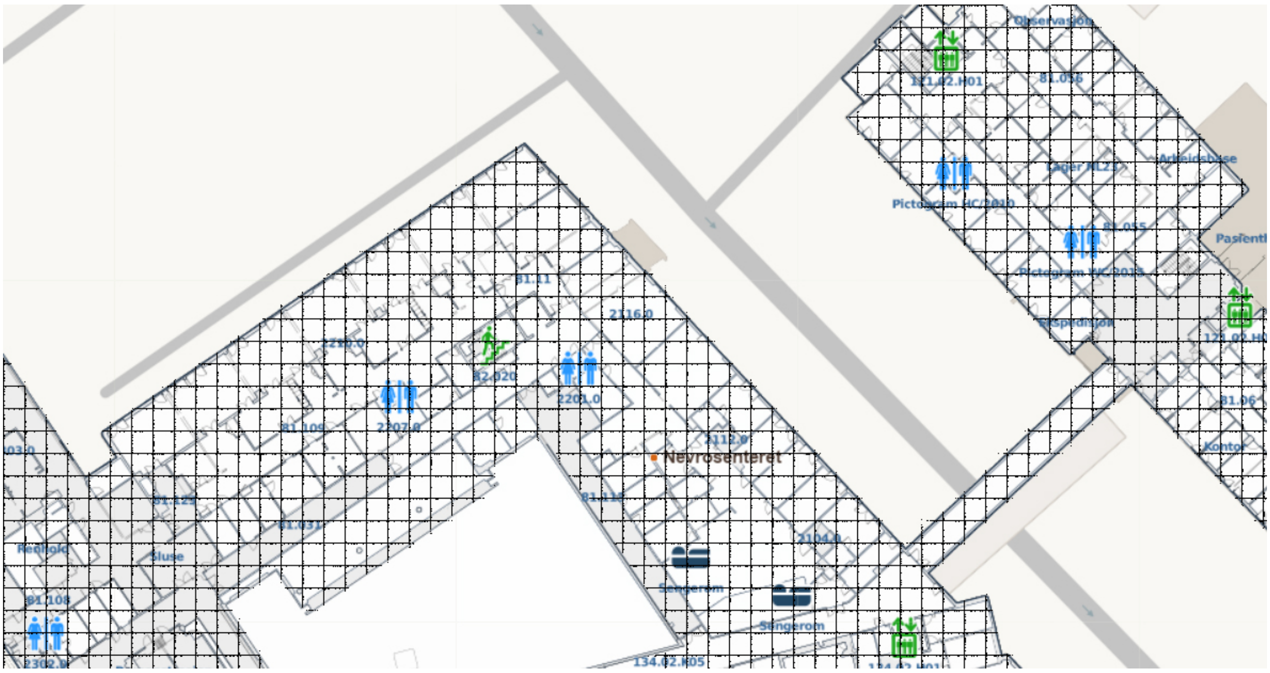

Fig. 4.6: Grid layout of Nevrosenteret

The IFC space property can be split up into cells and mapped on to a grid, consisting of a set of discrete nodes. Each cell is represented as a grid node in the map. A node will have a predefined size. The smaller, and therefore more nodes, increase the positioning accuracy, but this can result in a more advanced and computationally heavy process. A space, which can be a room or a corridor, is represented by several nodes, depending on the geometric size of the room. Then, a directed graph can be made by using these discrete nodes. The nodes are the vertices in the graph, representing the location, while the edges are values associated with the semantic and geometric information of the building elements. A possible path is then constructed by using the values of each node, telling if the node is navigable or not. The work is obtained from Lin. Et Al. [24], and adapted to fit more likely into the case at St Olavs.

4.6 Fingerprinting

This section presents another method for increasing the performance of IPS. Fingerprinting is a technique for comparing the estimated position with a database of pre-sampled data of the signal from the access points. It consists of two phases:

The offline phase primalry consist of constructing the radio map. This is where RSS readings are collected on to a WLAN device from all access points in area of interest. The coordinates are also stored with the radio signal readings into a database known as radio map. The radio map can effectively describe the spatial distribution property of the RSS in target area. This process requires time consuming manual work. In addition, if placements of the access points changes, there must be another round of collecting readings. As a suplement, filtering by using propagation algorithms or clustering, like K-means clustering algorithm, can be added.

The online phase begins by collecting real-time RSS readings as input. Then do a coarse positioning by matching clusters, following by a fine positioning by taking input from the offline phase. This can be based on a probability distribution. Optionally, check valid access points to a reference AP database, for making sure the readings are credible. At last, estimate the user position by matching a radio frequency sample with the radio map. A disussion about fingerprinting are presented in the next chapter.

4.7 Sensor Navigation

An introduction to sensors are presented as they are essential in many tracking solutions. Sensors, often referred to as Inertial Measurement Unit (IMU), gathers information by using different sensing technologies. Smart phones are equipped with a wide range of such sensing mechanisms. The most popular sensors are the following.

- Accelerometer to measure the heading, which is the target's moving direction. Orientation, or heading, is usually estimated from sensors, for instance an accelerometer on a smart phone.

- Gyroscope senses altitude and rotation. This can be used to detect when a tag or device is travelling by elevators and generally moving between floors.

- Magnetometers senses magnetic fields in an area. As the magnetic flux values variies depending on the area, a device with the magnetometer can therefore make sense of where this is, if the fields are previously known.

4.7.1 Pedestrian Deduced Reckoning

Pedestrian deduced reckoning (PDR) is a navigation technique using IMU. The technique can estimate the location at the next step from a known position, by observing the steps of a user and estimation the length and heading of each step. This means it depends on prior estimation, and used as a positioning technique alone, can skew the further estimations in a wrong direction. Therefore, it is generally used as a supplement for other navigation methods, which makes the solution more automotive or it can help extend the area of navigation [58].

4.8 The ultrasound combination

St. Olavs has sign a contract for testing out the ultrasound option by Sonitor. The thesis does not cover this, as it is still an early phase, therefore another solution is presented here. Holm [University of Oslo, 2009 [17]] proposed a hybrid solution which combined ultrasound and RFID. The solution used active portable transmitters as tags which transmitted a signal code to stationary detectors. Room-level accuracy was achieved by having at least one receiver in each room. The innovation in this solution occurred from reversing the direction of the ultrasound, signifying that the tags are the ones reviving the message from the detector in the room. After, the message was further transferred via radio frequency, using the Wi-fi, and then handled at a central server. Another key factor for this transmission to go smoothly, is a communication rate of only a few tens of bits per second. The system can therefore send burst transmissions, which made it able to handle a higher capacity. In conclusion, the advantage of ultrasound is achieved in term of precisely indication of room, and the RF secured quick communication. The time-delay measurement was not required, producing a more robust system overall.

5

Discussion

This chapter discusses the results and the retreived information from all the different sources. The different areas of research are covered, like sensors, algorithms and methods and other relevant factors that contribute to answer the question; how make an indoor positioning system that perform better, specially regarding the accuracy.

5.1 Validity of Results

The literature was retrieved from trusted scientific papers and libraries. Documentations and technical reports by companies were used as information sources, being up to date and cited elsewhere aswell. Discussions with developers and leaders at the hospital were informal and loose, and not documented. However, the sources were considered experts in their area, and therefore provided qualitative data.

5.2 Precision case - the outliers

A reason for the signal to fluctuate all the way across to the neighbor building is because of location accuracy tending to be lower at the edges and especially corners of a building. This is further because there are more access points in the middle that can measure distance, than on the edges. Figure 5.1 displays the location inspection tool from Cisco within the Wireless Control System, where calibrations can be made to the APs. The index in the top right area shows the location error visible from red as in worst to green as in best. This indicates on the figure that location accuracy is worse in the corners of a building.

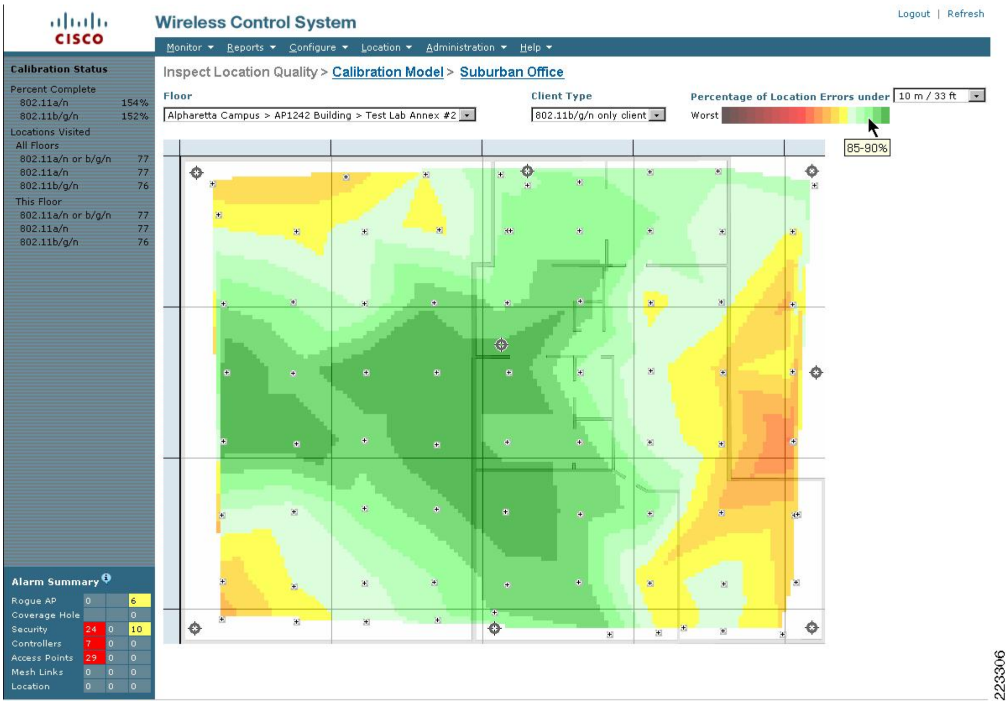

Fig. 5.1: Post-Calibration Location Inspection [8]

Still, if the signal is picked up from the other buildings AP and the system place the tag there, it should be examined if this is reasonable. Furthermore, there should be more tests of tags at different stationary positions, to see if the same results will happen at different location of the building.

5.3 Tag Intervals

The polling of each position estimate from Cisco is 30 seconds. In other words, the system will receive an update of the tags location each half a minute. This interval can be sufficient for tracking an objects current position, as a real-time location was not necessary. However, if the user wanted to analyze the path, in some scenarios where a tag was only in a room for less than 30 seconds, the data might be missing from the history. As far as tracking people goes, 0.5 seconds will give an adequate sampling of the movement of humans. In addition, the more data points will also give more information about the position of the tag, in turn improving the accuracy. Lowering the interval rate would therefore be a suitable solution. However, this interval might not be possible to change at first, judging by talks from developers and staffholders at St. Olavs. Other drawbacks are accelerated drain of the tags battery and heavier load of the computations at Jotne's system because of increased data traffic. The computation time must be considered here, which should be fast in a real-time location system, as in within seconds. The transmission interval should be further tested, to identify the necessary rate for proposing a robust solution without missing relevant data.

5.4 Sensors

Sensors are not currently in use in the case in this thesis, as standard active RFID tags are used. However, they add helpful information about the tracked object.

Velocity: The estimates of velocity can improve the impact of location accuracy. This could also cancel out the movement detection, when the tag is being stationary.

Heading: The information about the heading may very well improve the outcomes of other location techniques like map matching. However, it is not always reliable. For instance, disturbances in nearby magnetic fields may cause unstable heading. In addition, although impossible paths can be eliminated by setting accessibility constraints, the error in direction estimation often accumulates. An algorithm using this information may therefore need an ability to backtrack it's estimates. Holm proposes such positioning system using a particle filtering backtrack algorithm

5.5 Map matching

In many map matching techniques incorporate sensor data, from the device, which in most cases is a smart phone. These inertial sensor units like gyroscope and accelerometer are not available for ordinary RFID tags, at least not the ones at St. Olavs. Still, map matching algorithms are useful for using the rich spatial data available from the BIM.

The map matching techniques are often used to produce a path from a starting point to a destination. The end points are usually entered by the user. When the purpose is to track an object, obtaining the path is not the priority. The path can be useful, like for more detailed in how the object did arrive at the current point and for later analysis. However, for finding the current location, the user is first and foremost not interested in where it has been along the way. In the beginning, the map matching techniques can therefore be reduced to simpler design and implementation, focusing on the most important task of using the available data to improve the accuracy of the tag's position.

5.6 Fingerprinting

The fingerprinting methods require a lot of initial manual work. Updates are also a cumbersome job, like if some fingerprints being out of date because of updates in the structure. Due to the time-variation property of radio signals in indoor environment using Wi-Fi, the fingerprint methods can often be preferred, as these positioning techniques is based on offline data. By having a radio map of all the RSS readings from the APs, more information are available to use for accuracy improvement. However, the significant dependability of this property, may also be a challenge. If the signal changes over time, it will be difficult to match the online signals with the ones stored in the database, and this mismatch can lead to a substantial location error.

5.7 Fusion of technologies

Solutions that fuses different location technologies and methods are previously described in the background. Significant accuracy improvement was reported in all cases, which confirm that combining technologies should be considerated. However, it must be mentioned that the cost and deployment work increases, as new hardware are necessary.

5.8 Access point placement

Localization accuracy is dependent on the density of WiFi AP deployment, which is a topic of less importance to the hospital. The cost of investing in new access points or have them moved to facilitate for better location tracking, is a risk to take. Instead for this case, it is more profitable to work with what already installed, being the Cisco infrastructure with the new CMX engine, and Jotne's BIM server. From this, a more efficient and cost-effective solution seems to be possible.

5.9 Enterprise BIM usage

The EBIM explained in the background hold additional information that may prove useful to the positioning system. For instance, if we know schedules, work orders and other plans that can help know where the tagged object should be at a certain time, this could be factored in. If not improving the accuracy, then at least give the user some indication of where it is supposed to be.

5.10 Existing solutions

Many of the proposed solutions using Wi-Fi and RFID do not achieve a better location estimate; that is a mean error, than the existing solution at St. Olavs . They are still close, like 0.5-2 meters worse. The idea is therefore to use the already decent estimation from Cisco, and add suitable techniques (for instance map matching, particle filtering with sensors or fingerprinting) as an additional process step, before the best possible position is given to the user. Other solutions employing technologies which require new hardware, being Bluetooth, infrared or ultrasound, achieve mostly a slightly better positioning result. Just by having a slight increase in accuracy, like less than a meter, may help the system a lot since this could be enough to get a room-level accuracy. However, it is still not robust to be a fully reliable solution.

5.11 Privacy

Privacy is always a matter when tracking people. As long a equipment, AGV robots and wheelchairs and similar are the tagged objects, this is generally not any concern. If the system at St. Olavs progresses further into locating persons, as they want, it is important to be transparent about how they collect an use this data.

6

Conclusion and Further Work

This chapter concludes this master thesis. A summary of the results and its discussions are given and future research are also presented.

6.1 Conclusion

Based on research, there were lots of technologies, methods and systems providing accurate indoor positioning systems. For hospitals and other large building complexes, an IPS would be a valuable investement for facility management. Accuracy and reliability are important aspects for such systems. On the other hand, BIM is capable of providing detailed geometric and semantic information related to the buildings, where floor plans, navigation graphs and indoor positioning methods are developed using this information. BIM is not the major part in improving accuracy of IPS. However, it is beneficial when already in use. In addition, BIM serves great as aid in visualization, as well as being a common database where updated are immediately pushed to other users.

Going back to the research questions in more detail:

⇒ *How is it possible to use WLAN infrastructure and BIM-models to position persons and objects indoor in distinct rooms in a large building complex?*

and

⇒ *How is it possible to increase the accuracy of an IPS?*

Improving accuracy of indoor positioning systems, requires mostly two things. Extraction of semantic data from BIM models and well-designed algorithms for estimating locations and paths. Utilizing pre-existing WLAN infrastructure is a cost-efficient strategy, but combining with additional positioning technologies has a positive effect on the accuracy.

A Map matching algorithm which leveraged map data from BIM was described in more detail. The algorithm takes advatage of the information about obstacles and estimates a most likely path or position. It has yet to be integrated and tested with the existing system at St. Olavs, but related work acheived improved location accuracy.

Combining Wi-Fi with other technologies showed improvements to IPS. Especially, by adding ultrasound technuqes and hardware, a room-level positioning can be obtained. The research did not come as far as initially hoped. Since an implementation could not be achieved, and therefore neither a testing phase to evaluate the proposed techniques, the thesis remain as a study of current approaches and measuring them against a real case at a hospital. The results were promising in regards to improve the overall location estimates.

6.2 Future Work

There are still areas within this topic to research and develop, and a few touching points are mentioned here. Further testing is required to see if proposed designs and techniques hold promise for improving the overall accuracy. Additionally, there should be test to see if they are applicable to the existing system.

Future work could consider looking into Cisco's solution in more detail. The CMX offers additional tools to increase the performance of location estimations, like the FastLocate for gathering more locations per minute. This is not researched at a deep extent, as Jotne has already developed a further extension of the tracking solution. However, there are exciting technologies included, which by adjusting further holds a promise of improving overall positioning accuracy.

Cisco also has a tool for predicting the coverage of access points, by indicating the RSSI of each AP. Figure 6.1 shows a typical RF prediction heat map with access points covering one end of a building. The colors show the signal strength form RED (-35 dBm) through DARK BLUE (-85 dBm), and the patterns of the radio signals can be discovered.

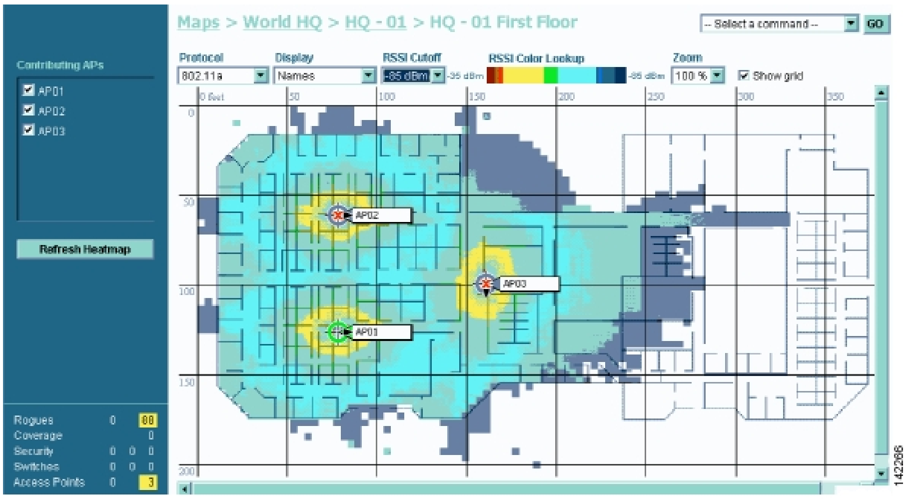

Fig. 6.1: RF Prediction Heat Map [12]

Other filtering techniques, like Extended Kalman Filter and Hidden Markov Models were briefly researched, but just barely mentioned in this thesis. The Cisco location system already uses filtering techniques. At the current state though, improvements to the filtering would still be possible, and the methods mentioned here could prove advantegous in making a more desirable indoor positioning system.

APPENDIX

A

Acronyms

AoA Angle of Arrival

API Application Program Interface

BIM Building Information Models

BLE Bluetooth Low Energy

CMX Connected Mobile Experiences

EBIM Enterprise BIM

GNSS Global Navigation Satellite System

GPS Global Positioning System

IMU Inertial Measurement Unit

INSM Indoor Navigation Space Model

IPS Indoor Positioning Systems

IFC Industry Foundation Classes

IR Infrared Radiation

ISO International Organization for Standardization

RTLS Real-Time Location Systems

MSE Mobility Service Engine

MSM Model Server Manager

NTNU Norwegian University of Science and Technology

PDR Pedestrian Deduced Reckoning

RFID Radio Frequency Identification

RSSI Received Signal Strength Indicator

REST REST Representational State Transfer

TDoA Time Difference of Arrival

ToA Time of Arrival

SLAM Simultaneous Localization and Mapping

UWB Ultra-Wideband

WLAN Wireless Local Area Network

WPAN Wireless Personal Area Networks

B

Model Server Manager

Screenshots of Jotne's BIM server software, the Model Server Manager (MSM).

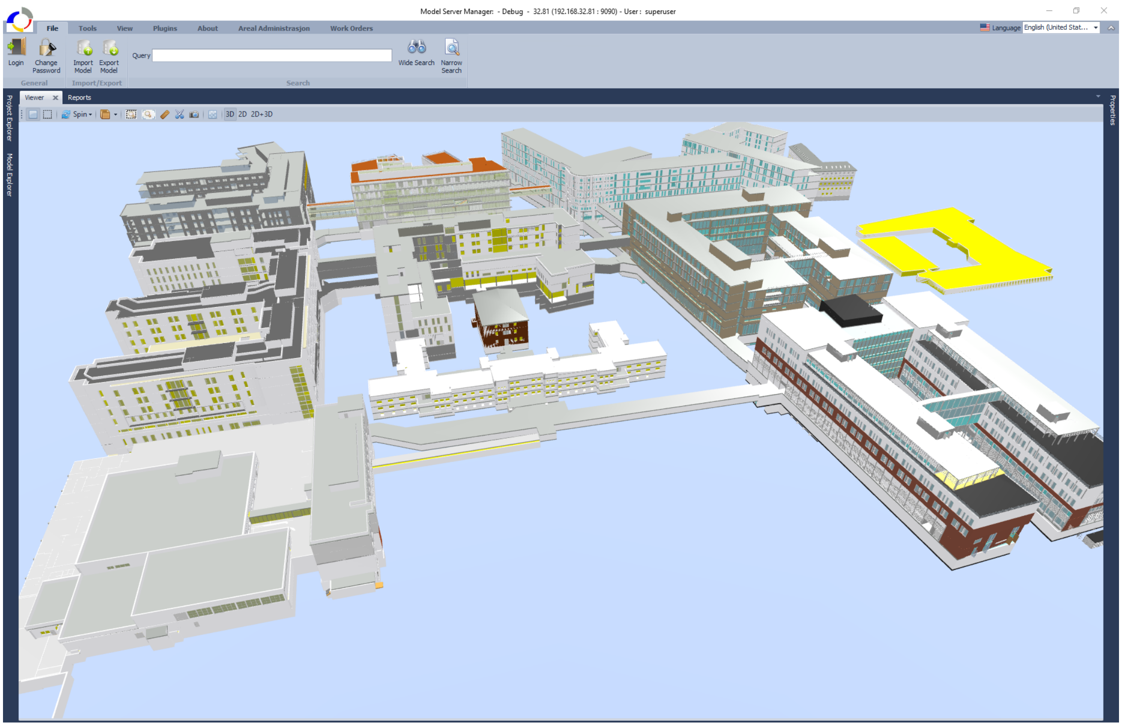

Fig. B.1: Overview of all Bim models at Øya.

The initial figure B.1 is a collection of all models of campus Øya. The view can be zoomed and rotated as the user wants.

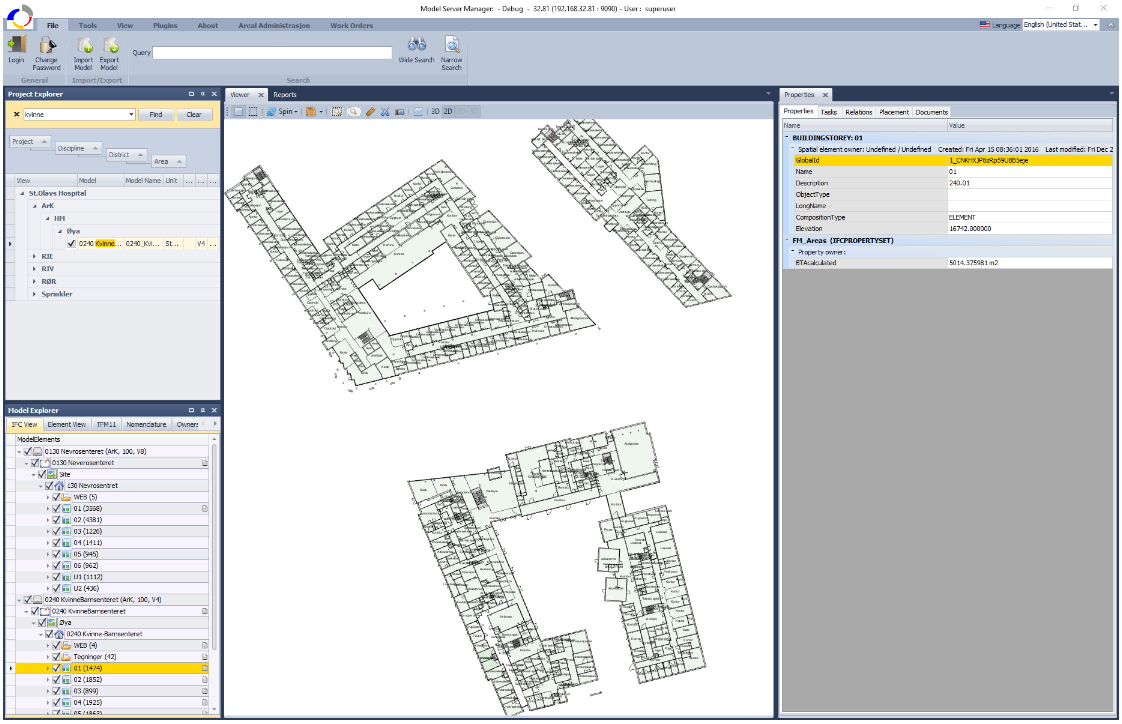

Fig. B.2: 2D representation of same floor in two models, Nevrosenteret and Kvinne-barn-senteret. Models are selected on the top left pane, floors at the bottom left. The attributes and data can be seen on the right.

Next, figure B.2 displays a 2D view of two of the models. The top building is called Nevrosenteret, which is frquently referenced to throughout the thesis. The bottom is Kvinne-Barn Senteret, another model which is often used for testing purposes in the system, becasuse of its rich features and central location.

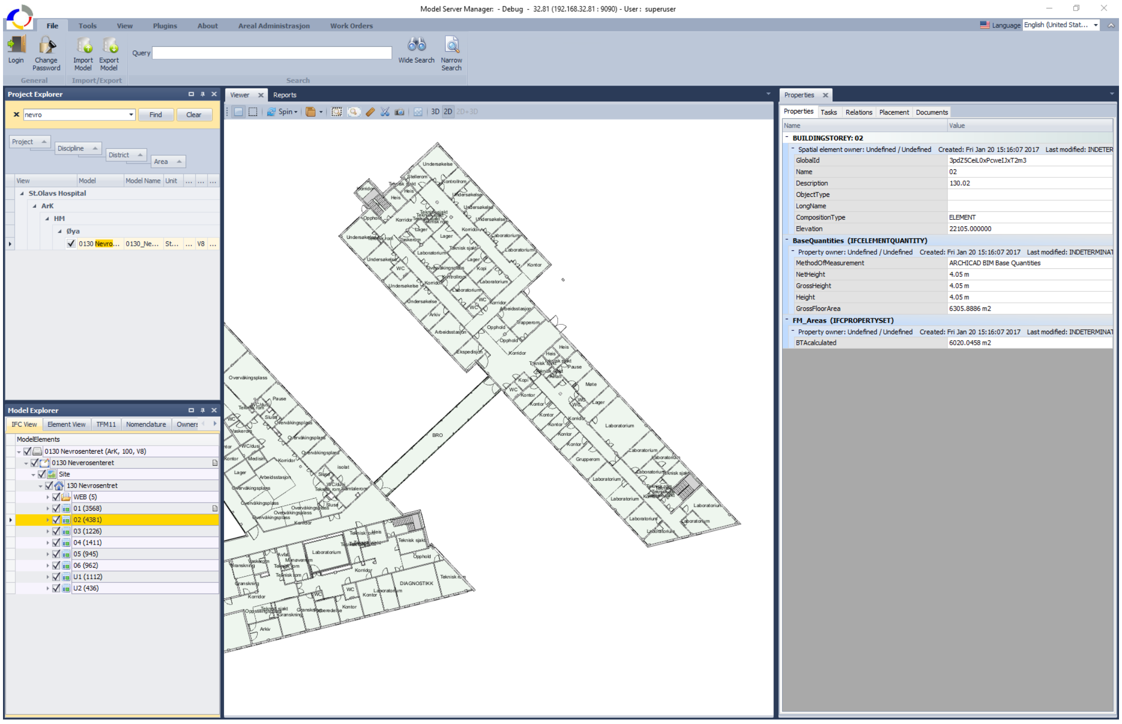

Fig. B.3: 2D representation of a more close up view of Nevrosenteret.

In figure B.3 The top building from previous figure is zoomed in for a better view of each rooms and corridors.

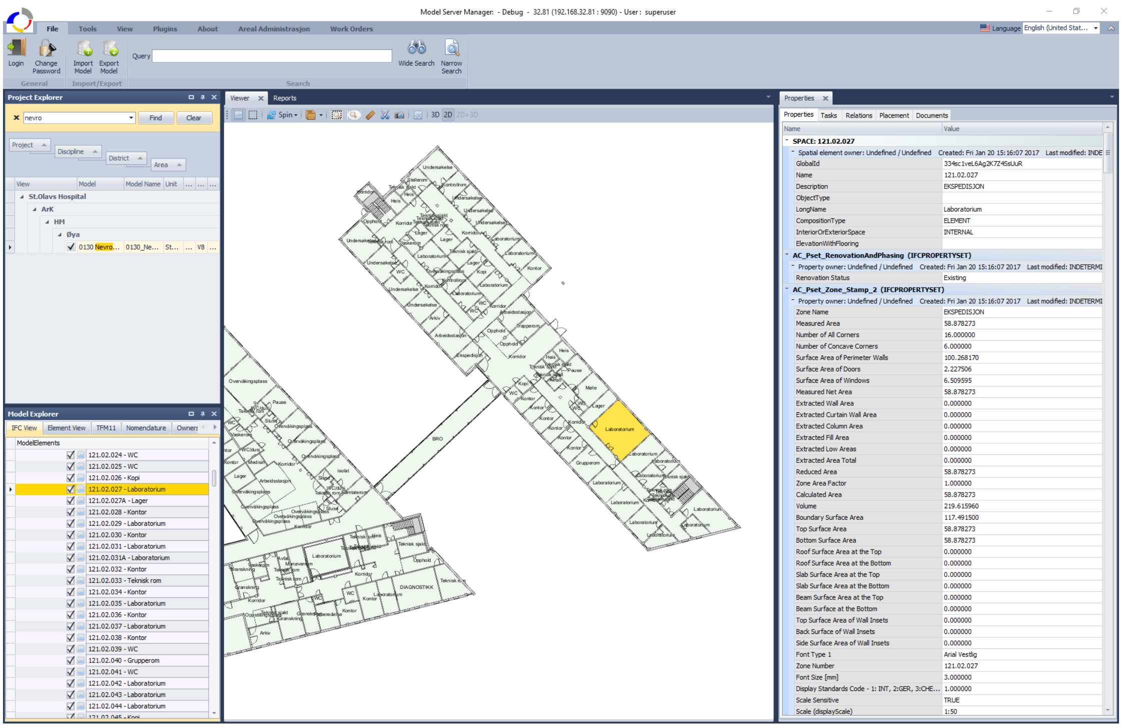

Fig. B.4: A specific room is selected in Nevrosenteret, where details and relations can be spotted on the right.

An arbitrary room is selected in figure B.4. Details like coordinates, size and how it relates to other rooms and hallways can be seen in the right pane.

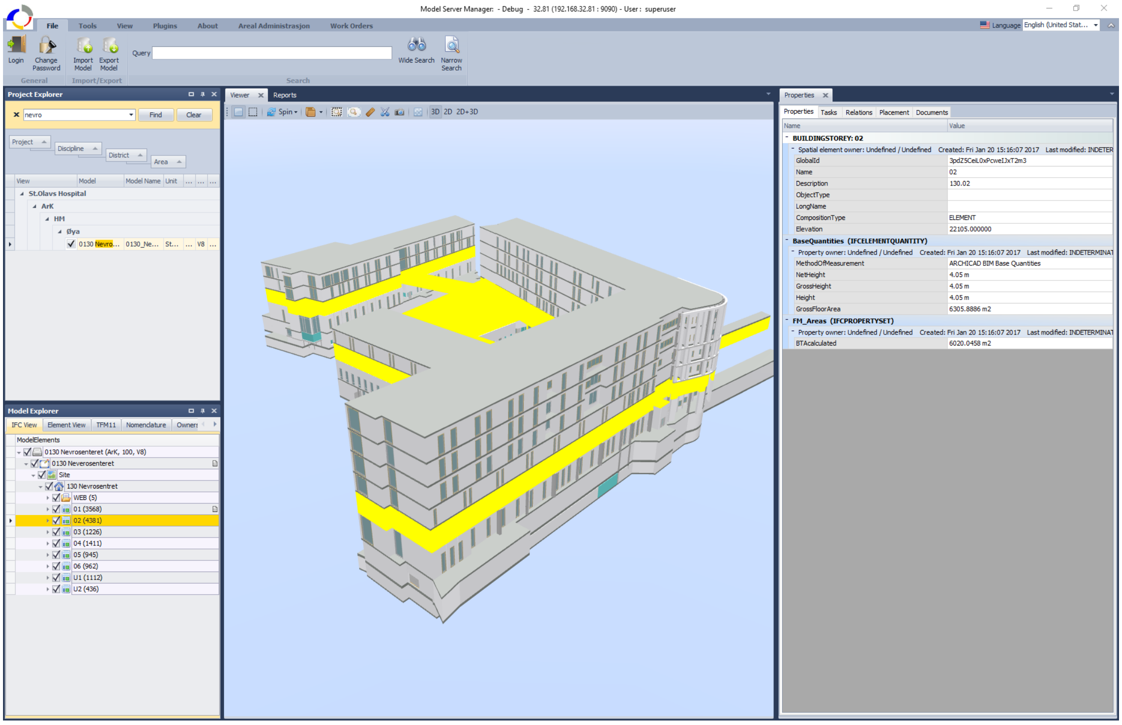

Fig. B.5: 3D representation of Nevrosenteret, where a selected floor is highlighted.

Figure B.5 displays a 3D view of the same model, where a whole floor is selected, making it a different color.

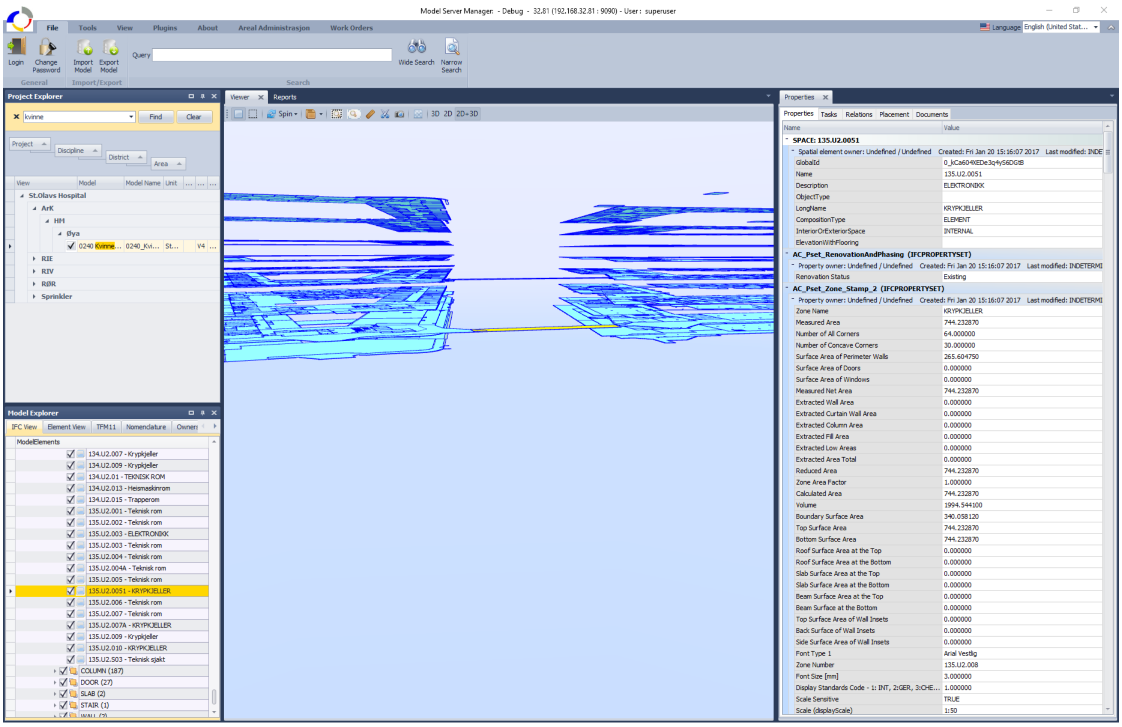

Fig. B.6: 2D/3D combination representation of Nevrosenteret.

In figure B.6 a combination of 2D and 3D view is selected. This makes it more convenient to get an overview of all floors at the same time in the same view.

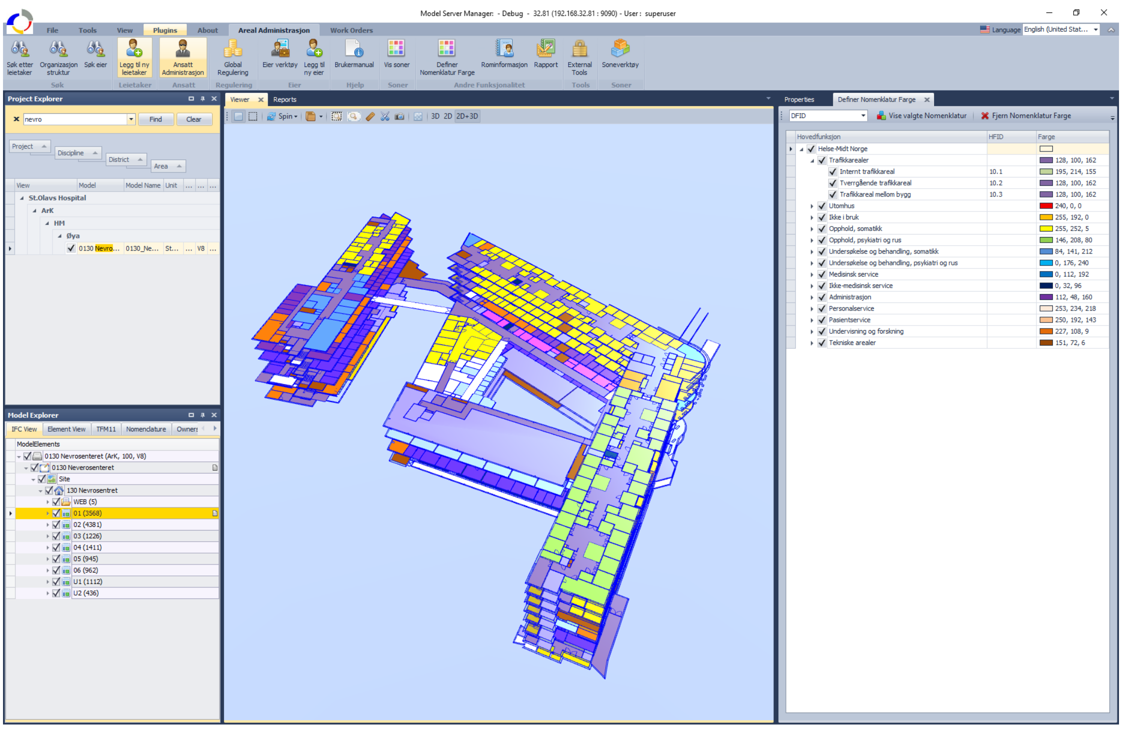

Fig. B.7: Nomenclature of Nevrosenteret, displaying different functionalities of each room.

The functionality of each room is shown in figure B.7. Each functionality has its own color, which is defined at an earlier stage.

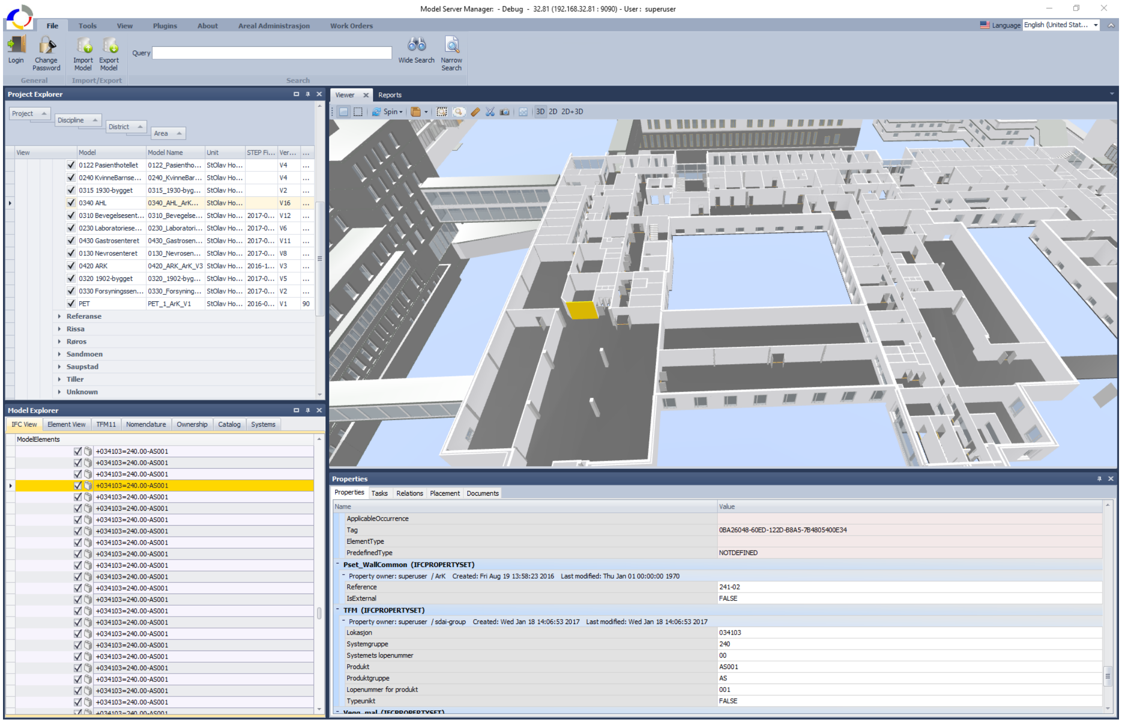

Fig. B.8: Inside 3D representation of a the BIM model Nevrosenteret. All elements can be selected in the left bottom pane. A targeted wall is highlighted and data can be gathered from the bottom pane.

Lastly, the view has moved inside the building in figure B.8. The indoor elements are modeled, only the simplest are needed for this case. A wall is selected and a bottom pane displays its properties.

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