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Human Mobility Patterns from Indoor Positioning Systems

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MASTER THESIS

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Sammendrag

Utendørs posisjoneringssystemer som GPS er allerede en naturlig del av folk sin hverdag og blir brukt i forbindelse med flere formål, slik som navigering og lokasjonsbaserte tjenester. Alt man trenger for å utnytte tjenestene GPS-teknologien har å tilby er en smarttelefon. Siden GPS signaler ikke når enheter innendørs, finnes det et enormt marked som ennå ikke er utnyttet. Derfor er det forventet at innendørs posisjonering vil ta markedet med storm i de neste årene. Cisco MSE er et slikt system som kan samle inn anonyme innendørs posisjonsdata som kan benyttes i innendørs lokasjonsbaserte tjenester. Dette systemet er i bruk på NTNU i dag.

I denne oppgaven er en web-applikasjon utviklet for å tolke, analysere og visualisere de anonyme innendørs posisjonsdataene samlet inn av Cisco MSE-systemet på NTNU Gløshaugen. Målet med applikasjonen er å identifisere optimale metoder for å visualisere innendørs bevegelsesmønstre, for så å presentere de tilgjengelige dataene i et nyttig format for potensielle interessenter. Applikasjonen presenterer visualiseringer av mengden bevegelse på campus, mengden bevegelse mellom bygninger på campus, nøyaktigheten av de registrerte posisjonsdataene, og bruken av innganger og utganger i bygningene. Prosjektet følger Design Science Research-metoden ved å først lage et forslag til ny forskning, før krav fra potensielle interessenter samles inn, noe som resulterer i et tentativt design. Deretter følger utviklingen av applikasjonen før en evaluering gjennomføres.

Evalueringen konkluderte med at informasjonen som applikasjonen tilbyr er regnet som nyttig for potensielle interessenter, spesielt for personell ansvarlig for drift av bygninger. Det kom fram at fremtidige applikasjoner som er mer tilpasset deres spesifikke behov i stor grad kan assistere de i arbeidet deres.

Abstract

Outdoor positioning systems such as GPS are already a natural part of people's daily lives, being utilized in various applications such as navigation, and location aware services. One does not need anything more than a smart phone in order to take advantage of the services the GPS technology has to offer. As the GPS signals do not reach devices indoors, an enormous market is yet to be exploited. Therefore, indoor positioning systems are expected to enter the market by storm in the next few years. Cisco MSE is such a system, collecting anonymous indoor positioning data which may be utilized in order to provide indoor location-based services. This system is utilized at Norwegian University of Science and Technology (NTNU) today.

In this thesis, a web application prototype is created in order to interpret, analyze, and visualize the anonymous indoor positioning data collected by the Cisco MSE system at NTNU Gløshaugen. The goal of the application is to identify optimal methods for visualizing indoor human mobility patterns in order to present the available data in a useful format for potential stakeholders. The application presents visualizations of the amount of movement on campus, the amount of movement between buildings on campus, the accuracy of the registered positioning data, and the usage of exits and entrances in the buildings. The project followed the Design Science Research method, first creating a proposal for a new research effort, before collecting requirements from potential stakeholders, resulting in a tentative design. Then development of the application or artifact is performed before evaluating the application.

Evaluations concluded that the information provided by the prototype is considered useful for potential stakeholders such as facility management, and that future applications tailored for their specific use cases can assist them in their work significantly.

Preface

This thesis is the result of my research in Informatics at the Department of Computer and Information Science (IDI) at the Norwegian University of Science and Technology (NTNU) from the fall of 2014 to the spring of 2015. I would like to thank my supervisor John Krogstie for allowing me to select this specific project, as well for his support throughout the whole process. I would also like to thank the people at MazeMap for all assistance during the development of my prototype application, especially Åsmund Tokheim, Dag Jomar Mersland and Thomas Jelle. Dr. Dirk Ahlers at IDI also deserves recognition for providing great insights during the development process. In regards to the collecting of requirements and evaluation, I would like to thank Jan Sverre Rønning at NTNU Studieavdelingen, as well as the staff from NTNU Operations and Statsbygg Trondheim. Finally, I am eternally grateful for the support from my family and friends during my education, allowing me to fully focus on my studies.

Kristoffer Gebuhr Aulie

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Acronyms

AoA Angle of arrival

API Application Programming Interface

CPU Central Processing Unit

DR Design Research

DSR Design Science Research

GPS Global Positioning System

GSM Global System for Mobile Communications

GUI Graphical User Interface

IDI Department of Computer and Information Science

IPS Indoor Positioning System

JSON JavaScript Object Notation

MVC Model View Controller

NTNU Norwegian University of Science and Technology

NTNU-CMA NTNU Crowd Movement Analysis

PEOU Perceived ease-of-use

PU Perceived usefulness

RFID Radio-frequency identification

RSSI Received Signal Strength Indication

RTLS Real Time Locating Systems

SaaS Software as a Service

Cisco MSE Cisco Mobility Services Engine

TAM Technology Acceptance Model

ToF Time of flight

WLAN Wireless Local Area Network

XML Extensible Markup Language

Chapter 1

Introduction

This chapter contains an introduction to the Thesis, providing an overview of the research performed. First, the motivation behind the research is explained before the project is defined. Then the research methods utilized are described, as well as a short summary of the results. Lastly, an outline of the complete thesis is presented.

1.1 Project Background

This work has been done in connection to work in Wireless Trondheim Living Lab[1], which is a research and development project made possible through the joint efforts of the Norwegian University of Science and Technology (NTNU), the city of Trondheim, the Sør-Trøndelag County Council, SpareBank 1 Midt-Norge, Adresseavisen and Trondheim Energiverk. The project provides an environment for testing new products and services, featuring real users and real world wireless conditions[2]. In parallel, also other work is done relative to this dataset by Jeppe Benterud Eriksen[3], focusing on visualizing the presence of people inside the buildings at NTNU. In some use cases, such as monitoring changes in presence in specific rooms, his methods for visualization of indoor position data might be more useful than the ones described in this project. Thus the two projects complement each other.

1.2 Motivation

Global Positioning System (GPS) has become an established part of people's everyday lives, and the technology is instantly available through the propagation of today's smart phones utilizing location aware applications. While people are benefiting from this technology outdoors, there is still a lot of unrealized potential when it comes to utilizing location aware applications indoors, where GPS does not work because of the buildings blocking the GPS signals. Several companies are currently working towards realizing this potential, such as Apple (2.1.1) and Cisco (2.1.3). Countless possibilities arise when Indoor Positioning System (IPS) infrastructures becomes sufficiently widespread, so that it may function seamlessly in combination with people's devices. These include marketing, real estate management, security and entertainment.

The various technologies require different types of infrastructures, and utilizing a system that does not call for extensive upgrades in this infrastructure is attractive for both economical and practical reasons. When such an infrastructure is in place in a facility utilized by a great number of people, the foundation for retrieving substantial amounts of position data is present. Analyzing this information, human mobility patterns emerge, making it possible to research the patterns in which people are moving in the facility in question. Limited amounts of research have been performed with a significant data foundation recorded over time. Determining how this information may be utilized and visualized in the most effective and beneficial way possible is important in order to move forward towards exploiting the full potential of human mobility patterns from indoor positioning systems. For these reasons, the purpose of this study is to identify useful ways to utilize the indoor positioning data collected over time from people moving about at NTNU, and how to visualize the information in a beneficial way for potential stakeholders.

1.3 Project Definition

In this project, a web application is created in order to interpret, analyze and visualize the indoor positioning data collected. The application includes several types of visualizations, making it possible for potential stakeholders to experience different ways to interpret and display the information for multiple scenarios. This includes visualizing movements on campus for a specific date and time range in form of a heatmap, which displays different colours on the map based on the indoor mobility patterns. Also, visualizing the number of people moving among the different buildings on campus in a specified time range, and displaying where devices are first and last positioned in a day in order to locate the entrances and exits being used most and least frequently are also possible. In addition, the application is able to visualize the accuracy of the data recorded on campus, providing an overview of the quality of the wireless infrastructure.

Before the application is created, a literary review is performed in order to identify previous related work. Also, meetings with potential stakeholders is held to determine which types of information visualization may be useful. In the final stages, the application is evaluated by several potential stakeholders, revealing the usefulness of the application as well as potential future work. In the rest of the thesis, the prototype web-application will be referred to by it's name: NTNU Crowd Movement Analysis (NTNU CMA).

1.4 Methodology

When selecting a set of research methods for this project, the two main research questions of the thesis is in focus.

1. Which types of visualizations of indoor position data may be useful in the jobs of potential stakeholders?

2. Which methods can be utilized in order to process and analyze position data to produce mobility patterns useful for potential stakeholders?

These two research questions do of course intertwine in that the visualizations provided for the stakeholders are built on top of the handling of the position data using programming code. The selected research methodology utilized in this project is the Design Science Research (DSR) method. The reason for this selection is that this project aims to research better ways to design an application for visualization of indoor human mobility patterns, in order to gain knowledge which may be used in new applications and research. This fits well with the principal of DSR, which is elaborated in section 1.4.1 below.

1.4.1 Design Science Research

DSR is a a set of synthetic and analytical techniques and perspectives for performing research in Information Systems. It involves design of innovative Artifacts together with an analysis of their use and performance, along with reflection and abstraction in order to improve and understand the behaviour of aspects of Information Systems. Examples of such Artifacts are algorithms, human/-computer interfaces and system design methodologies or languages. DSR separates from Design Research (DR) in that DR is *research into or about* whereas DSR is primarily research using design as a research method or technique [4].

A typical DSR process is performed as illustrated in figure 1.1 and elaborated below:

Awareness of Problem: An awareness of an interesting problem provides the opportunity for application of new findings to the researcher's field, resulting in a Proposal for a new research effort.

Suggestion: Suggestion follows as a creative step wherein new functionality is envisioned based on novel configuration of either existing or new and existing elements, resulting in a Tentative

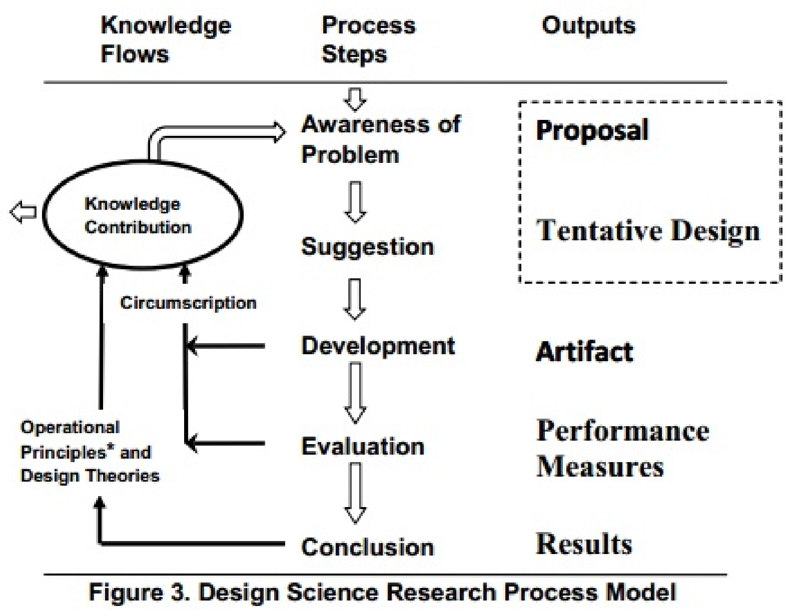

Figure 1.1: Design Science Research Process Model[4]

Design.

Development: The Tentative Design is further developed and implemented, resulting in an Artifact.

Evaluation: The Artifact is evaluated according to the Proposal, and deviations from expectations are noted and explained. The hypothesis rarely corresponds with the results, and the evaluation phase produces additional information, which is fed back to another round of Suggestion, resulting in a research cycle gaining more knowledge for each iteration.

Conclusion: This phase could be the end of a research cycle or is the end of a specific research effort. The result in the end is typically an acceptable result which may not completely correspond with the hypothetical predictions, but are considered ”good enough”.

1.4.2 Implementation of DSR

For each process step in DSR, the related processes for this particular project are elaborated below.

Awareness of Problem: In this project, the problem was to identify optimal methods for analyzing, processing and visualizing indoor human mobility patterns. The awareness of the problem emerged from the increased research efforts related to Indoor Positioning System (IPS)s, being that today's wireless infrastructure together with the propagation of smart phones facilitates for numerous innovation possibilities. The Proposal is therefore the project description itself; to create a web application in order to interpret, analyze and visualize indoor positioning data.

Suggestion: The main functionalities to be implemented in NTNU CMA described in the previous step were decided. Since the focus of the project was limited to a few potential stakeholders, qualitatively focused interviews were performed before development was started. Qualitative research allowed going into the depth of what the potential stakeholders are looking to do with the available data, which in turn provided an adequate foundation to build an application on top of. Also, qualitatively focused meetings with position data professionals provided detailed information useful when dealing with the processing of the position data. The result is a Tentative Design forming the requirements of NTNU CMA.

Development: NTNU CMA, in other words the Artifact, was then developed according to the Tentative Design.

Evaluation: In the end, qualitatively focused evaluations were performed in order to determine whether the results may be useful for the potential stakeholders. A model called the Technology Acceptance Model (TAM) was tailored for the specific use of this project and utilized for evaluating the perceived usefulness of NTNU CMA. Using this model provided a simple, yet informative indication of the perceived usefulness of NTNU CMA for potential stakeholders.

Conclusion: The conclusion of this project is considered as the end of a research cycle, in that the Artifact is a prototype that can be utilized as knowledge contribution to a new research cycle as illustrated in figure 1.1.

1.5 Outline

This thesis begins with a background study of related theory in Chapter 2. Here, existing indoor location-based technologies are presented, as well as some technologies utilized for creating web applications such as the one developed in this project. A detailed description of NTNU CMA with all it's main functionalities created in this project is presented in Chapter 3. Chapter 4 explains the analysis and processing of the available data in order to uncover various mobility patterns. A presentation and discussion of the results from the visualizations in NTNU CMA, together with an evaluation, is provided in Chapter 5. Chapter 6 discusses various business opportunities arising from the utilization of indoor human mobility patterns, as performed in NTNU CMA. Finally, chapter 7 concludes the thesis and presents recommendations for future work with NTNU CMA.

Chapter 2

Background

In the following chapter, technologies directly related to IPS are presented in order to provide background information necessary to understand parts of this thesis. First, two different main IPS-technologies, Bluetooth and Wi-Fi, are presented. Then, the specific IPS utilized for collecting the data being used in NTNU CMA is explained, before an application currently utilizing this IPS is introduced. A section on human mobility patterns follows, before a presentation of data formats, privacy and web-applications is conducted.

2.1 Indoor Positioning Systems

Real Time Locating Systems (RTLS) have grown to become vital in existing location aware systems. The GPS has solved most outdoor RTLS problems[5], but is not operational indoors due to GPS signal obstruction from building masses[6]. According to Dempsey[7], an IPS is

"a system that continuously and in real-time can determine the position of something or someone in physical space such as a hospital, a school a shopping centre, etc."

In order to fulfill this definition, the system would have to somehow locate the target object several times throughout a time interval, making it possible to detect movement.

Several technologies for utilizing IPSs exist, each having their own respective advantages and limitations. The most common technologies are Radio-frequency identification (RFID), Bluetooth, ultrasound, infrared and Wi-Fi.

In NTNU CMA, the Wi-Fi technology has been utilized; mainly because it does not require as much additional hardware from the user as the other technologies are. RFID, Bluetooth, ultrasound and infrared all require additional infrastructure in the facility in question, as well as one hardware unit for each user to be tracked. Since this thesis focuses on Wi-Fi technology, the other technologies previously mentioned are not explained as they have little relevance for the rest of the thesis. However, the iBeacons technology utilizing Bluetooth is presented in section 2.1.1 below because it is one of the major IPSs relevant in the current market.

2.1.1 iBeacon

An example of an IPS utilizing Bluetooth is Apple's iBeacon technology, allowing compatible IOS devices to alert apps when entering or leaving a location with an iBeacon, for example a display or a checkout counter at a retail store. With this technology, only the proximity is detected, there are no coordinates recorded[8]. Apple have integrated the system to work seamlessly with the supported devices, allowing application developers to create apps utilizing the beacons. This may strengthen the technology's position in the market, however it does exclude all unsupported devices.

2.1.2 Wi-Fi

Wireless Local Area Network (WLAN) allows public creation of networks operating between the frequencies of 2.4 and 5 GHz, utilizing the IEEE 801.11 standard[9].

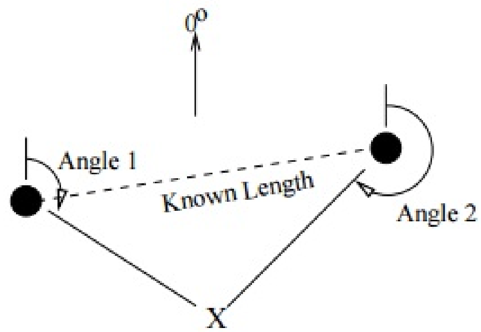

Figure 2.1: Triangulation[10]

WLAN, which often is a network of Wi-Fi ready devices, is widespread throughout larger facilities where IPSs are applicable, such as in university campuses, hospitals, office buildings and shopping malls. The fact that this infrastructure is already in place, makes Wi-Fi an attractive choice when installing an IPS. In order for this method to be sufficiently accurate, the infrastructure should inhabit a large number of access points, making it possible to perform triangulation or trilateration. These are positioning techniques used in combination with WLAN, and they both make use of measurements towards the target device such as the Time of flight (ToF), Angle of arrival (AoA) and signal strength.

Triangulation

Triangulation is performed by using primarily angle or bearing measurements. In order to locate a device in two dimensional space, two angle measurements and one length measurement should suffice. However, locating a device in three dimensions, in other words determining which floor the device is located on, requires one length measurement, one azimuth measurement, and two angle measurements[10]. The triangulation technique is illustrated in figure 2.1.

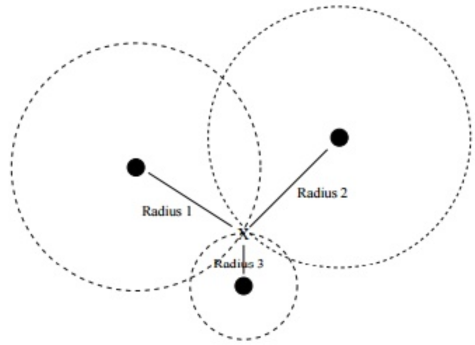

Figure 2.2: Trilateration[10]

Trilateration

Trilateration can be used to calculate the position of an object in two dimensional space using distance measurements from three non-collinear points, and in three dimensions using four non-collinear points[10]. There are three general approaches to measuring the distances from the respective points to the object; Direct, ToF and Attenuation[10]. The trilateration technique is illustrated in figure 2.2

2.1.3 Cisco Mobility Services Engine

Cisco Mobility Services Engine (Cisco MSE) is a wireless infrastructure that is able to calculate time, position and MAC address of devices with Wi-Fi enabled inside the coverage area of the network. This allows systems to analyze the flow of devices within facilities inhabiting a Wi-Fi infrastructure, such as schools, offices, shopping malls and hotels. The data from this analysis has potential value in regards to operational efficiency, marketing, security and retail function[11].NTNU is currently utilizing the Cisco MSEv8[12].

Privacy is an important factor when dealing with position data, and it should be noted that only devices with Wi-Fi enabled can be located. Additionally, the main focus is on utilizing great collections of data to generate general patterns, not performing individual tracking[11].

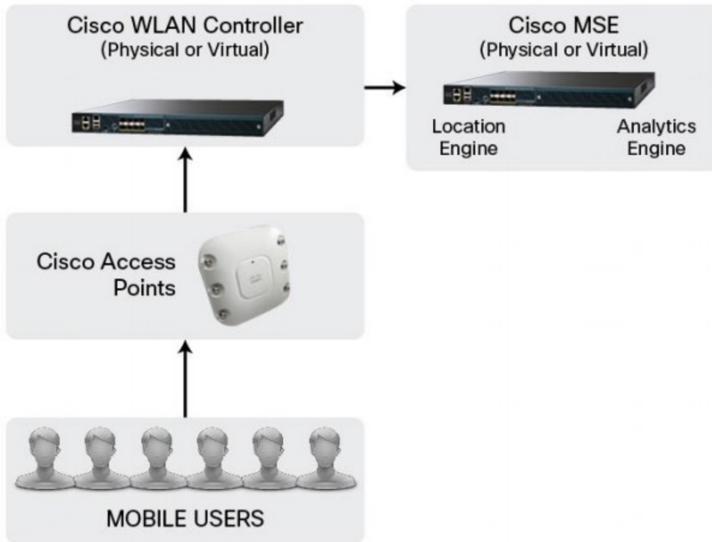

Figure 2.3: Cisco MSE: Flow of position data[11]

The data is captured by listening for probe requests from a Wi-Fi-enabled device. The Cisco access points gather these probe requests along with the device's MAC address and Received Signal Strength Indication (RSSI). These are forwarded to the wireless LAN controller managing the access points, which further forwards the information to the MSE which is calculating the position of the device using trilateration as explained in section 2.1.2. The flow of the information is illustrated in figure 2.3. The time interval between probe requests, and in turn position points, may vary due to device differences. It both depends on the device type, the state of the device as well as the applications running on the device. Smartphones with their screen off may transmit requests once a minute, while phones with their screens turned on have a transition rate of 10-15 times per minute[13]. However, a chronological trail of positions is available, making it possible to track an individual's movements inside the facility. The system automatically considers a trail as finished if there have been no recorded data points within the last hour[11].

The Cisco MSE has an Application Programming Interface (API) making it possible to access the movements of any given unit if the MAC address is known.

2.1.4 MazeMap

MazeMap is an application for both web and mobile platforms, IOS and Android, helping people to find their way in large facilities such as university campuses and hospitals[14]. The application was first created by Wireless Trondheim and NTNU for use on Gløshaugen, the biggest campus on NTNU. Currently, the application is utilized on seven locations in Norway; NTNU Gløshaugen, NTNU Dragvoll, Bergen University College, Norwegian Business School (BI), University of Tromsø, Trondheim University Hospital (St. Olavs), Oslo Airport, and the office building of Evry. A snapshot from the MazeMap application can be found in figure 2.4.

MazeMap have created a product called GeoPos utilized by the MazeMap application. The main functionality of GeoPos is to make sure a unit only can ask for its own position, and works as a layer between the Cisco MSE and the MazeMap application. In other word, all the position data made use of in the application originates from the Cisco MSE. MazeMap have also created an anonymization module on top of the GeoPos utility, hashing the MAC address in order to make it impossible to back-trace the specific unit from the position data. Each device is instead assigned a random ID which changes each day, making it impossible to track a single device over multiple days. This module is approved by The Norwegian Data Protection Authority[12].

The application itself is developed as a Software as a Service (SaaS), using the MazeMap API to help the user finding the way to a specified point in the facility. This way, people can receive real-time wayfinding guidance when navigating towards an unfamiliar location with an accuracy of 5-10 meters[15].

MazeMap have also implemented support for both indoor and outdoor navigation by switching between GPS when outside, and Wi-Fi localization when inside. However, this only works inside the specified area of the location, for example the whole campus area.

A master thesis written by Trond Thingstad and Hoang Thanh Tran at NTNU in 2014[16], per-

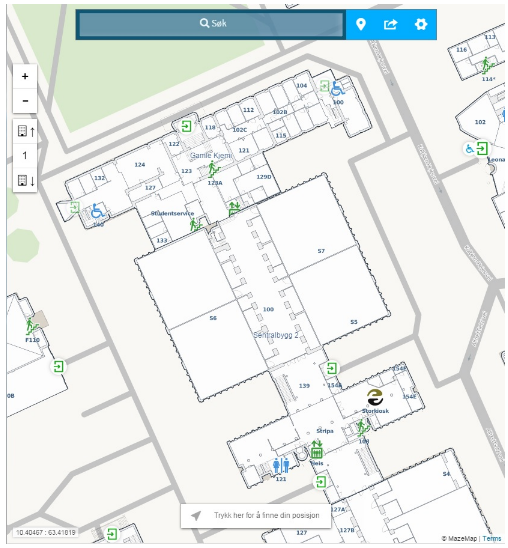

Figure 2.4: The MazeMap application, displaying the first floor of Sentralbygg 2 on NTNU Gløshaugen

formed research on how to utilize live anonymous position data from the Cisco MSE. They created an Android application helping students to locate available reading rooms on NTNU Gløshaugen. MazeMap was also integrated in the application, allowing users to request a route description to a selected reading room. This work resulted in an article in the International Journal of Information and Learning Technology[17].

2.2 Human Mobility Patterns

The study of human mobility patterns has reached new possibilities in the later years when the use of location aware devices has increased rapidly. Studying outdoor mobility patterns has been possible through the GPS and Global System for Mobile Communications (GSM) technologies, but a sufficient data foundation for the study of indoor mobility patterns was long out of reach. With technology like the Cisco MSE (section 2.1.3), obtaining an extensive overview of people's movements indoors is now achievable.

Methods for extracting meaningful mobility patterns from raw position data may be essential for the information to have any real business value. How this can be performed depends on the localization data format. With IPSs using Wi-Fi, a movement trace of a single device may be retrieved by using the method utilized by the Cisco MSE (2.1.3); collecting WLAN probe requests from the device and in turn calculate the time and position of each request, resulting in a consecutive trail of positions representing a movement. Using this method, one can both obtain aggregated mobility patterns, as well as trails of individual movement.

A master thesis written by Santiago Diez Martinez at NTNU in 2013[18] performed research on human mobility patterns from users of the MazeMap application at Gløshaugen, the biggest campus at NTNU. The data foundation for this research was a collection of wayfinding requests performed by users of the application. A wayfinding request is registered when a user requests directions to an indoor campus location, for example a specific lecture hall, resulting in a suggested path from the user's current position to the requested location. Based on a collection of these wayfinding requests from more than 20,000 unique devices[18], analyzing the aggregated start- and finish locations of a suggested path resulted in an overview of the human mobility patterns on campus. However, these data only show the movements suggested by the MazeMap application, there is no guarantee that the user actually made the suggested movements.

2.2.1 Business Value

The information retrieved from the study of human mobility patterns may be valuable in several different use cases. On university campuses, the information may be used to optimize class schedules by minimizing movement on campus between classes, locate potential bottleneck staircases and corridors, as well as coordination between faculties in regards to use of lecture halls and meeting rooms[15]. In hospitals, the research may identify which parts of the facility is most populated during the day, and may require additional maintenance and staff capacity. Also, keeping track of staff and equipment is practicable. In shopping malls, the owners may determine which parts of the facility being the most popular among the customers, providing a foundation for adjusting the store rent accordingly. Tailor made advertising may also be possible by detecting shopping patterns among customers and identify logical connections between stores. Emergency preparedness may also benefit from this information, allowing first responders to obtain an overview of the amount of people located in a facility[15].

2.2.2 Data Accuracy

When dealing with human mobility patterns indoors, systems like the Cisco MSE have a variable accuracy. As we can derive from the Business Value section above, most of the data considered useful is aggregated data with a great number of tracked objects. For that reason, small-scale inaccuracies in the position data have little consequence for the results. However, for some use cases such as individual tracking of people or equipment in for example hospitals, the accuracy is important. Tracking of individials providing a personal service for the user, like the MazeMap application (2.1.4), also require greater accuracy in order to deliver a high-quality service.

Several methods exist for improving accuracy of position data and mobility patterns. One solution is the History Aware Based Indoor Tracking System (HABITS) which is modelling the movement habits of users in a structured environment, and exploit this information when dealing with black-spots or inaccurate mobility patterns. This way, HABITS can calculate the probable correct mobility pattern[19]. A different approach uses a grid, calculating the most frequently crossed grid edges in order to determine the most probable route between two points[20].

2.3 Data Format

In this Thesis, several data formats are being utilized in the different systems for location based applications. This section presents an overview of the most important data formats.

Geographic Latitude and Longitude

When dealing with position data around the globe, presenting positions in terms of a combination of latitude and longitude coordinates is the standard method.

The ”latitude” of a point on the Earth’s surface is the angle between the equatorial plane and the straight line that passes through that point and through (or close to) the centre of the Earth. The ”longitude” of a point on the Earth’s surface is the angle east or west from a reference meridian to another meridian that passes through that point. The combination of these two components specifies the position of any location on the surface of the Earth, without consideration of altitude or depth[21].

This coordinate system is the standard positioning notation of the GPS technology, but can also be calculated and used for IPSs, such as in the Cisco MSE (2.1.3).

JSON

JavaScript Object Notation (JSON) is an open standard format used primarily for data transmission between a server and web application[22]. JSON is supported as both parameter and return format in the Cisco MSE API[23]. The Extensible Markup Language (XML) is also supported, but only JSON will be utilized in this Thesis.

2.4 Privacy

In Norway, the use of location aware services in regards to personal privacy is strictly regulated. When implementing such a system, one must consider the legal aspects related to the service. In order to collect position data from a user, one of the following three requirements must be fulfilled[24].

- The service provider must have voluntarily approval from each user they want to collect position data from. The provider is also required to clearly state for which purposes the data will be used.
- The location based service is necessary in order to fulfill an agreement.
- The service provider has legal rights to obtain and use personal position data.

The GeoPos service explained in the MazeMap section (2.1.4) has evaded these regulations by anonymizing the data, making it possible to obtain approval from the The Norwegian Data Protection Authority. This had to be done because the service does not fulfill the above requirements. It does not explain to the users what the purpose of the information gathering is, it is not a part of an agreement, nor have the service provider any special legal rights to obtain the data.

2.5 Web Applications

With the increasing propagation of access to high-speed Internet connections through different platforms like smart phones, tablets and computers, web applications have increased in popularity. The main benefit of a web application is that the developer does not have to build a client for a specific type of computer or operating system. The client instead runs inside a web browser, which is a standard feature of all types of smart phones, tablets or personal computers. The fact that the user does not have to download and install a particular software client, makes it a mutual beneficial solution for both developers and end users[25].

Web applications normally use programming and markup languages like HTML, CSS and JavaScript on the client side dealing with the presentation, while using PHP or ASP on the server side dealing with the processing and storing of the data[25]. Lately however, the use of JavaScript on the server side through the Node.js framework has increased significantly due to the reasons explained in the Node.js section (2.5.1).

2.5.1 Node.js

Node.js was first announced in 2009 by Ryan Dahl at a JavaScript conference in Berlin. The breakthrough was being able to run JavaScript on the server, not just in the client as developers were used to. This presents a significant benefit for developers, being able to develop both client and server side of an application using the same programming language. Also, it is able to match the performance of existing preferred server technologies like Apache or Nginx, due to the V8 JavaScript interpreter and virtual machine created by Google[26]. This opens up the possibilities for creating more efficient real time web applications.

Even though there are a lot of benefits to using Node.js in a web application, for example for usage with JSON APIs, there are some disadvantages as well. Application servers with heavy Central Processing Unit (CPU) usage and little input-output operations may be better of written in a different programming language[27].

2.5.2 AngularJS

AngularJS is an open-source web application framework maintained by Google. Its main purpose is to provide a client side Model View Controller (MVC) architecture, making it easier to structure a single-page application by separating the different main functionalities resulting in a more maintainable and expandable application. This architecture consists of *views*, the design and forms visible to the user, *controllers* controlling the behaviour of the elements in the *view*, and *services* providing services like server requests. A major benefit from using AngularJS is that it supports two-way data binding, allowing the application to update a value in the *controller* which automatically updates the corresponding value in the *view* without refreshing the whole web page. The framework is written in JavaScript, and is supported by all major browsers[28].

2.5.3 Bootstrap

Bootstrap is a front-end framework including a collection of HTML and CSS based design templates for typography, forms, buttons, navigation and other interface components[29]. The main purpose for utilizing the framework in a web site or web application is to make it responsive, meaning that it automatically adapts its design to the screen it is displayed on. The backbone of this framework is structuring Graphical User Interface (GUI) elements in rows and columns. This property has increased in importance with the substantial increase in use of mobile devices such as smart phones and tablets.

2.5.4 Leaflet

Leaflet is an open-source JavaScript library for interactive maps. It is easy to use, works efficiently across different platforms using modern web technology, and can also be extended with plugins, allowing developers to tailor the map for their specific application[30].

Chapter 3

Application

In this chapter, NTNU CMA is described. First, the requirements for the application is presented. Then, the technology utilized in the application is described, before the design choices are elaborated. Each main functionality in the application are also explained in their own respective sections, before the performance and usability is discussed. NTNU CMA and instructions on how to use it is added to this thesis as a digital appendix, but is not a part of this document.

3.1 Requirements

Before initiating the process of creating NTNU CMA, a representative from NTNU Studieavdelingen was interviewed in order to identify which types of information and visualizations that might be useful in their jobs, as well as other possible use cases related to facility management. As the representative provided knowledge and ideas not only on behalf of himself and his own department, he also had insights in what other stakeholders might be interested in. Therefore, the interview resulted in a rough list of requirements that could work as a starting point for creating NTNU CMA. Towards the end of the application development, a new interview with the same representative was conducted. The main points of feedback on what the information provided by NTNU CMA can be utilized for are categorized by domain below.

Facility Architecture

- Identify flaws and possibilities in facility design.

Business

- Regulate prices for areas within facilities, such as in shopping malls.

Research

- Research how to handle data insecurity in the IPS.

- Research how to optimally visualize the information provided by the IPS.

Security

- Determine if the existing emergency exits are sufficient.

- Determine if the fire security regulations are sufficient.

Traffic

- Minimize traffic related to the class schedule.

- Decide if the doors are big enough and identify bottlenecks.

From these points of interest, a list of functional requirements for the project is created with the goal of covering the most critical functionalities. Functional requirements describe what the system should do, while non-functional requirements define how the system is supposed to be, such as the performance and response time of the system. Only functional requirements are considered in this project, due to NTNU CMA just being a prototype where the performance and architecture of the system is not vital.

Functional requirements

1. The system should visualize movements on campus within a specified date and time interval.
2. The system should visualize movements between the specific buildings on campus within a specified date and time interval.
3. The system should visualize the accuracy of the registered position data within a specified date and time interval.
4. The system should visualize the exits and entrances being utilized most and least frequently within a specified date and time interval.

3.2 Application Technology

NTNU CMA is created using Node.js (2.5.1) on the server side, and Angular.js (2.5.2) together with Bootstrap (2.5.3) on the client side. Also, a few plugins are utilized in order to make use of the Leaflet (2.5.4) map together with Angular.js. The overall architecture of the application is illustrated in figure 3.1.

Node.js is selected for it's ease of use together with a web-based client, in that JavaScript can be utilized on both the server side and client side. As stated in the Node.js section (2.5.1), the

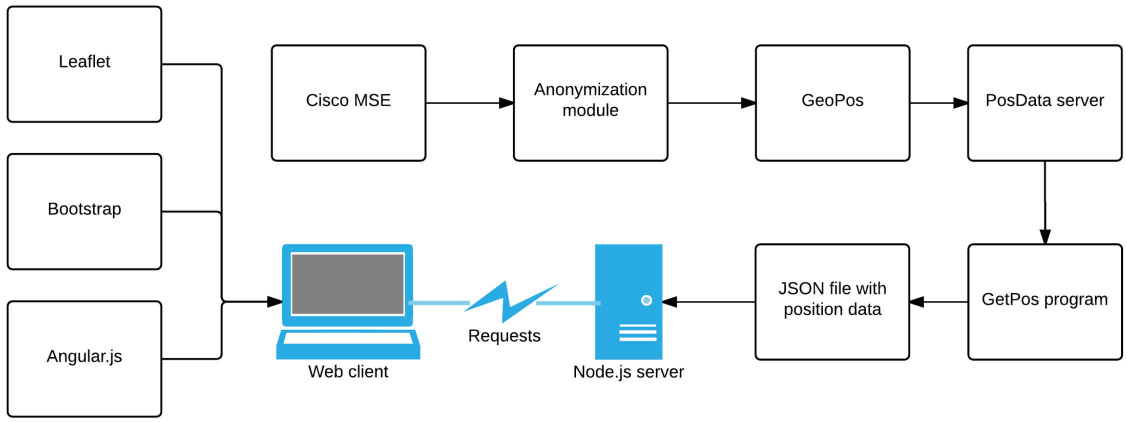

Figure 3.1: The overall architecture of NTNU CMA. The application is running in the client browser, performing requests towards the Node.js server, which in turn reads data from the JSON file containing positioning data retrieved from the PosData server through the GetPos program. This server contains eight weeks of data sent from GeoPos, which gets the data from Cisco MSE through the anonymization module.

framework is not optimal for CPU heavy operations, but since NTNU CMA is targeted as a prototype, small datasets with limited processing are considered sufficient.

Angular.js is chosen because the framework is designed for creating web applications with highly structured code by using an MVC design as explained in the Angular.js section (2.5.2). Also, collecting and processing data from user forms, as well as updating NTNU CMA when new information is available without reloading the entire web page, is beneficial for this type of application. This way, a user can submit a request through a *view*, a *controller* can transmit the request to a *service*, which in turn transmit a request to the server. When a response is available, the *service* returns the data to the *controller*, which automatically updates the information in the *view*. NTNU CMA has several functionalities, and Angular.js supports the use of *states*, making it easy to separate the code in the *views* by using tabs, and by using separate *controllers* and *services*.

Bootstrap is a framework utilized for structuring the GUI of a web application, as explained in section (2.5.3). When using Bootstrap, the web page or web application automatically adapts to different screen sizes. In this project, the framework is utilized mainly for the great looking GUI elements such as buttons and input forms, resulting in the design of NTNU CMA looking more usable for potential stakeholders. Additionally, in case of further development of NTNU CMA, the framework makes it easier to insert new design elements without compromising the existing layout.

Leaflet (2.5.4) is utilized for displaying the indoor map of the NTNU campus Gløshaugen. In order to display the indoor map, a new layer containing the campus has to be applied to the map before adding the specific building layers. The code performing these tasks can be viewed below.

```
leafletData.getMap().then(function(map) {
    // Loading campus layer
    var campusLayer = require('MazeMap/Campus/L.WMS.CampusLayer')(1).addTo(map);
    // Adding a building layer group to the map
    var _buildingsLayerGroup = L.featureGroup().addTo(map);
    // Getting buildings
    var Building = require('MazeMap/Building/Building');
    // When all buildings have been loaded, add each building to the map
    $.when( require('MazeMap/Rest').getAllBuildingsInfo(1) ).done( function(buildings){
        $.each(buildings, function(idx, val) {
            var building = new Building(val, {layer: _buildingsLayerGroup, campusid: 1, noClosing: true, floorSelector: false } );
            building.open();
            buildingsDict[ building.model.getId() ] = building;
        });
    });
});
```

Leaflet.heat is a lightweight plugin utilized for generating heatmaps on top of Leaflet maps[31].

Heatmaps are generated by feeding the plugin a list of positions, which the plugin uses in order to paint different colors on the map based on the density of the provided positions. The result allows one to see where the density of the positions are highest and lowest, which is very useful when analyzing which parts of campus having the most and least human traffic.

Leaflet PolylineDecorator is a Leaflet plugin allowing one to draw patterns along coordinate paths[32]. This is useful in NTNU CMA when visualizing movement between positions on campus, for example between two buildings.

3.3 Application Design

Even though usability is not a main focus in this project, and is therefore not weighted in the evaluation in section 5.3, it is attempted to make the GUI structured and organized in a natural matter, enabling users to adopt the application quickly without extensive training. With that in mind, the NTNU CMA interface is divided into five main pages or ”tabs”. One front page containing general information and four tabs, each representing one distinct functionality of the application. An screenshot from the full window of NTNU CMA may be viewed in figure 3.2. Each of these functionalities are addressing one main requirement from the list in section 3.1. All four tabs utilize the same design and setup of GUI elements; the input forms on the left side of the screen, and the map on the right side. If one learns how to use one functionality, in practice one has learned them all, resulting in a reduced learning period.

Using Bootstrap allows one to create a modern design which can adapt to changes in screen size, also on mobile devices. However, NTNU CMA is not targeted for mobile devices, and is not optimally customized for such use because of the non-resizable map. It could be possible to implement a responsive map as well, but is of little to no importance in this particular project.

When performing a visualization in the Buildings tab, the resulting tables displaying the move-

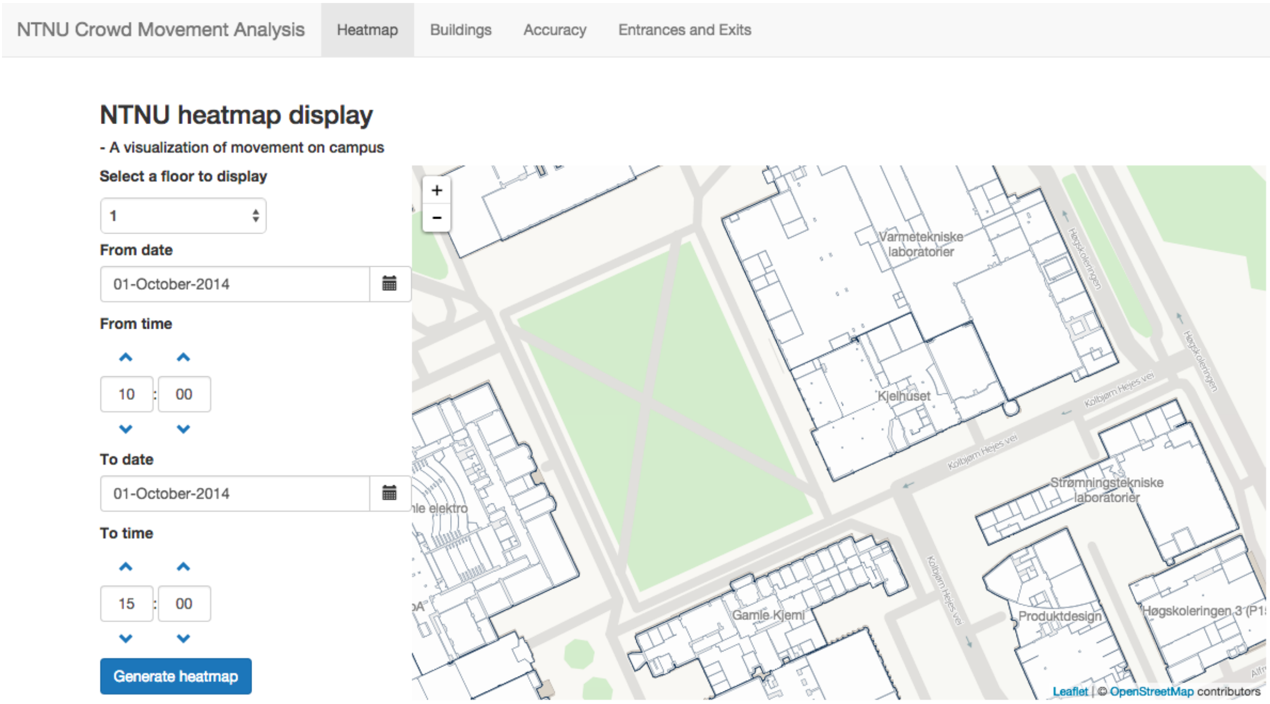

Figure 3.2: The full window of NTNU CMA. In this screenshot, the Heatmap tab is selected.

ments between buildings are too big for the screen, and especially the matrix presenting all building movement combinations is difficult to read. Therefore, each table has an "Export to Excel" function, allowing the user to download the tables as spreadsheets.

3.4 Application Functionality

Each of the main functionalities corresponding to the four main functional requirements listed in section 3.1 are described in this section. The subsection titles are marked with the corresponding requirement number.

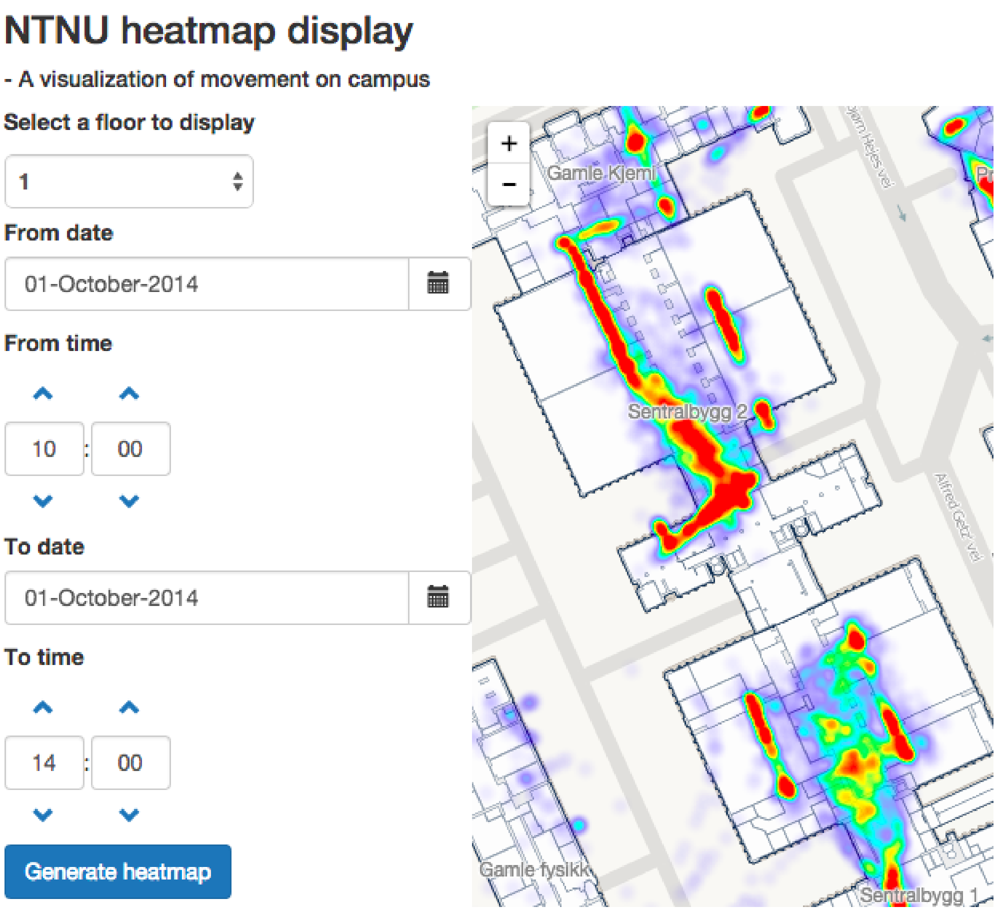

Figure 3.3: An excerpt from the Heatmap tab, displaying a heatmap of all movements from 10:00 to 14:00 the 1st of October, 2014.

3.4.1 Requirement 1 - Heatmap

In the Heatmap tab, NTNU CMA allows the user to generate a heatmap of all the movements on campus in the specified time frame. The time frame is decided by the user through a form where ”From date”, ”From time”, ”To date” and ”To time” is selected. The user then post a request by pushing the ”Generate heatmap” button. A loading spinner is displayed until the heatmap has been generated and displayed on the map as shown in figure 3.3. The user can select which floor to display in the menu through a drop-down menu. When selecting a new floor, the specified floor of the buildings are shown, and the heatmap is repainted based on the current floor’s movements.

3.4.2 Requirement 2 - Buildings

The Buildings tab holds the functionality allowing users to visualize movement between buildings on campus. Like in the Heatmap tab, the user may select the starting and ending dates and times. Also, the user may choose to generate a visualization based on ”All movement”, taking into account all traces entering new buildings as explained in section (4.4.2), or ”Start/stop”, only taking into account movement with final destinations as elaborated in section (4.4.2). When the request has been handled, the movements between the buildings are visualized on the map in addition to three tables with detailed information:

1. A table showing the top ten movements among buildings (figure 3.7).
2. A table showing all buildings in alphabetical order with the count of movements from and to the respective buildings (figure 3.8).
3. A matrix showing the number of movements between all buildings (figure 3.9).

On the map, each building has its own circle of a size relative to the total number of movements from and to the respective buildings. In other words, a big circle indicates that there is a lot of movement from and to that particular building compared to the other buildings. By hovering the mouse on top of a circle, the number of movements from and to the building is displayed. An illustration may be viewed in figure 3.4.

Above the map are two toggle buttons and one drop-down menu. The drop-down menu decides the X number of lines between buildings the user wishes to visualize on the map when clicking a circle, while the toggle menu will decide whether to display paths from, paths to, or both paths from and to the building. Which buildings the lines are drawn between is decided by the top X movements between the clicked building and the other buildings. The size of the arrows on top of each line is relative to the number of movements, resulting in lines with a great number of

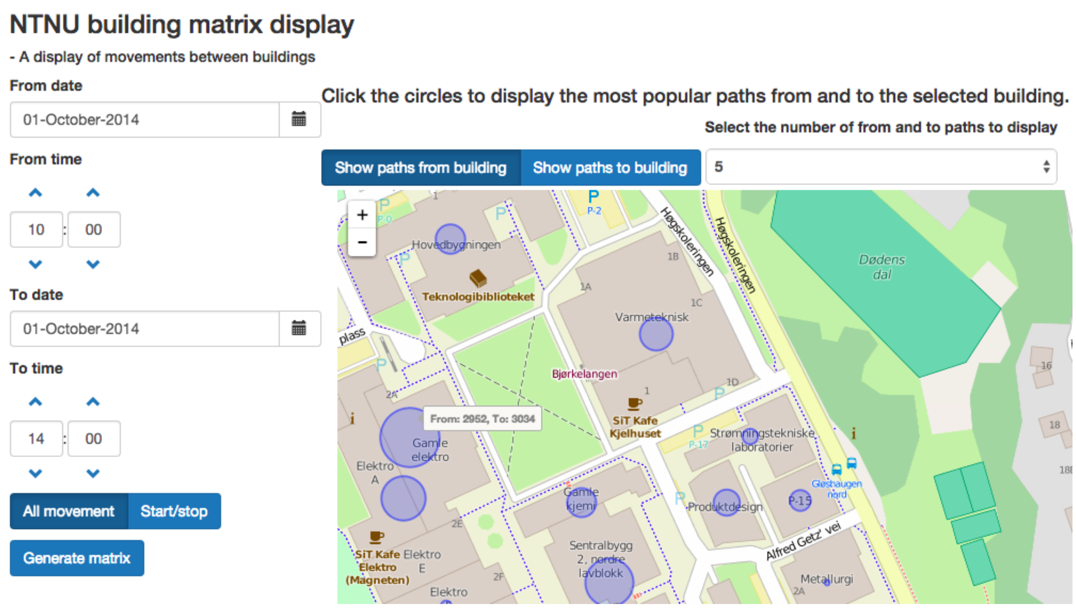

Figure 3.4: An excerpt from the Heatmap tab, displaying movements between 10:00 and 14:00 the 1st of October, 2014.

movement being assigned bigger arrows. Also, when hovering the mouse over a line, the number of movements between those two buildings is displayed as presented in figure 3.5 and figure 3.6.

In other words, the circles over each building with different sizes are a visualization of the data in table 2 (figure 3.8), while the lines being visualizations of the data in table 3 (figure 3.9).

3.4.3 Requirement 3 - Accuracy

This tab is not created for movement visualization, but rather an analysis of the accuracy of the data retrieved throughout the entire campus. The input form is identical to the form in the Heatmap tab, except for three colour boxes displayed over the map. A red box labelled "Accuracy below 50% of average", a blue box labelled "Accuracy between 50% and 150% of average" and a green box labelled "Accuracy over 150% of average".

When the user request is processed, all position data inside the selected time frame is displayed on the map in form of coloured dots as presented in figure 3.10. Registered positions with an

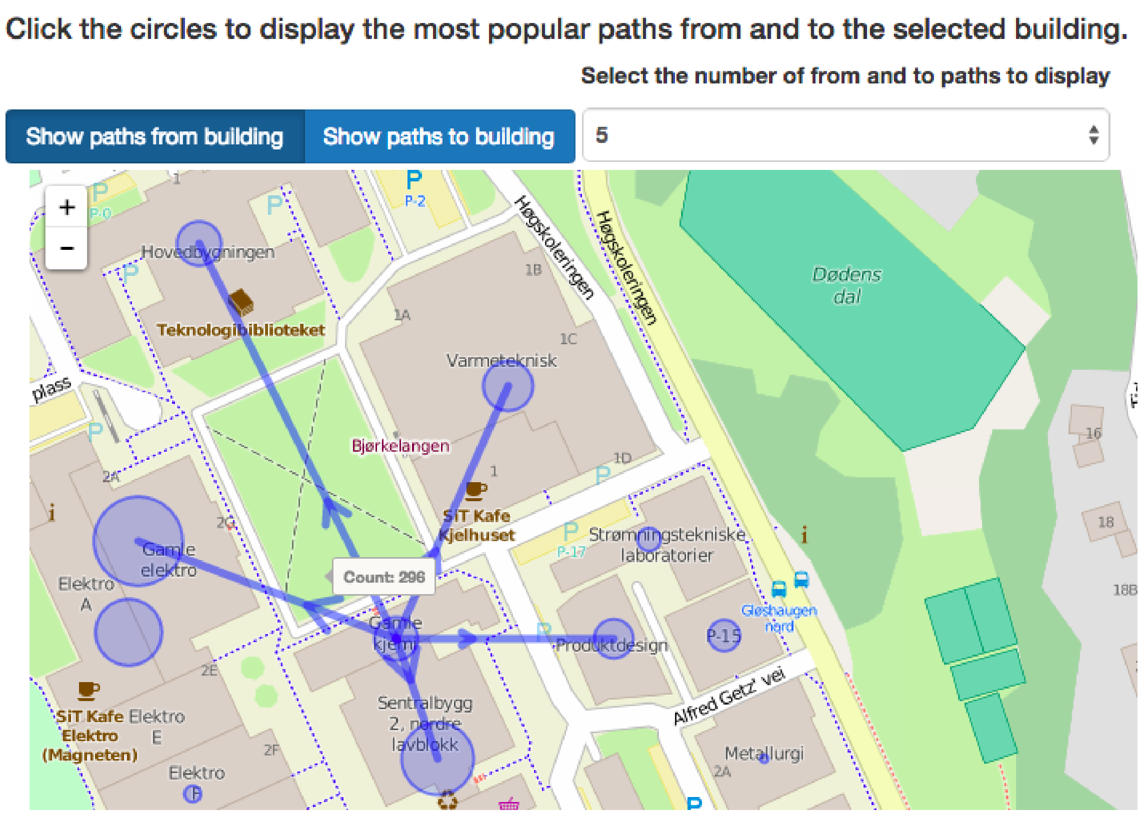

Figure 3.5: An excerpt from the Buildings tab, displaying movements between buildings from 10:00 to 14:00 the 1st of October, 2014. The map shows the top five combinations of movements from the building "Gamle Kjemi". The mouse is hovered on the line towards "Hovedbygningen", showing the count of 296 movements.

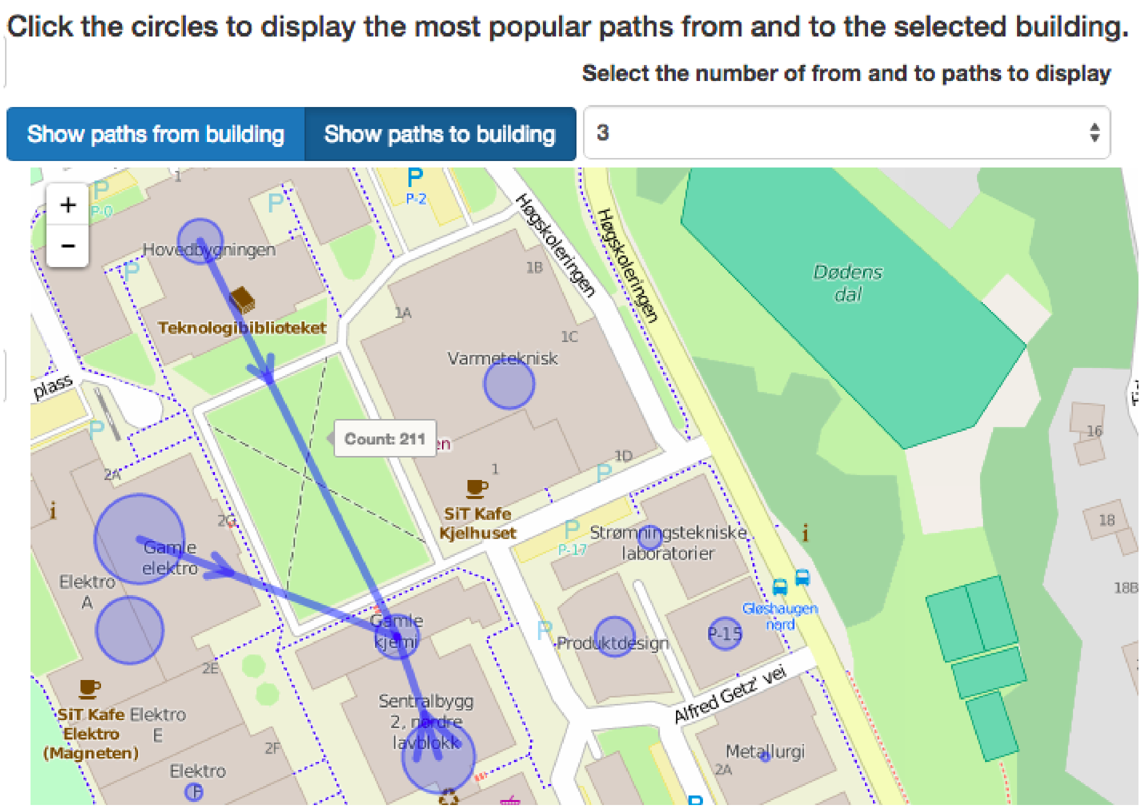

Figure 3.6: An excerpt from the Buildings tab, displaying movements between buildings from 10:00 to 14:00 the 1st of October, 2014. The map shows the top three combinations of movements to the building ”Gamle Kjemi”. The mouse is hovered on the line from ”Hovedbygningen”, showing the count of 211 movements.

Export list to Excel

Shows the top ten movements among buildings.

From	To	Count
Elektroblokk A	Gamle Elektro	1308
Gamle Elektro	Elektroblokk A	1245
Byggteknisk	Realfagbygget	1107
Sentralbygg II	Sentralbygg I	1083
Sentralbygg I	Sentralbygg II	1031
Realfagbygget	Byggteknisk	1003
Realfagbygget	Kjemi 3	800
Materialteknisk	Driftssentralen	742
Kjemi 3	Realfagbygget	660
Driftssentralen	Materialteknisk	633

Figure 3.7: A table from the Buildings tab, displaying the top ten movements between buildings from 10:00 to 14:00 the 1st of October, 2014.

Export count table to Excel

Summary of movements started and ended at each building.

Building	From count	To count
Berg	1084	1140
Byggteknisk	1201	1357
Driftssentralen	1686	1350
Elektroblokk A	2203	2276
Elektroblokk B	663	679
Elektroblokk C	215	235
Elektroblokk D+B2	554	476
Elektroblokk E	553	563
Gamle Elektro	2952	3034

Figure 3.8: An excerpt of a table from the Buildings tab, displaying the number of movements from and to all buildings from 10:00 to 14:00 the 1st of October, 2014.

Export table to Excel

Shows all movement counts from and to each building. Y-axis is start and X-axis is end.

0	Berg	Byggteknisk	Driftssentralen	Elektroblokk A	Elektroblokk B
Berg	0	6	6	2	0
Byggteknisk	5	0	82	0	0
Driftssentralen	11	91	0	3	1
Elektroblokk A	2	0	3	0	172
Elektroblokk B	2	1	0	188	0

Figure 3.9: An excerpt of a table from the Buildings tab, displaying the number of movements between all buildings from 10:00 to 14:00 the 1st of October, 2014.

accuracy below average are visualized as red dots, positions with average accuracy are given blue dots, and green dots denote high accuracy positions. Together, these dots form a heatmap with only the three colours, indicating where on campus positions with low, average or high accuracy are registered. The user is able to select between floors by using the floor drop-down menu, repainting the dots to match positions registered in the corresponding floor.

3.4.4 Requirement 4 - Entrances and Exits

The layout of this tab is similar to the accuracy tab, with the only difference being that only two boxes with colours are displayed over the map. A red one labelled ”Exits”, and a green one labelled ”Entrances”. Upon request, the map displays a heatmap of red and green dots, where red dots indicate the last registered position in a building inside the selected time frame, while the green dots indicate the first registered position in a building within the same time frame, as elaborated in section (4.4.4) and illustrated in figure 3.11. Also in this case, the floor may be changed by using the drop-down menu, resulting in the entrance and exit points being repainted corresponding to the floor. This functionality aims to visualize which entrances and exits are being most and least frequently used.

Figure 3.10: An excerpt from the Accuracy tab, displaying the accuracy of all registered positions from 10:00 to 14:00 the 1st of October, 2014.

3.5 Performance and Usability

As explained in section (4.5), the performance of NTNU CMA is too low for production standards. For a prototype only aimed at presenting some possibilities using the available data however, it would seem acceptable as stated from potential stakeholders interviewed in section 5.3. The usability of NTNU CMA is of course also affected by the performance, but the design itself is easy to understand according to the same potential stakeholders (5.3).

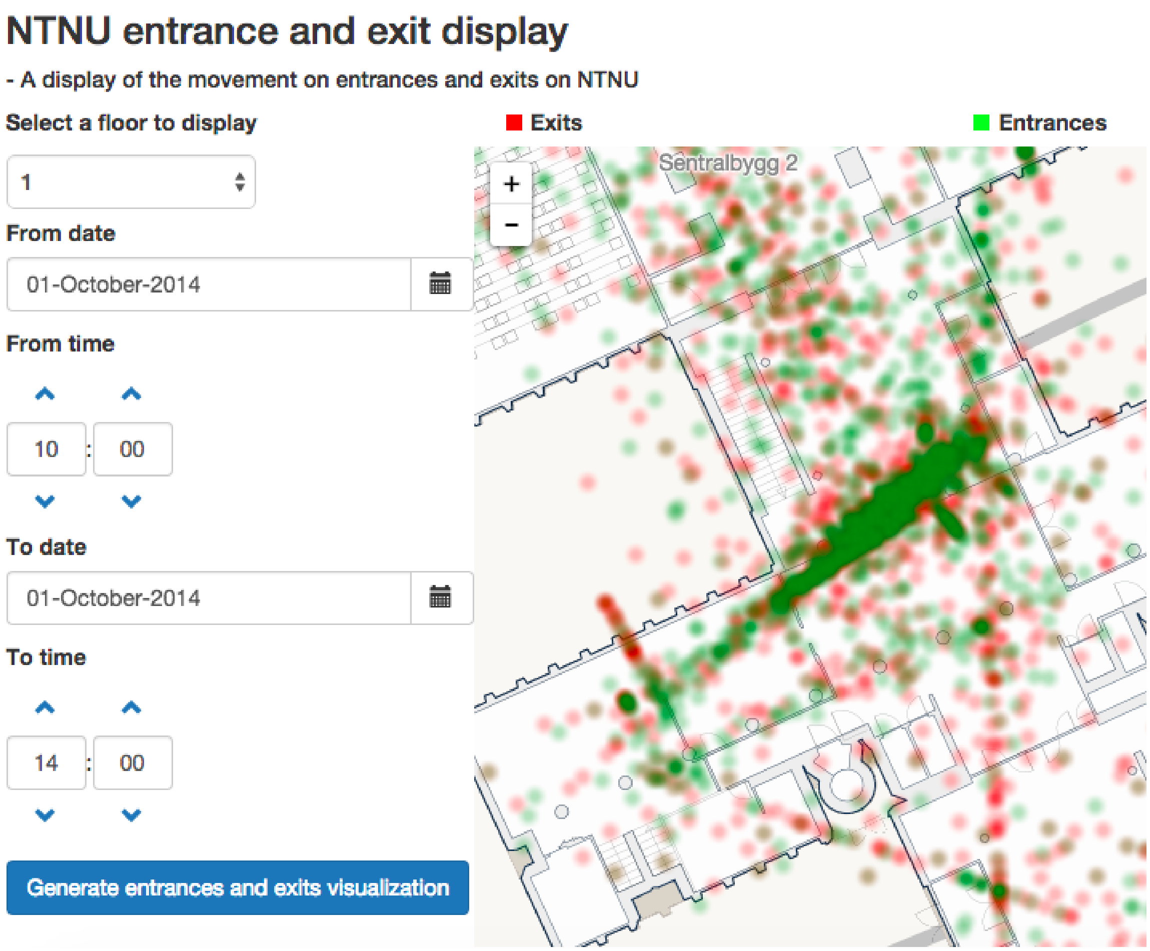

Figure 3.11: An excerpt from the Entrances and Exits tab, displaying the entrance and exit points on the map.

Chapter 4

Datasets and Processing

In order to retrieve, process and analyze the gathered position data in NTNU CMA, several operations must be performed to convert the data into a useful format. This chapter explains in detail how the position data is collected before describing how the data is read and processed. Lastly, the different ways in which the data is analyzed for different purposes in NTNU CMA is elaborated.

4.1 NTNU PosData Server

NTNU has utilized the Cisco MSE in their WLAN infrastructure. Having more than 18,000 WLAN access points spread over 350,000 square meters with more than 60 buildings and 13,000 rooms[15], there exist a profound foundation for extensive position data analysis in this particular location.

From September 2nd 2014 to November 2nd 2014, all positioning data from the GeoPos server described in the MazeMap section (2.1.4) was collected and stored on a server located at the Department of Computer and Information Science (IDI) called PosData. These eight weeks of position data were stored in JSON (2.3) format like presented in the example below showing two unique positions.


```
{
    "hierarchy": "Gloshaugen>Byggteknisk>2. etasje",
    "timestamp": 1412121602,
    "longitude": 63.414807488500585,
    "salt_timestamp": 1412121602,
    "latitude": 10.406423365692884,
    "id": "331",
    "accuracy": 12.19199998146816
},
{
    "hierarchy": "Gloshaugen>Sentralbygg II>9. etasje",
    "timestamp": 1412121606,
    "longitude": 63.417629199819125,
    "salt_timestamp": 1412121602,
    "latitude": 10.404063596263212,
    "id": "334",
    "accuracy": 21.945599966642686
}
```


Explanation of fields

- hierarchy: The campus name, building name and floor of the position.
- timestamp: The time of the position in UNIX unix datetime format[33].
- longitude: This is in fact the *latitude* of the position, due to an error on the PosData server where the latitude and longitude coordinates are switched.
- latitude: This is in fact the *longitude* of the position, due to an error on the PosData server where the latitude and longitude coordinates are switched.
- salt_timestamp: The time when the last generation of the salt value was performed. This value

is hashed together with the MAC addresses of the devices in order to generate anonymous device IDs. Within the same salt_timestamp, one can be confident that two position objects with different IDs originate from different devices.

- id: The ID of the specified device being tracked within one day. Locating all the position objects with the same ID within one day in chronological order, results in a movement trace of the specific device.

- accuracy: The uncertainty of the accuracy of the position measured in centimeters. Higher values equals low accuracy, while smaller values equals high accuracy.

4.2 GetPos Program

The data from the PosData server is accessible through a Python program called GetPos. This program requires a key in order for the user to gain access to the server, which is only given to a minimum amount of people working with the data, making it sufficiently secure. The program works by entering a command specifying the "from" timestamp and "to" timestamp in Unix Timestamp format[33], as well as a chosen output file name. The program then downloads the data between the timestamps and saves it in JSON format with the chosen file name. Below is an example of a command running the program, requesting the data from October 1st 2014 at 00:00 to October 2nd 2014 at 00:00, and saving the data in a file named 'results.json'. The command is run from the terminal while the currently selected folder contains the getpos.py program. Python 2 and Python 2 Setuptools are required in order to run the program. Several minutes of waiting should be expected.

```
Usage: python getpos.py [-h] [--from timestamp] [--to timestamp] [--output file]
Example: python getpos.py --from 1412121600 --to 1412208000 --output results.json
```

4.3 Reading the Data

When reading the JSON file containing the position data, the file is located in NTNU CMAs project folder. When the user requests a visualization from the application, a POST request is made from the client side of the application to the server side utilizing Node.js (2.5.1). Subsequently, a stream is created using the Node.js File System API[34], specifically the function *createReadStream*. This streams chunks of data from the JSON file, allowing the program to process the data continuously while it is being read. This way, data may be processed before the whole file is read, which is a necessity when handling server side processing in the browser. Reading the whole file before starting processing would eventually lead to the memory filling up, resulting in the program crashing.

As chunks of data from the JSON file is continuously being read, the chunks are analyzed in order to separate the distinct data objects described in section 4.1, enabling the program to process one object at a time. This operation is performed by locating start ({) and end (})-braces indicating the beginning and end of the objects. When a start brace is located, all the following text until reaching an end brace is considered a single object, and is then forwarded to a new function for processing. This operation is repeated until the end of the file, and thus the last object, has been reached. The results of the processing explained in the section below are then returned to the client.

This process of reading the JSON file every time a request is made in NTNU CMA, is resulting in the program spending a long time to process the information. Reading and processing one entire day of data may take one minute, which is suboptimal when it comes to providing a satisfactory user experience. However, being that the JSON file is the only way of retrieving the data for now, the performance of the application is not the main priority of this project. Reading the file can perhaps be done faster by using a different server technology than Node.js, in that CPU heavy operations may not be one of the framework's strengths. A more optimal solution could be a RESTful API[35] server utilizing a structured database holding the position data, allowing an application to query the information directly from the server without using JSON files. Such an application architecture is proposed in section 7.2.

4.4 Processing the Data

As NTNU CMA holds several different main functionalities, each one is processed in it's own way. In this section, the processing behind all the functionalities are explained, both how the processing is performed as well as the reasoning behind the selected methods. Common for each functionality is that they are all based on processing the position objects explained in the previous section.

4.4.1 Heatmap

When a heatmap of the movements on campus within a specified time frame is requested, the objects are processed by checking if the timestamp is within the time frame specified in NTNU CMA. If so, the building name and the floor number are extracted by processing the hierarchy string. For easier extraction of these data, it may have been a better solution to use building numbers instead of building names in a string, because the names provided from the PosData server does not always correspond to the building names provided by MazeMap. Also, it could have been more effective to have an own floor field in the position object, because having to analyze a string for retrieving the floor number and building name is unnecessarily time consuming.

When displaying the heatmap, only devices in movement are visualized. Therefore, after the building name and floor number have been acquired, NTNU CMA checks whether a previous position for the specific trace exist. A two-dimensional array *latlngMap[ID][list-of-positions]* is holding all the traces of all device IDs, so that *latlngMap[24]* will hold the list of positions in movement, here called the trace, provided by the device having the ID 24. When checking a previous position for the ID 24, the previously recorded position for the ID

```
(latlngMap[24][latlngMap[24].length-1])
```

is extracted and compared to the position of the object currently being processed. The distance between these two positions are then calculated, and if the distance proves to be greater than a selected constant of 10 meters, the device is considered as *in movement* and is added to both the *latlngMap*, as well as another two dimensional array *latLngList*, holding the list of all positions from all devices being in movement at the index of the floor. In other words, the *latlngMap* is used for keeping track of the different device IDs in order to find a previous position for a specific device's trace, while the *latLngList* is the list of floors, each floor having a list of positions in movement that is later returned to the client in order to display the heatmap.

To deal with negative floors, the *latLngList* has an offset for floor indexes. In this case, the offset is 5 due to the lowest floor on campus being -5. Thus, the list of positions from floor -5 is found at index 0 in the *latLngList*, and floor 1 is found at index 5. This is accounted for on the client side of NTNU CMA. Supporting more dynamic applications, the floor offset would have to be dynamically determined from the processing of the position objects, and returned to the client side taking the given value into account when displaying floors.

The method used for determining if a device is in movement by checking if the last position of a device is more than 10 meters from the previous one, has both strengths and weaknesses. The strengths are that it is simple to calculate, and when dealing with such large amounts of data as in NTNU CMA, the main goal of this particular visualization is to provide a "bigger picture" overview, rather than provide detailed and highly accurate information. The weaknesses are that the interval of each consecutive position for a specific device varies greatly based on the interval of the Wi-Fi probe requests transmitted by the device, as described in section (2.1.3). Setting a static variable like 10 meters may suggest that a device has moved more than 10 meters in 10 seconds, or more than 10 meters in one minute. Possible solutions could be to compare the timestamps of the positions as well, and thus determine the time interval between the probe requests. As with the dynamic floor functionality, this is not considered vital for NTNU CMA, hence it is not implemented.

4.4.2 Buildings

When the user of NTNU CMA requests a display of movements between buildings during a specific time frame, two main choices are available. Either all movement between buildings can be displayed, including traces that do not stop at a specific building, or only complete start and stop movements can be shown, only taking into account those having a defined start and stop of the movement. In the following sections, the two scenarios are explained in detail.

All Movement

In short, selecting all movement means that a movement from building A to building B are registered if a position object in a trace is at building A, and later in the same trace at building B. In detail, this is performed by checking if the objects are within the given time frame. If they are, the whole object is added to the two-dimensional array *latlngMap* where the ID of the devices work as indexes, and each device's objects are in the array at the ID-index, just like in the heatmap example (4.4.1). When all the objects have been read and put into *latlngMap*, each array, in other words each trace at the ID-indexes is iterated. For each position object in the trace, building names and floor numbers are retrieved. The first building of each trace are set as the current building A, until a position object with a different building name B is reached. When this happens, a movement between building A and B is registered in a building matrix. Building B is then set as the current building, and the iteration continues until a new building C is found and a movement between building B and C is registered. This continues until all the traces in the *latlngMap* have been iterated, and the building matrix *fromToMatrix* is finally returned to the client.

The building matrix where the movements are registered is structured as a two-dimensional array, having all buildings listed in alphabetical order on both the X- and Y-axis. When a movement is registered between building A and B, the indexes of both buildings, A-index on the Y-axis and B-index on the X-axis, are found. Then, the number located at the intersection of the indexes (*fromToMatrix[A-index][B-index]*) in the matrix is incremented by one. An excerpt from the building matrix can be viewed in figure 4.1.

The "All Movement" approach has a few limitations, including the fact that a device in reality does not have to enter a building in order to be registered as a movement. If the owner of the device walks outside the walls of the building, the device may be detected by the WLAN access point inside the building, assigning the registered position to that building. Also, there is no guarantee that the destination building of a registered movement is in fact the final destination of the user holding the device. It may just be on the path to a different building, which is the real final destination. An approach towards meeting this challenge is explained in the next section.

An additional limitation of this approach is the fact that each device is granted a new ID each day as explained in section 2.1.4, meaning that analyzing data stretching over multiple days may result in various devices having the same ID. In other words, creating a trace in the *latlngMap* using IDs as indexes, may include more devices in the same trace. A solution addressing this problem is to create a new *latlngMap* when a new salt_timestamp appears in a trace, having one matrix of traces for each date. As explained in section 4.1, within the same salt_timestamp, one can be confident that two position objects with different IDs originate from different devices. However, implementing this feature has not been of crucial importance in this project, being that the primary focus lies in obtaining results from one day at a time.

Start and Stop

The "Start/Stop" functionality which can be selected in NTNU CMA instead of the "All Movement" option is attempting to identify movements, having defined start and stop movements. This way, the goal is to only register movements towards buildings being the final destination of the user holding a device, not just being passed by on the way to some other building.

Also in this approach, NTNU CMA checks whether the position objects are within the spevified

0	Berg	Byggteknisk	Driftssentralen	Elektroblokk A	Elektroblokk B
Berg	0	6	6	2	0
Byggteknisk	5	0	82	0	0
Driftssentralen	11	91	0	3	1
Elektroblokk A	2	0	3	0	172
Elektroblokk B	2	1	0	188	0
Elektroblokk C	0	0	0	14	103
Elektroblokk D+B2	1	5	4	30	84
Elektroblokk E	0	0	1	415	5

Figure 4.1: An excerpt from the building matrix. 91 movements are registered from Driftssentralen to Byggteknisk, while 415 movements are registered from Elektroblokk E to Elektroblokk A in this time period. Movements internally in buildings have not been counted.

time frame, and the whole objects are added to the two-dimensional array *latlngMap* with device IDs as indexes. After reading all the position objects, each IDs trace in *latlngMap* is iterated. The key in this process is that for each position object, the distances between the last three positions are measured. If the distances between all three positions are greater than 10 meters, a movement start is registered and the building name A is saved. The iteration of the trace continues, and when the distances between three positions in a row are all smaller than 10 meters, a movement is considered stopped and is registered as a movement between building A and the current building by incrementing the *fromToMatrix* as explained in the previous section. When all traces have been examined for starts and stops, *fromToMatrix* is returned to the client.

Even though this solution avoids the problem of bypassing buildings being registered as movements, several issues emerge when utilizing this feature in NTNU CMA. Firstly, this pattern of movement may not be representative of the actual movements of a person. This method presupposes that people moving from one building to another does so in one consistent movement with a clearly defined start and stop, which is rarely the actual case. Secondly, because of the inconsistency of probe requests described in section (2.1.3), registering a start or stop based on three consecutive position objects is unreliable. Taking the timestamps of the position objects into account may solve parts of the problem, but being that this will lead to even fewer registered movements, the effects would probably be minimal.

A different possible approach using the time spent in a building could be to register a start of movement when the device's position objects have been in the same building for a given amount of time, and then enters a new building, also spending a given amount of time there and being registered as a movement stop between the buildings.

4.4.3 Accuracy

This particular functionality is created in order to obtain an overview of the overall accuracy of registered position objects on campus, providing an indication of which buildings may be in need of upgrading the WLAN infrastructure.

This data is collected by processing each position object within the specified time frame, retrieving the building name and floor number, and adding all positions along with the building name and accuracy field in a two-dimensional array called *accuracyList*. Each position is added in the array at the index of the corresponding floor, incremented by 5 as described in section (4.4.1). In other words, each index of the array indicates the floor number + 5, and each floor holds a list of objects with position, building name and accuracy. As the objects are added, the sum and number of accuracy values are being calculated, resulting in an average accuracy value. This value is returned to the client along with the *accuracyList*. All positions have been taken into account here, not just movement. This is because the main goal is not to analyze movement, but to provide an overview of the infrastructure's accuracy on different locations around campus. By providing the average accuracy value, the client may decide for each position if the accuracy is worse than, equal to or better than the average accuracy.

4.4.4 Entrances and Exits

In order to locate which entrances and exits are being used most frequently by people at campus, this functionality visualizing the first and last coordinates recorded for a building is implemented. Each position object within the specified time frame is added to the *latlngMap* array for each IDs index the same way as for the buildings processing (4.4.2). Subsequently, each IDs position lists are iterated, retrieving each position object's building name and floor number. If a new building name appears in a position object, the position is added to an array called *entranceList*, and the position previous to the current position is added to an array called *exitList*. The reason for selecting this method is that when a new building appears in a trace, it is the first position registered in the building for the device, thus being logically close to the entrance. Hence, the previous position registered in the preceding building is the last position recorded for the device in that building, in other words the exit position.

In this solution, the first building appearing in a trace is never registered as an entrance. This is because the program, within the specified time frame, have no way of knowing if the trace have previous registered positions in the building previous to the time frame. Therefore, for an entrance and an exit to be registered, a new building must appear in a trace *after* a different building appears in the same trace.

Example of a trace of positions, only writing the building names A and B and their sequence number representing the position:
<u>This trace does not have a registered entrance or exit:</u> [A1, A2, A3, A4, A5, A6, A7, A8]
<u>This trace do have the registered entrance (B1) and exit (A4):</u> [A1, A2, A3, A4, B1, B2, B3].

If the connection to the WLAN access points started or stopped working the second a device enters or leaves a building, this solution would probably work satisfactory. However, because of the unreliable intervals of the WLAN probe requests (2.1.3), the first and last positions may be recorded for example 40 seconds after entering the building, or 40 seconds before leaving it. For collecting data from specific points like building entrances and exits, other technologies such as Bluetooth (2.1.1) or RFID may be suitable, as presented by Wawrzyniak and Korbel[36].

4.5 Issues

Several issues emerge when dealing with the different functionalities explained in this chapter. This section elaborates on some of the most important challenges regarding the implementation of NTNU CMA, how they are affecting the application, as well as how they may be overcome.

4.5.1 Limited Number of Days in Dataset

When downloading the position data from the PosData (4.1) server using the GetPos (4.2) program, the JSON file containing the output data is quite large. A typical file containing 24 hours of data is more than 700-750 MB. When using Node.js (2.5.1) as a server, reading such substantial amounts of data is demanding, especially since a Node.js operation, except for I/O operations, runs as a single threaded process[26]. When reading and processing a larger file, for example a 3.2 GB file containing one week of data, the process freezes. With this in mind, using Node.js may not be the best option for NTNU CMA when looking to visualize data from a time frame greater than 24 hours. However, the main purpose of NTNU CMA is to identify how the data can be utilized as well as how it can be visualized in the best possible way for potential stakeholders. Thus, the size of the dataset utilized in order to meet these requirements are not considered crucial. Also, for use in production, the data would have to be available through an API connected to a database, not text files downloaded from a server, which in turn would eliminate the issue related to the file reading.

4.5.2 Processing Speed

As stated in the previous section, having to read the position objects from a file results in an extremely long processing time, which is not very user friendly. This is because the file needs to be streamed into the program chunk by chunk, forcing an analysis of all incoming text in order to separate the individual objects for processing. Visualizing 24 hours of data may have a processing time of two minutes, which is not acceptable. This could be improved by cleaning the JSON files, removing the unused fields in the objects and create a new file, but it would only be a shortcut, not a solution. Receiving the objects directly from a database through an API as stated in the previous section would probably be the superior solution.

4.5.3 Simple Algorithms

Due to the limitations in processing speed described in the previous sections, only relatively simple algorithms for movement analysis have been utilized. More complex algorithms might disclose more descriptive mobility patterns, such as identifying regular mobility patterns[19][20].

4.5.4 Positions Clustering in Lines

Generating heatmaps of the position data shows that the registered positions often are clustered on lines within the buildings. These lines probably do not represent the actual positions because they are unnatural. An example is that the positions registered within a lecture hall are visualized clustered on one line across the room. The explanation for these phenomena may be the way the WLAN access points are placed throughout the rooms and halls, causing the positioning algorithm to misplace most of the devices onto one line. An illustration of such a phenomenon is shown in figure 4.2.

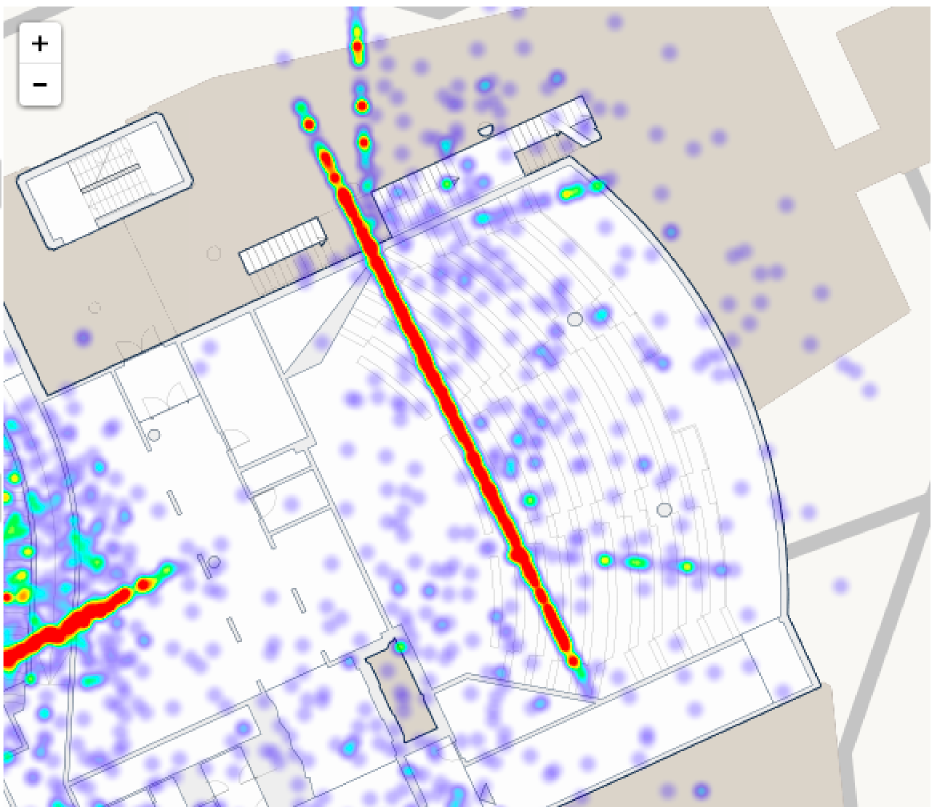

Figure 4.2: A excerpt from NTNU CMA showing the heatmap from the lecture hall R2 in Realfagbygget. Most of the positions are clustered on one line, which is probably not representing the actual movements.

Chapter 5

Results

NTNU CMA is presented in the previous chapters, as well as the methods utilized in order to process the available datasets. In this chapter, the actual results that the use of NTNU CMA provides are presented. This includes the raw results derived from each main functionality in NTNU CMA, as well as a comparison between the results from this project and the previous similar project from NTNU Gløshaugen by Martinez in 2013[18]. In addition, an evaluation of NTNU CMA itself is presented.

5.1 Human Mobility Patterns

In order to present the results regarding the indoor human mobility patterns, the findings from each main functionality of NTNU CMA are described in its own respective sections. Because of the limitation of NTNU CMA regarding processing of multiple days presented in section 4.5 and 4.4.2, this analysis is focused primarily on position data collected October 1st 2014. This particular date was a normal day with lectures and no special events. The goal is to identify everyday trends by analyzing the movement from this date. However, a different date, September 17th 2014 is also analyzed. This date was the second day of Norway's largest career fair on NTNU Gløshaugen called KarriereDagene[37], where businesses have their own stands in a large tent located on the lawn behind Hovedbygget. It is interesting to identify the effects this event has on the movements on campus. In the Heatmap, Buildings and Entrances and Exits sections, the following periods are analyzed in order to provide an adequately wide foundation for representative and descriptive results.

- The whole day between 08:00 and 18:00, a total of 10 hours.
- One hour between 08:00 and 09:00.
- One hour between 11:00 and 12:00.
- One hour between 15:00 and 16:00.
- 15 minutes during lectures, 09:45 to 10:00.
- 15 minutes between lectures, 10:00 to 10:15.

5.1.1 Heatmap

When generating a heatmap of the movements on NTNU Gløshaugen, the main focus is to visualize the overall movement trends without going into the details of the data. In other words, it provides a rough image of where the traffic is higher or lower on campus.

08:00 to 18:00

When looking at the heatmap generated with data between 08:00 and 18:00, there are some major locations on campus standing out when in comes to movement traffic. For the first and second floor, the hallway between Sentralbygg 1 and Sentralbygg 2 called "Stripa" looks to be one of the more trafficked indoor places on campus together with Realfagbygget. Also, the hallways of Elektrobygget and Hovedbygget contain a lot of movement. The entrance to IT-bygget Sydfløy is also trafficked, probably because of the large popular lecture hall F1 is located there. None of these results present any surprises, in that popular lecture halls and reading rooms are located in these buildings. Among the buildings containing less movement are Metallurgi, Berg and P15, which is also not that surprising, being that there are few or no lectures in these buildings. P15 does have some movement on the third and fourth floor inhabited by computer rooms, but people tend to sit still in these rooms, resulting in them not being caught by the movement analysis of NTNU CMA. There are obviously less movement in the higher floors on campus, but Realfagbygget does have considerable traffic in the hallways up to the fifth floor. The fact that large lecture halls result in more traffic is confirmed when looking at the fourth floor in Hovedbygget, where there are a lot of movement around the lecture hall H3, with less movement on the rest of the floor.

08:00 to 09:00

In this time frame there are little movement on campus. Some of the more popular buildings are the same as the ones from 08:00 to 18:00, being Hovedbygget, Realfagbygget, Stripa and Elektrobygget. The hallway on the fourth floor by lecture hall H3 in Hovedbgget does yet again stick out, having more concentrated movement than elsewhere, indicating that a lecture found place within the time frame. A screenshot from the heatmap can be viewed in figure 5.1.

11:00 to 12:00

The heatmap from this time frame displays a lot more movement than the previous one, indicating that some students and personnel start their day on campus a bit later than 08:00. The most and least popular buildings have not changed. A screenshot from the heatmap can be viewed in figure 5.2.

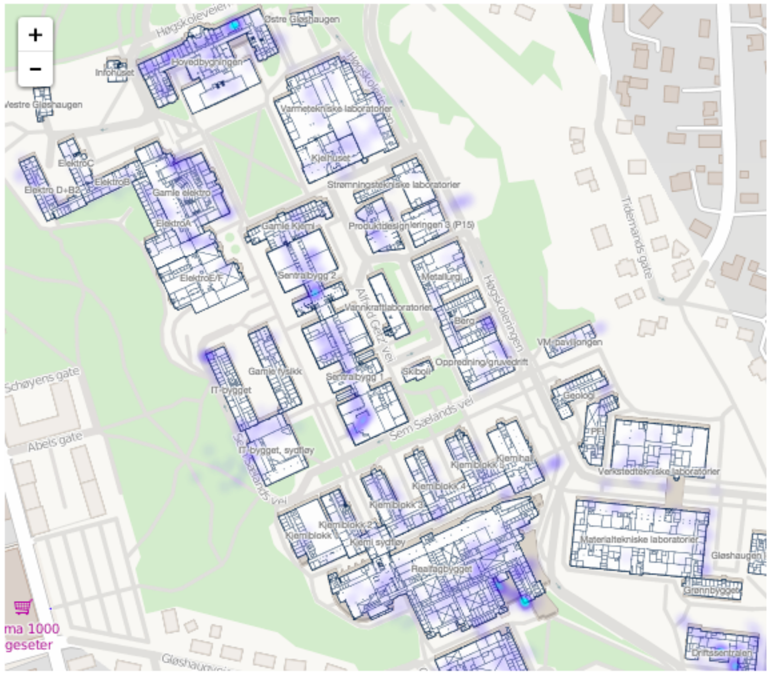

Figure 5.1: A heatmap of the 1st floor of NTNU October 1st 2014 between 08:00 and 09:00.

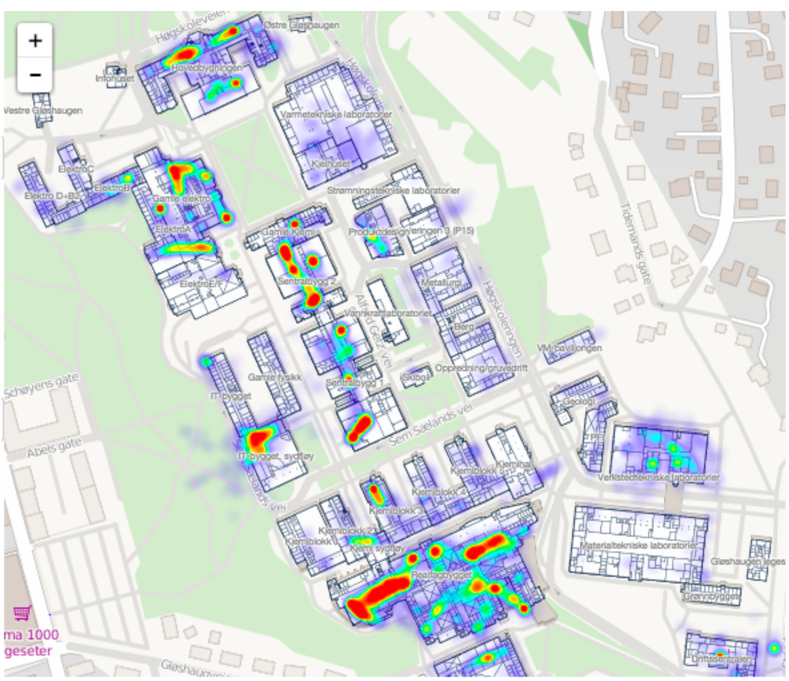

Figure 5.2: A heatmap of the 1st floor of NTNU October 1st 2014 between 11:00 and 12:00.

Figure 5.3: A heatmap of the 1st floor of NTNU October 1st 2014 between 09:45 and 10:00.

15:00 to 16:00

Within this time frame, a bit more movement than in the previous time frame is displayed. In other words, there are more people moving around campus at the end of the workday than at the beginning. The movement ratio between the buildings is unchanged.

09:45 to 10:00

Limited movement is visualized in this time frame, but not a lot less than in the time frame between 08:00 and 09:00, even though the time frame is 45 minutes shorter. This may indicate that people tend to start their day at campus in this time frame. A screenshot from the heatmap can be viewed in figure 5.3.

Figure 5.4: A heatmap of the 1st floor of NTNU October 1st 2014 between 10:00 and 10:15.

10:00 to 10:15

More movement is visualized in these 15 minutes than in the previous 15 minutes from 09:45 to 10:00. This is an expected effect because the lectures at NTNU mainly ends at 10:00 and a new lecture starts at 10:15, resulting in students moving between lectures in this time period. A screenshot from the heatmap can be viewed in figure 5.4.

5.1.2 Buildings

Visualizing the movements between buildings allows for a more detailed view at the human mobility patterns on campus. The functionality also provides a more dynamic experience, enabling the user to explore the data both visually and by hard numbers. This tab offers two main types of movement analysis, ”All movement” and ”Start/stop”, as described in section 4.4.2. Because the ”Start/stop” method has limited success in comparison with the ”All movement” method, only the results from the latter are thoroughly analyzed, while the former are summarized and compared to the latter in the end of this section.

08:00 to 18:00

When looking at the number of movements to and from each building, several patterns of interest emerge. Firstly, for all buildings, the number of movements to the building is close to the number of movements from the building. For example, the number of movements from Realfagbygget is 11,650, while the number of movements to the same building is 11,920. In Sentralbygg 1, the from and to numbers are 4969 and 5235, respectively. This pattern is common among all the buildings, and makes sense in that people entering a building eventually have to leave it during a day.

Secondly, the buildings with the greatest number of movements from and to the buildings are Realfagbygget, Gamle Elektro, Elektroblokk A, and Sentralbygg 1 and 2. The most remarkable of these results are Gamle Elektro and Elektroblokk A, which are indeed popular locations, but maybe not as popular as Sentralbygg 1 and 2. An explanation for this phenomenon is the fact that Gamle Elektro and Elektroblokk A are adjacent to each other only connected by a short hallway, basically classifying them as one building with a substantial amount of internal movement. This explanation is confirmed when looking at the top ten movements among buildings, having the two combinations Elektroblokk A to Gamle Elektro and Gamle Elektro to Elektroblokk A ranked first and second. The same statement could be made about Sentralbygg 1 and 2, but these two points, although connected by the same hallway, are further from each other than the previous buildings, also confirmed by the top ten buildings combination list, ranking the combinations between these two buildings fifth and sixth. The buildings with the lowest number of movements from and to them are buildings without many lecture halls and study rooms, like Internasjonalt Hus, Elektro C and Oppredning/Gruvedrift.

Thirdly, exploring the top paths taken from and to each building reveales that buildings close to each other often are on each other's top lists. However, a more interesting discovery is that some

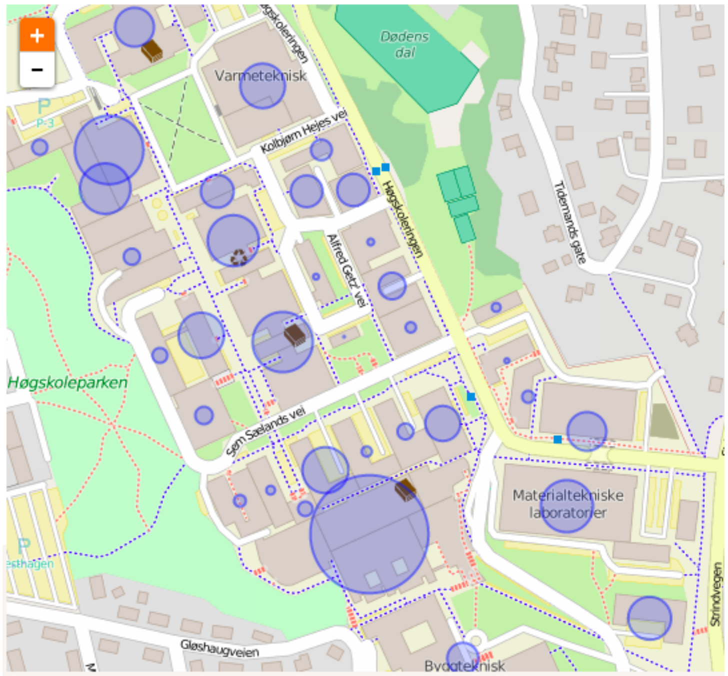

Figure 5.5: A map showing the relative amount of all movements to and from the different buildings on NTNU October 1st 2014 between 08:00 and 18:00.

buildings with no logical relevance to each other possess a substantial number of registered movements between them. These buildings include IT Vest to Elektro D+B2 and P15 to Verkstedteknisk, and are most likely a result of the fact that people's devices are registered inside the buildings while walking past on a road passing both buildings. Such roads and paths do exist in both cases, exemplifying the weakness stated in section 4.4.2 of not knowing whether a movement is actually between the two buildings, or just passing them. Buildings close to popular roads are therefore probably assigned more movement than they should, like Vekstedteknisk and Materialteknisk. A screenshot from NTNU CMA illustrating the amount of movement to and from each building can be viewed in figure 5.5, confirming that buildings close to popular roads have big circles.

08:00 to 09:00

In this hour, the buildings with the greatest number of movements from and to them are a bit different from the ones in the previous time frame from 08:00 to 18:00. A clear pattern emerges in

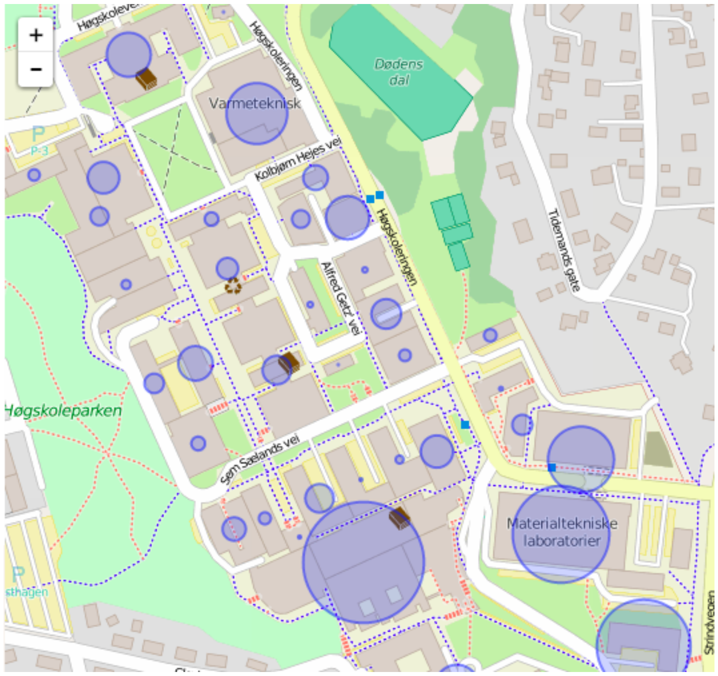

Figure 5.6: A map showing the relative amount of all movements to and from the different buildings on NTNU October 1st 2014 between 08:00 and 09:00.

that buildings close to popular roads are the ones with the most from and to movements, such as Materialteknisk, Driftsentralen, Verkstedteknisk and Varmeteknisk. This result may be studied in figure 5.6. None of these buildings contain popular lecture halls or study rooms, but are all assigned movements from people walking past them, just as explained in the previous section. These results indicate that a considerable amount of people are taking these roads to campus within this time frame.

11:00 to 12:00

This hour proves to be different from the earlier hour in that the buildings close to popular roads possess a significantly lesser share of the movement on campus. The distribution of movements from and to each building has turned to be more similar to the movements recorded between 08:00 and 18:00, being more representative for the whole day rather than the morning. These results indicate that people have settled in on campus at this time of the day, supporting the results from

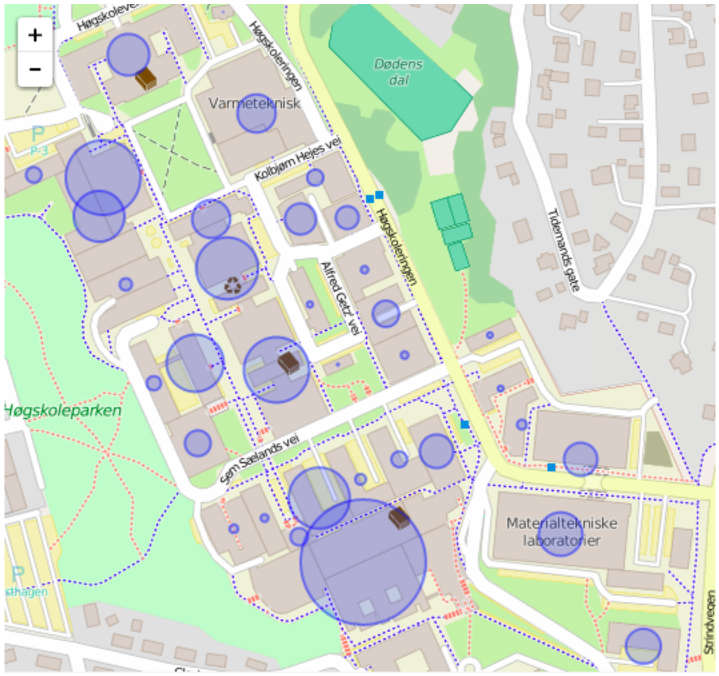

Figure 5.7: A map showing the relative amount of all movements to and from the different buildings on NTNU October 1st 2014 between 11:00 and 12:00.

the heatmap section within the same time frame. The result may be viewed in figure 5.7.

15:00 to 16:00

Also in this time frame, the results are similar to the ones representative for the whole day. The number of movements from and to the most popular buildings are quite similar to the time frame between 11:00 and 12:00, exemplified by these data from Realfagbygget:

11:00-12:00 From: 1314, to: 1326

15:00-16:00 From: 1433, to: 1290

These results may not indicate the same increase in movement as the heatmap section did for the same time frame, but the differences in the heatmap were minor, and the differences are therefore of little significance.

09:45 to 10:00

This quarter contains the same movement patterns as the time period between 15:00 and 16:00, although on a recognizably smaller scale because of the smaller time frame.

10:00 to 10:15

Within these 15 minutes, the number of movements between buildings have escalated in comparison to the previous 15, just like described in the heatmap section within the same time frame. As previously stated, this is a result of the lecture schedule with lectures ending at the whole hour and new lectures starting 15 minutes later. Examples of the number of movements from and to two of the most popular lecture buildings supporting these results are listed below, each showing an increase in movement.

Realfagbygget 09:45-10:00 From: 155, to: 175

Realfagbygget 10:00-10:15 From: 196, to: 201

Gamle Elektro 09:45-10:00 From: 115, to: 93

Gamle Elektro 10:00-10:15 From: 167, to: 215

Start/stop

When generating visualizations using the "Start/stop" method, the greatest difference compared to the "All movement" method is that the number of registered movements are considerably lower. However, the buildings located close to popular roads and paths, but not containing popular lecture halls and study rooms, have a significantly lower share of registered incoming movements than they do using the "All movement" method. This may be because the "Start/stop" method successfully

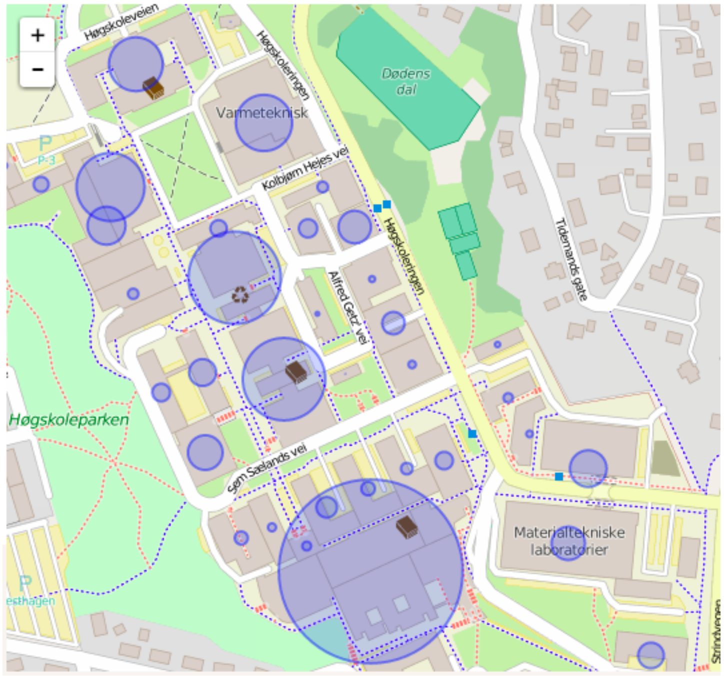

Figure 5.8: A map showing the relative amount of start/stop movements to and from the different buildings on NTNU October 1st 2014 between 08:00 and 18:00.

filters out the movements that are just passing by without the building being their final destination. For example, using the ”All movement” method resulted in Realfagbygget having 3.17 times more incoming movements than Verkstedteknisk, while using the ”Start/stop” method resulted in the same relationship being 8.95. An even more significant comparison is between Realfagbygget and Driftssentralen, where the latter is located close to a main pathway to campus, but only being utilized by employees of NTNU Operations. In the ”All movement” method, Realfagbygget had 2.95 times more incoming movements than Driftsentralen, while using ”Start/stop” resulted in Realfagbygget having 19.15 times more incoming movement. This result indicates that a method not registering people just passing by may work, but has to be optimized in order to capture more movements. In figure 5.8, the difference between this method and the ”All movement” method shown in figure 5.5 is significant.

5.1.3 Accuracy

Because this section does not analyze movement patterns, but is rather exploring where the data quality is better or worse, the time of the day should not affect the recorded results. Therefore, only a result from 5 hours midday between 10:00 and 15:00 are analyzed. As a reminder, a heatmap consisting of three colours are generated. Blue indicates registered positions with an accuracy between 50% and 150% of the calculated average accuracy, green indicates registered positions with an accuracy of more than 150% of average, while red indicates accuracy below 50% of average.

When looking at the visualization of the accuracy and all registered positions within the time frame, several differences among the buildings are observed. Within Hovedbygget and Geologi, the accuracy seems to be generally satisfactory, having mostly green and blue colours in the heatmap. Kjelhuset and Varmeteknisk do have more of an equal spread between red, blue and green colours, indicating a more variable accuracy. On the east side of Varmeteknisk and Driftsentralen, outside the building on the road, several positions are marked as red with low accuracy, which most likely are people passing by the building without actually entering it. This obviously makes it harder for the WLAN access points to calculate an accurate position, being that the coverage is best indoors. The same effect can be seen on the east side of P15 where a bus stop is located, even for second, third and the fourth floor as illustrated in figure 5.9.

People walking by, driving by, or standing at the bus stop are registered from several different floors, but because they are located outside of the building where the WLAN coverage is reduced, the accuracy is low. Inside the building however, the accuracy is generally high. The PFI building is one of the buildings registering positions with the worst accuracy for higher floors, having mostly red and some blue positions in the third floor of the heatmap. Generally, the accuracy seems to be more precise in the lower floors than in the higher ones.

An interesting result appears when looking at the 13th floor of Sentralbygg 1 and 2. The heatmap in Sentralbygg 1 is mainly contained within the walls of the building, but for Sentral-

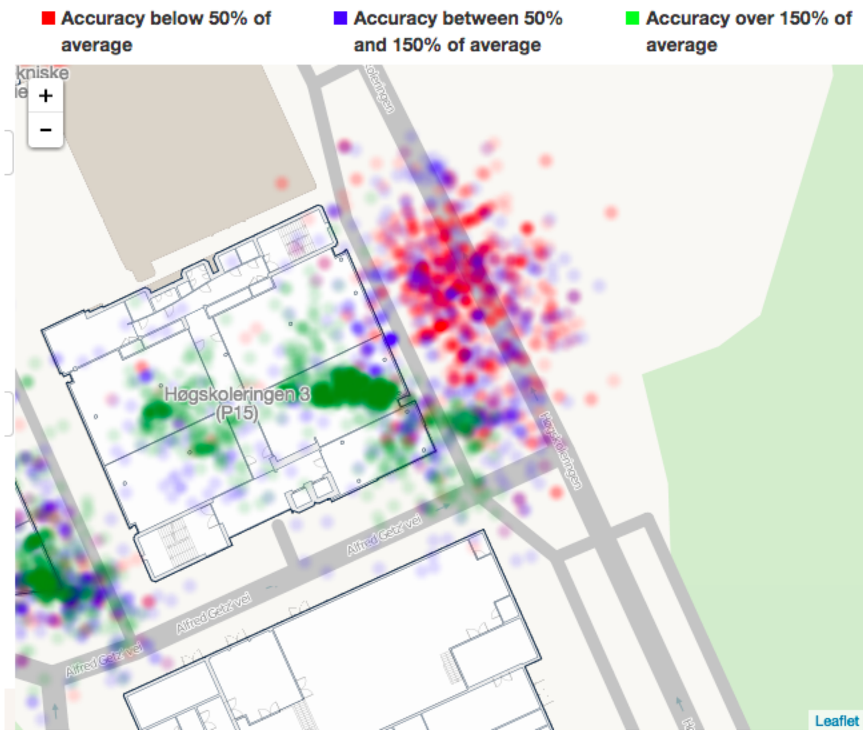

Figure 5.9: A map showing the accuracy of the registered positions on the third floor of P15 on October 1st 2014 between 10:00 and 15:00.

bygg 2, the heatmap stretches outside the building in ”the air”. The accuracy indicators show that most of the positions registered within Sentralbygg 1 are of high accuracy, while Sentralbygg 2 contains more lower accuracy registrations as illustrated in figure 5.10. These results correspond well with the heatmap looking more realistic for Sentralbygg 1.

5.1.4 Entrances and Exits

Visualizing the first and last positions registered in a building for each trace, should allow one to obtain an overview of which entrances and exits are being utilized in each building.

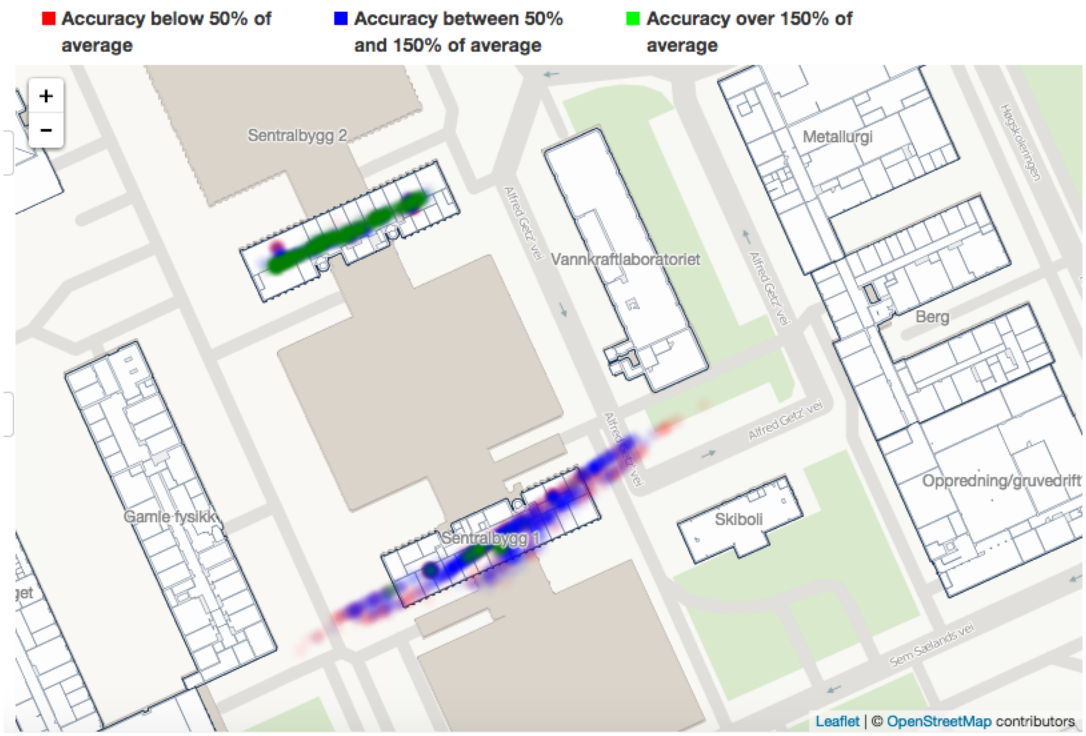

Figure 5.10: The accuracy heatmap of the 13th floor for Sentralbygg 1 and Sentralbygg 2.

08:00 to 18:00

Looking at the resulting entrance positions in green and exit positions in red, both entrances and exits are registered in all parts of the buildings, not just the entrances and exits. This effect is probably due to the unpredictable intervals of the probe requests as described in section 2.1.3. Also, several entrance and exit positions are located outside the buildings along popular roads, caused by the people moving past the buildings, especially by the bus stop outside of P15 as described in section 5.1.3.

However, several clusters of entrance and exit positions do exist close to actual entrances and exits of buildings. The entrance to It-Syd shows a lot of entrance and exit points which can be seen from a screenshot of NTNU CMA in figure 5.11. The same goes for the entrance to Sentralbygg 2, Sentralbygg 1, both main entrances of Realfagbygget, the main entrance of Produktdesign, and the main entrances of Gamle Elektro and Elektrobygg A. This functionality does in other words

Figure 5.11: A map showing the entrances and exits registered nearby lecture hall F1 in IT-Syd on October 1st 2014 between 08:00 and 18:00.

provide indications of which entrances are being most frequently used, however the accuracy of these data are extremely varying, limiting this functionality to a tool for obtaining an overview rather than hard data.

08:00 to 09:00

Very few entrances and exits are registered within this time frame, but some patterns do in fact come into view. The entrances of Sentralbygg 2, Gamle Elektro and the south entrance of Realfagbygget have the most activity. In the south entrance of Realfagbygget, there are more registered entrances than exits, maybe because people have entered the building in the morning through this entrance, and exited the building in an entrance which is leading to the rest of the campus. This is confirmed by looking at the north entrance of Realfagbygget, having more registered exits than entrances. Some entrances and exits are registered close to the most popular bus stops on campus, which is explained by people arriving campus in the morning.

11:00 to 12:00

Also in this hour, clusters of entrance and exit positions are located around the two main bus stops on campus. There are considerably more registered positions within this time frame compared to the one between 08:00 and 09:00, supporting the results found in section 5.1.2. The most popular entrances and exits on campus in this time frame are the same as found in the time frame between 08:00 and 18:00.

15:00 to 16:00

One might expect for there to be more registered exits than entrances, being that it is late in the day, but the distribution of registered entrances and exits are close to equal. Also, there are no obvious changes in which entrances and exits are being utilized.

09:45 to 10:00

Extremely few entrances and exits are registered within this time frame, but the ones actually registered are close to popular entrances.

10:00 to 10:15

In these 15 minutes, both entrances and exits are registered near the most popular entrances to buildings containing common lecture halls, indicating that people are moving between lectures as discovered in section 5.1.2. The number of registered entrances and exits have increased since the previous 15 minutes, supporting the theory of more people moving between buildings from one lecture to another, also stated in section 5.1.1 and 5.1.2.

5.1.5 Karrieredagene

Karrieredagene 2014 took place at NTNU Gløshaugen from September 16th to September 18th. A great number of businesses were available on stands inside the tent on the lawn behind Hovedbygget, and it is interesting to investigate the effects this event had on the mobility patterns on campus. Since October 1st was considered a regular day, comparing this date with September 17th will reveal if special events can result in visible changes in the movements on campus. One must keep in mind that many of the registered movements in the buildings close to the tent, might be people walking past outside as explained in section 4.4.2. However, this still provides an indication of the changes in movement caused by the event.

08:00 to 18:00

When looking at the movements between buildings in figure 5.12 compared to the movements in the same time frame on October 1st in figure 5.5, the distribution of movements between the buildings are quite different. The buildings close to the tent on the lawn behind Hovedbygget have a much greater share of movements compared to the other buildings, which was not the case on October 1st. Also, the number of movements in total has increased significantly in these buildings, not just their share compared to the other buildings.

11:00 to 12:00

In this hour, both the movements between buildings and the heatmaps between September 17th and the normal day October 1st are compared.

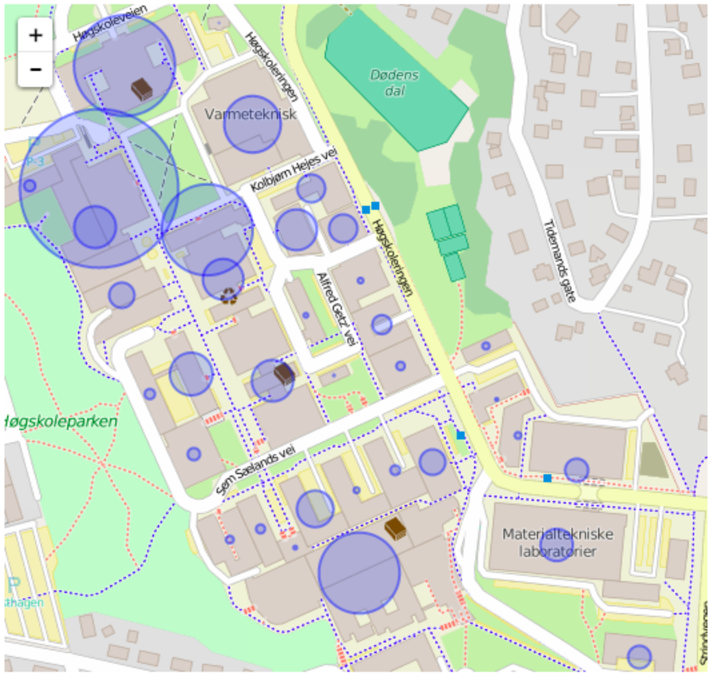

Figure 5.12: A map showing the relative amount of all movements to and from the different buildings on NTNU September 17th 2014 between 08:00 and 18:00.

Buildings

Comparing the movement between buildings in this hour on the day of the event in figure 5.13 to the normal day in figure 5.7 reveals the same trend as shown in the previous section. The buildings close to the tent have both more movements in numbers and greater shares of movements compared to the other buildings.

Heatmap

Also when looking at the heatmaps from this hour on the day of the event in figure 5.14 and the normal day in figure 5.2, the amount of movements on campus has increased, especially in the buildings close to the tent.

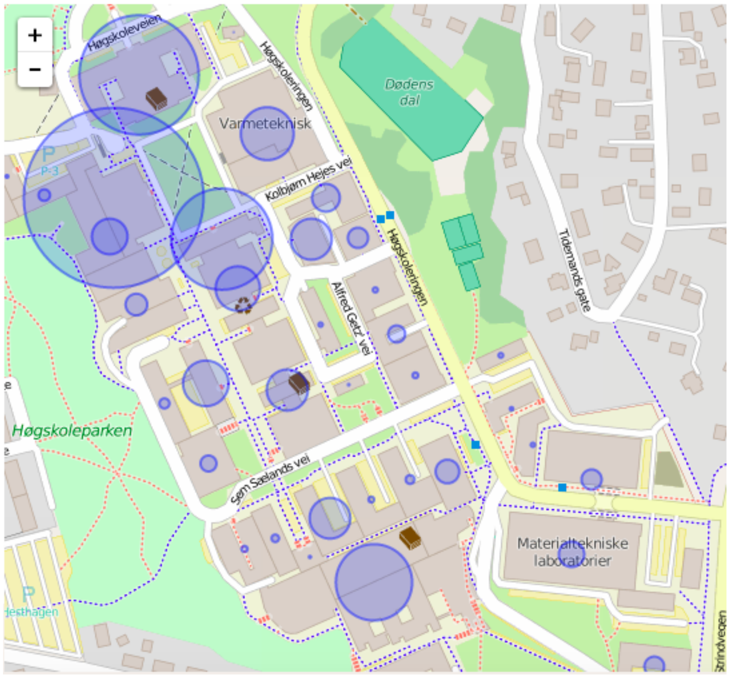

Figure 5.13: A map showing the relative amount of all movements to and from the different buildings on NTNU September 17th 2014 between 11:00 and 12:00.

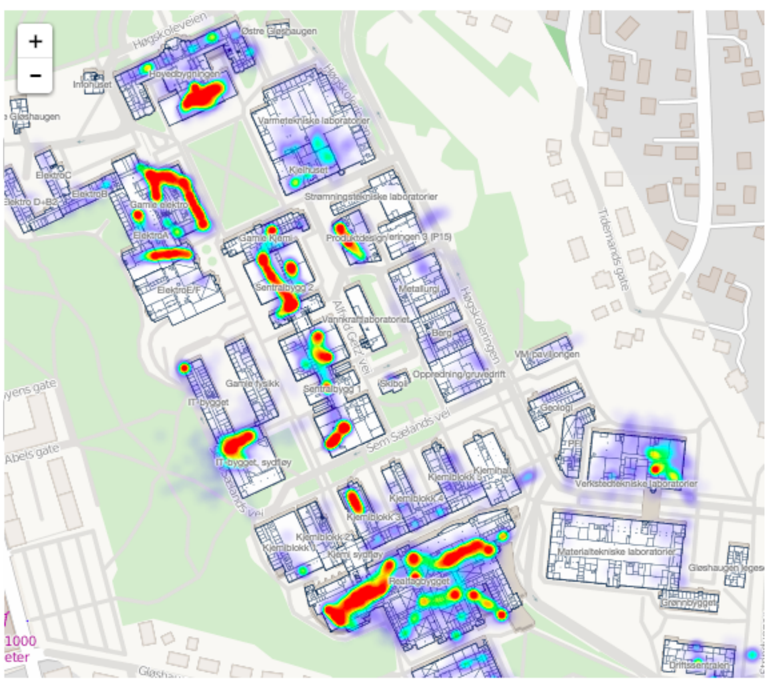

Figure 5.14: A heatmap of the 1st floor of NTNU September 17th 2014 between 11:00 and 12:00.

5.2 Comparing MazeMap Wayfinding Requests and Actual Movements

As described in section 2.2, a previous master thesis was written by Martinez in 2013[18], addressing wayfinding request made by the MazeMap[14] application, helping people to find their way on campus. Accumulating these wayfinding requests resulted in an overview of the number of people *guided* to each building on campus. There are no guarantees that people actually went to the buildings they were guided to, but since NTNU CMA is using actual position data from users, it may be interesting to compare the results from the two projects.

In the thesis written by Martinez[18], the number of wayfinding request towards rooms in each building is counted, providing an overview of how many people that *may* be walking into a building. Since only people asking for help to find the way using MazeMap are counted, only a small part of the people actually walking towards the buildings are registered. Therefore, comparing the raw numbers may not be as appropriate as comparing the distribution of movements entering each building. Thus, this section is comparing the relative destination popularity per building at Gløshaugen from the MazeMap data described by Martinez, with the same from the *to*-numbers in the Buildings section (4.4.2) of NTNU CMA. The distribution from Martinez's results is displayed in figure 5.15, and the distribution from the results of this project is illustrated in figure 5.16.

When analyzing these results, it is important to take into account the fact that Martinez' results are based on wayfinding request to a room within the registered buildings, while the results from NTNU CMA are based on registered movement towards a building. This means that if the wayfinding requests were actually followed, they are probably more precise than NTNU CMA's results. As addressed in the previous paragraphs however, the results of Martinez are based on considerably fewer movements and there are no guarantees that these are actual movements.

Looking at the diagrams, several similarities are present. Sentralbygget, Realfagbygget and

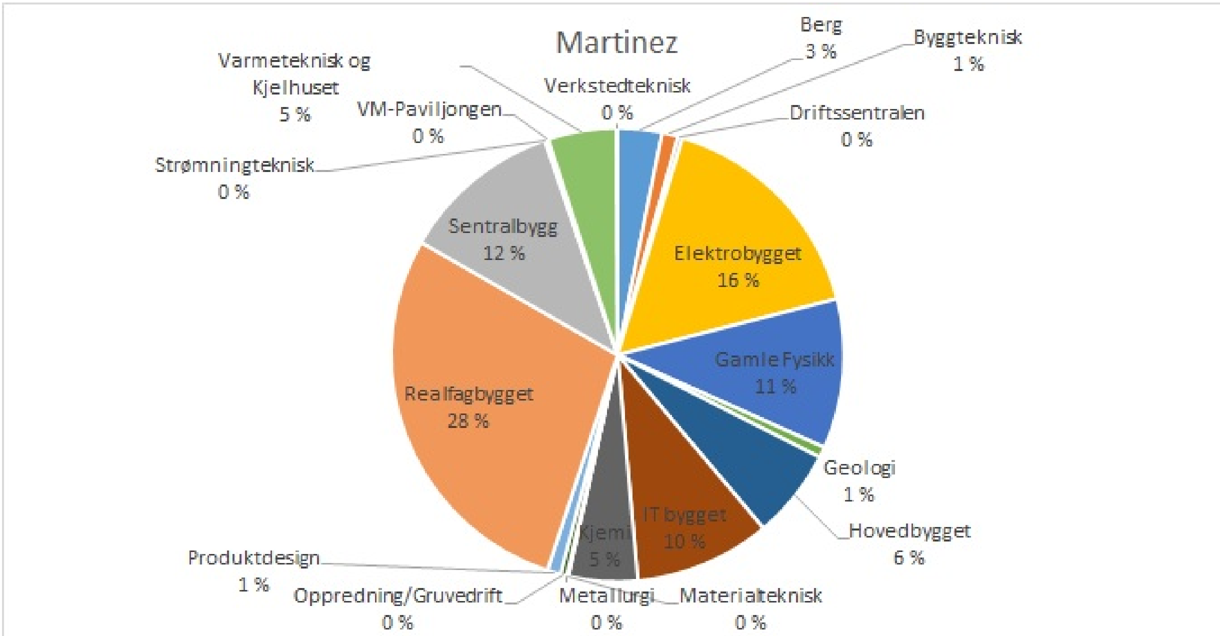

Figure 5.15: The percentage of wayfinding destinations for each building on campus.

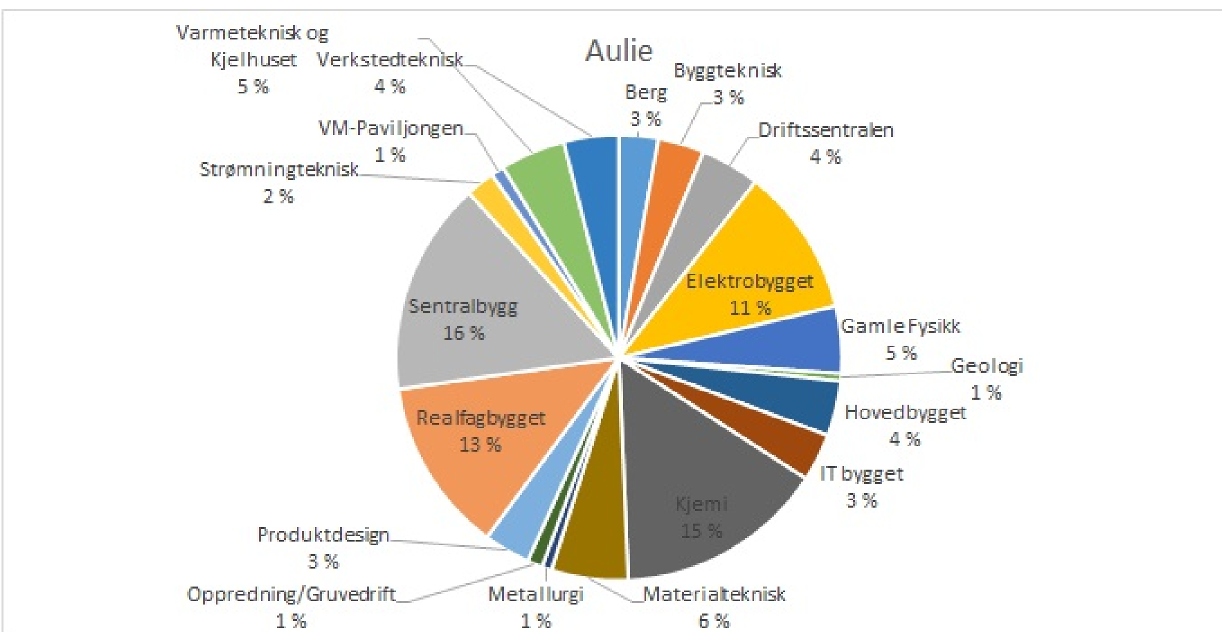

Figure 5.16: The percentage of movement destinations for each building on campus.

Elektrobygget all have major shares in the distribution. Some substantial differences do however exist. Kjemi from the Martinez diagram have a share of 5%, while holding 15% in the Aulie diagram. An explanation for this result may be that Kjemi is close to one of the main entrances of Realfagbygget, resulting in that people entering Realfagbygget are registered as entering Kjemi instead. This theory also explains why Realfagbygget have a considerably smaller share in the Aulie diagram with 13%, while being 28% in the Martinez diagram. Thus, in the Aulie diagram, several of the percentages from Kjemi should maybe have been assigned to Realfagbygget.

Another interesting result is that buildings located on the side of popular roads, such as Driftsentralen and Verkstedteknisk, holds a higher share in the Aulie diagram than in the Martinez diagram. This result strengthens the theory discussed in section 4.4.2 that people moving past the buildings are registered without actually entering the buildings. One must also consider the fact that the results from Martinez may be affected by how hard it is to find rooms in the specific buildings. Buildings holding more rooms on several floor levels such as Realfagbygget may receive a greater number of wayfinding request than other buildings.

5.3 NTNU Crowd Movement Analysis

The following sections are determining the value of NTNU CMA for several intended purposes, as well as an evaluation based on interviews with potential stakeholders.

5.3.1 Requirements Evaluation

Earlier in this chapter, extensive testing of the functionalities in NTNU CMA is performed. Thus, each of the requirements listed in section 3.1 have been directly tested and evaluated in their respective sections. The list below states the sections testing and approving which requirements. All requirements are considered fulfilled, although each section describes some weaknesses in the results.

Requirement 1: Section 5.1.1.

Requirement 2: Section 5.1.2.

Requirement 3: Section 5.1.3.

Requirement 4: Section 5.1.4.

5.3.2 User Evaluation

In order to perform a qualitative evaluation of NTNU CMA, potential stakeholders are interviewed. The reason for selecting a qualitative evaluation is that NTNU CMA is only meant to be used by a few targeted stakeholders with special interests in property management, as well as management of people using these buildings. The perceived usefulness of NTNU CMA by these few stakeholders is therefore more useful than collecting quantitative evaluations from people who are not potential end-users.

Before creating NTNU CMA, qualitative interviews of potential stakeholders were also conducted, providing an indication of what exactly potential end-users are looking for in such an application as presented in section 3.1. Together with the continuous input from position data professionals, NTNU CMA was developed iteratively in order to end up with an optimal prototype application.

A total number of nine potential users from Statsbygg and NTNU Operations were interviewed, but only six were able to stay and conduct the survey explained in section 5.3.4. Statsbygg is the Norwegian government's key adviser in construction and property affairs, building commissioner, property manager and property developer. They have 877 employees, situated in Oslo, Porsgrunn, Bergen, Trondheim and Tromsø[38]. NTNU Operations are responsible for the daily operations and continuous maintenance of the NTNU properties[39]. These were selected as potential stakeholders because obtaining knowledge of how people are using the facilities they are administrating may be crucial in order for them to do their work properly. Also, a representative from NTNU Studieavdelingen was interviewed as stated in section 3.1. This department is responsible for both organizing class schedules and the booking of rooms on campus. Thus, the information provided by the results of this project may be of use for them as well. No questionnaire was filled out by NTNU Studieavdelingen because the interview was performed earlier in the process when the stage of final evaluation was not yet reached.

NTNU Studieavdelingen Interview

As stated in section 3.1, a representative from NTNU Studieavdelingen was interviewed and the following list of interest points were identified, here categorized by domain.

Facility Architecture

- Identify flaws and possibilities in facility design.

Business

- Regulate prices for areas within facilities, such as in shopping malls.

Research

- Research how to handle data insecurity in the IPS.

- Research how to optimally visualize the information provided by the IPS.

Security

- Determine if the existing emergency exits are sufficient.
- Determine if the fire security regulations are sufficient.

Traffic

- Minimize traffic related to the class schedule.
- Decide if the doors are big enough and identify bottlenecks.

Several of these points are possible with NTNU CMA. Minimizing traffic related to class schedules can be done by analyzing the number of movements between buildings in the 15 minutes between classes, as performed in section 5.1.2. One can for example identify the differences in movements after the class schedule has been changed, and determine whether there are more movements between buildings far away from each other or close to each other. The latter would be the most optimal alternative, resulting in less overall traffic on campus. Identifying bottlenecks and fire security sufficiency are also possible by checking the heatmap of the movements and identify locations with a great deal of traffic. The overall amount movements in a place visualized by the heatmap may also be utilized when determining which locations being more attractive for commercial reasons, such as stores in shopping malls. Also, as feedback has been taken into account during the whole development process, the visualization of the information has become closer to optimal.

NTNU Operations Interview

When interviewing the staff from NTNU Operations, three staff members are present during the whole meeting, while one staff member is present for parts of the interview. They all have slightly different job descriptions within the field, thus providing a sufficient foundation for retrieving varied feedback. First, NTNU CMA is presented to the staff members, demonstrating the main functionalities and visualizations available. Then, a discussion is held in order to uncover their impression of NTNU CMA. The staff members also provide suggestions on how to improve NTNU CMA and the use of data for their daily use cases. A few key feedback points are categorized by domain below.

Security

- Analyzing movements during an emergency such as a fire alarm is interesting.

Traffic

- Analyzing movements in order to identify which entrances and exits are being used most and least frequently is useful. More concrete numbers are desired, not just visualizations.
- Recognizing which rooms are being used as well as those not being used is interesting.
- Visualizing the number of people moving between the different buildings may not be that useful in their jobs.
- Knowing which directions people are coming from when entering campus may be interesting.
- Determining the actual roads and pathways being used outside between buildings is interesting.

Some of these remarks are in some way working in NTNU CMA. Analyzing movement during an emergency is definitely possible if data has been collected during such an event. A visualization of entrances and exits are also implemented, however with varying results due to inconsistencies in the data, as explained in section 4.4.4. Identifying the degree in which rooms are being used is in this solution only possible for movements in rooms, but by taking into account all the data without filtering out the devices not moving, as well as utilizing the bounds for each room allowing one to assign a given position to the correct room, this solution may be implemented. Visualizing the actual roads being used outside is not possible from the data utilized in this project. The Cisco MSE can only detect devices close to or inside buildings with WLAN infrastructure, thus not registering most positions outside. An indication of the roads and paths being used can however be provided by looking at the number of movements between buildings, and identify the paths most likely to be utilized.

Even though the staff members are not spending a lot of time with NTNU CMA, they express that the user interface looks organized and intuitive, making it easy to use if not for the long processing time. The user interface has not been a priority in this project as much as the visualizations, but knowing that this is a satisfying way to compose such an application user interface is helpful when considering further development.

Summarized, the staff members are very interested in the different possibilities the visualizations have to offer, and the above points could be tremendously helpful in their jobs. However, NTNU CMA would have to be more tailored to their specific needs, as well as having a greater performance than the version demonstrated.

Statsbygg Interview

Five staff members were present in the interview with Statsbygg, however some were only available in parts of the meeting. Also in this case, employees with different job descriptions were interviewed, resulting in diverse feedback. Like in the previous interview, NTNU CMA is demonstrated and feedback together with suggestions for improvement are recorded. Key feedback points are listed below, categorized by domain.

General Feedback

- The staff members immediately recognize the potential present in these data.
- Facility renters may also have use for this type of information.
- NTNU CMA needs to be tailored in order for it to be optimal for their daily jobs.
- Combining a system like NTNU CMA into a complete facility management system would be optimal.

Traffic

- Determining which entrances and exits are being used is interesting.
- Analyzing whether the capacity of the facilities are sufficient compared to the actual movements is important.
- Determining which parts of the facilities are most trafficked is useful when coordinating cleaning and maintenance.
- Mapping the number of people in each room is useful. So far this has been performed by manual counting.
- Knowing the amount of movement between the different buildings is useful.
- Analyzing movement between rooms internally in the buildings may also be interesting.

These staff members expresses many of the same interests and wishes as the once at NTNU Operations, such as the use of entrances and exits, determining maintenance, mapping the use of single rooms, and desiring that NTNU CMA would be tailored to their specific needs. They are enthusiastic about the potential this information has to offer, both for themselves as well as their facility renters. Analyzing movement between single rooms may be very interesting in larger buildings, such as Realfagbygget. This does however require a lot of processing using the data currently available since all positions need to be assigned to a room bound. This may be a possibility when creating a more powerful system using data directly from a database rather than a file, as well as performing all processing on a robust server. Also in this interview, the staff members appreciate the modern looking and easy-to-use user interface of NTNU CMA.

5.3.3 Technology Acceptance Model

In order to evaluate NTNU CMA the Technology Acceptance Model (TAM) was utilized. TAM is an evaluation model for information systems introduced by Davis in 1986[40]. It is based on the idea that several factors influence a user's adaption of new technology, especially Perceived usefulness (PU) and Perceived ease-of-use (PEOU). PU is defined by Davies as ”the degree to which a person believes that using a particular system would enhance his or her job performance”, while PEOU is defined as ”the degree to which a person believes that using a particular system would be free from effort”[41]. Together, these two factors can determine whether an information system is useful and easy to use for the intended users.

5.3.4 TAM Results

When utilizing TAM for NTNU CMA, the perceived ease-of-use is not weighted as much as the perceived usefulness. This is because the main goal of this project is to identify how the available data may be utilized for something useful. It is not as important whether NTNU CMA is easy to use, as it is not meant to be be used by any stakeholders in its current form. Only the results produced when utilizing it is interesting. It is important to note that for TAM to provide a full-fledged evaluation, a greater number of people would have to be questioned. However, the results form this qualitative utilization of **??** provide an indication of the perseived usefulness of NTNU CMA.

	Unlikely						Likely
Perceived usefulness	1	2	3	4	5	6	7
Using the system in my job would enable me to accomplish tasks more quickly		1			3	2	
Using the system would improve my job performance		1	1			4	
Using the system in my job would increase my productity				2	1	3	
Using the system would enhance my effectiveness on the job				2	1	3	
Using the system would make it easier to do my job				1	3	2	
I would find the system useful in my job				1		4	1

Figure 5.17: The distribution of answers on the perceived usefulness of NTNU CMA in TAM.

The staff members all expressed that NTNU CMA appears user friendly, but as it is not in focus for this evaluation, only the perceived usefulness is considered by tailoring TAM for such a use case. TAM does not work properly without the perceived ease-of-use results, thus only an average score produced from the perceived usefulness questionnaire is considered. With 1 indicating the least perceived usefulness and 7 indicating the highest perceived usefulness, the average score is 5.2, resulting in a score of 0.74 on a scale from 0 to 1. The distribution of the collected scores can be viewed in figure 5.17. The result thus indicates that the perceived usefulness is quite high, however one would require a better result for a production application. If NTNU CMA had been tailored towards the potential stakeholder's specific use cases, the score would probably be higher. The indication this evaluation test provides shows that there is a market for this type of information in facility management.

Chapter 6

Business Opportunities

As the market for IPSs are expected to grow rapidly in the next few years, large players such as Apple and Google are making strides towards providing the same location services indoors as those already available outdoors. Apple are well on their way with iBeacon (section 2.1.1), while Google are allowing facility owners to submit their floor plans to Google for free, allowing Google to integrate the indoor maps with their standard Google Maps service[42]. This crates a win-win situation where Google gets to add more functionality to their service, while facility owners are making it easier for people to utilize their spaces.

The presence of such indoor maps together with a wireless infrastructure creates possibilities not just in terms of research on mobility patterns, but also in terms of revenue generation. Indoor location retail revenues are expected to reach $5 billion in 2019[43]. At first, analytics such as the once performed during this project is a fundamental first step. In the long term however, stores may provide offers based on a person's in-store position and other services supporting smartphone shoppers such as hyperlocal search and in-application advertising[43]. Nevertheless, this chapter is merely focusing on the business opportunities related to the data available in this particular project. The reason for this limited discussion is that revenue generation in stores as described above is already quite widespread. Thus, it is more interesting to explore the specific business opportunities the data from this project has to offer.

6.1 Hospitals

Hospitals are generally large facilities containing hallways, rooms, entrances and exits with a substantial amount of human mobility traffic. Being able to identify locations with excessive traffic may be vital when it comes to providing an optimal environment for helping people and saving lives. Discovering which hallways and rooms are being used the most is allowing one to increase personnel capacity if necessary. Also in case of an emergency, emergency services may identify people's positions inside the hospital, resulting in a more effecting rescue operation. An example of such a system assisting firefighters is proposed by Granmo, Lazreg and Radianti[44]. This does require live visualizations, which is common for facilities of all types, not just hospitals. Common for all venues with limited room capacities are also the desire to detect which rooms are being utilized and which are not. Companies able to provide both a wireless infrastructure as well as live and historical visualizations of the movement and presence inside a facility, will have a valuable tool for the facility owners to buy and utilize.

6.2 Conventions and Events

Providing the same type of wireless infrastructure together with live and historical visualizations of movement and presence for events such as conventions, may provide valuable insights in which parts of the events being most and least popular. This may be useful in a live perspective for the staff members managing the event in terms of resources and security, as well as historical data for determining which event attractions being the most popular. This can affect the planning of how to conduct the next event, for example to increase potential revenue.

6.3 Shopping Malls

Monitoring the human mobility patterns within shopping malls entails several interesting possibilities. By identifying which parts of the mall having the most human traffic, one identifies the most attractive store locations. Also, the locations with the highest mobility might be the most attractive locations to place advertising. The most trafficked locations in the mall could entail the highest advertising prices. In addition, one could identify connections between stores by looking at the paths taken by customers. If a large number of customers visits store A before visiting store B, a clear relationship between store A and B might exist. Thus, these stores might benefit from any form of cooperation, such as advertising for each other as long as they are not direct competitors[15]. Comparing the mobility in the malls with the total turnover of the stores within the mall might provide interesting insights in terms of calculating the share of visitors actually purchasing merchandise from the stores. Looking at the mobility during campaigning periods compared to normal periods might also be useful in determining whether the campaign is considered successful, in addition to the turnover results. As with the other facilities, general benefits from maintenance and security also follows with a system visualizing indoor human mobility patterns.

6.4 Public Transportation

With public transportation follows masses of people. Travellers on the move are constantly moving through train stations, bus terminals and airports. Monitoring the traffic in such places might help the transportation companies to adjust their resources accordingly. Even at bus stops on the side of the road, a system could detect the number of people present and alert the central coordinators if extra buses are necessary.

6.5 Summary

Common for all facility types are the usefulness of monitoring indoor human mobility patterns in order to delegate resources, maintenance and make possible changes in the facility architecture. Monitoring the general amount of movement can be done by using the heatmap functionality in NTNU CMA. Looking at combinations between buildings or eventually stores or other parts of a building, allows for extensive insights into how people are moving between locations, all the way down to hard numbers. This can be done in the Buildings functionality of NTNU CMA. Identifying the popular entrances and exits like in NTNU CMA can also help facility owners to allocate resources in a profitable matter, while looking at the accuracy of the registered data can provide information on where the wireless infrastructure should be improved. The above possibilities may allow facility owners to save costs as well as improving their services, resulting in increased revenue.

Chapter 7

Conclusion and Recommendations for Further Work

The following chapter concludes the findings in this project before a discussion of the results is conducted. Lastly, recommendations for future work with the findings are elaborated.

7.1 Conclusion

This research has examined the different possibilities in which indoor human mobility patterns may be useful for potential stakeholders, as well as identifying the optimal methods for the visualization of this information. The main focus has been to determine the usefulness of the provided information, conveyed by a prototype web application (NTNU CMA) able to analyze and visualize the mobility patterns on NTNU Gløshaugen. Thus, the prototype is aimed at demonstrating how indoor positioning data may be utilized in a useful way for different potential stakeholders. The research questions from section 1.4 are presented below, and are answered in this section.

1. Which types of visualizations of indoor position data may be useful in the jobs of potential stakeholders?

2. Which methods can be utilized in order to process and analyze position data to produce mobility patterns useful for potential stakeholders?

The results in chapter 5 concludes that the information provided by analyzing indoor human mobility patterns reflect expected tendencies in human behaviour on campus, as well as how special events on campus impact the mobility patterns. The same chapter also discovers several weaknesses in the data accuracy and processing methods which need to be addressed in order to obtain an optimal result. Also, it answers research question 1 by presenting which visualizations from NTNU CMA being useful in their jobs. These visualizations are mainly those displaying the use of building entrances and exits, movements between buildings, and movements within buildings. Chapter 4 shows that the available data is not optimal in it's present form, and should be made available in a more effective platform than raw text files. It also answers research question 2 by explaining the methods for processing and analysis being utilized in order to produce useful mobility patterns. These methods are mainly detecting movement in paths of single users, as well as determining which buildings the paths are passing through. Section 4.5 uncovers limitations related to the methods utilized in NTNU CMA in terms of performance and data accuracy. Section 5.3 reveals that the information on indoor human mobility patterns is useful for several potential stakeholders, such as facility management, marketing, sales, indoor resource allocation and security. An important conclusion is that the visualizations of the information need to be tailored for the different usage scenarios of distinct stakeholders in order to be useful in their daily operations. Also, the applications would have to be easy to use. Even though usability is not a main focus for NTNU CMA, interviews in chapter 5.3 reveals NTNU CMA is intuitive, but the performance needs to increase for any potential production version.

7.2 Recommendations for Further Work

Since the purpose of this project is to create a prototype with the goal of identifying the types of information and visualizations from indoor human mobility patterns which might be useful for potential stakeholders, only a limited application is created. Therefore, this section offers recommendations for future work towards creating a more fulfilling product for these stakeholders.

7.2.1 Create a Structured Database for Position Data

To be able to analyze and process the indoor positioning data in an effective way, the dataset in which one is working with needs to be well-structured. NTNU CMA's dataset is retrieved from a JSON file which has to be read and analyzed in order to obtain useful information. Placing this data in a structured database system such as SQL[45], allowing one to perform direct queries towards the data, will be substantially more efficient than reading from a file. Also, the position objects should be better structured. In the current state, the campus name, building name, and floor number are all clustered in one string property called ”hierarchy”, as explained in section 4.4.1. For easier queries, these three should all have their own property fields, resulting in a position object like the one below figure 7.1. Building and campus names may also be replaced by ID-numbers, eliminating the issue from this project where buildings have different names across applications. This would also remove the potential problem of buildings changing names, which would cause problems with historical data. In order to avoid further confusion, the error where latitude and longitude are swapped should be fixed. An overall architecture of how the improved application utilizing a database may look like is illustrated in figure 7.1.

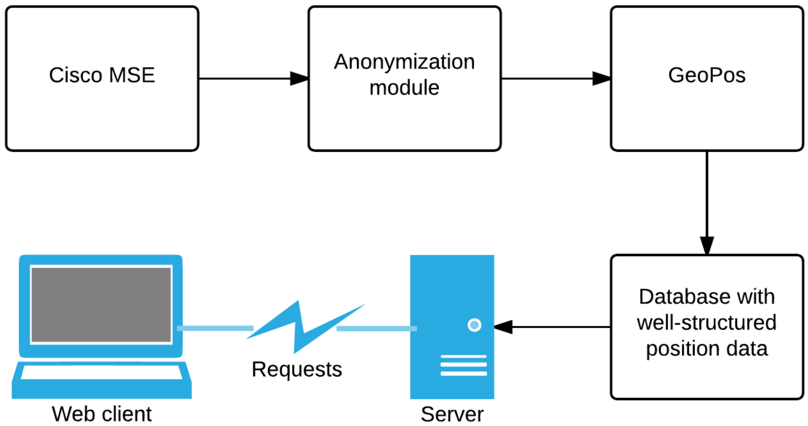

Figure 7.1: The overall architecture of a possible improved application. The web-application is running in the client browser, performing requests towards the server which in turn reads data from the database containing positioning data. This database contains data from GeoPos, which gets the data from Cisco MSE through the anonymization module.


```
{
    "campus": 1,
    "building": 5,
    "timestamp": 1412121602,
    "longitude": 10.406423365692884,
    "salt_timestamp": 1412121602,
    "latitude": 63.414807488500585,
    "id": "331",
    "accuracy": 12.19199998146816
}
```


7.2.2 Analyze Movement Between Rooms

As NTNU CMA is able to register movements between buildings, interviews with potential stakeholders from section 5.3 reveals that visualizing movements between rooms internally in buildings might be interesting. This can be performed by using the room coordinate bounds, which eventually should be available through the MazeMap API[12], and assign positions to these bounds together with the floor number to identify the current room. If possible, the room numbers can have their own property fields in the position objects, resulting in that the applications do not have to calculate the room by using the coordinate bounds.

7.2.3 Utilize Better Algorithms for Detecting Movement

The two methods for detecting movement between buildings presented in NTNU CMA, namely ”All movement” (4.4.2) and ”Start/stop” (4.4.2), are not optimal in that the former is registering buildings which are just being passed, while the latter is not capturing all movements. Developing more accurate algorithms for identifying movements between buildings and rooms should be a priority. By using a more powerful server system than the one used in NTNU CMA, more complicated algorithms should be done effectively. For example, one can utilize the ”All movement” method with the addition of checking the timestamp of the next position objects. If all positions within the next given number of minutes are in the current building, it is registered as a destination.

7.2.4 Tailor an Application for a Stakeholder

The interviewes in section 5.3 reveals that all potential stakeholders will require the applications to be tailored for their specific use cases in their daily work life. Functionalities aiding the staff of such stakeholders in specific work tasks should be developed. Some functionalities may be common for several different stakeholders, such as a simple heatmap of movement in a selected time frame. However, it will be interesting to create a complete application for one specific stakeholder to aid them in one or more specific work tasks.

References

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