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Utilizing Building Information Models with Mobile Augmented Reality and Location-Based Services

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Abstract

The increasing availability of Building Information Models in the construction industry open for maintenance applications capitalizing on this opportunity. In this thesis Mobile Augmented Reality and Location-Based Services are utilized to develop an application targeting maintenance workers with access to Building Information Models.

Building Information Models contain information about every object in a building, down to the millimeter. Having access to this detailed and up-to-date information on a mobile device help workflow efficiency. In a maintenance work environment such a solution liberate the personnel from carrying folders with blueprints of the entire building. Adding Mobile Augmented Reality technology enables the maintenance worker to be presented a visualization of the object, without the need for further interpretation. The mobile device is used to superimpose the object on the real world in its precise location. To retrieve an accurate location for the object, Location-Based Services are utilized.

The application is evaluated to examine the applicability in a maintenance work environment. Two tests where conducted. The first at University of Tromsø, and the second at the Norwegian University of Science and Technology in Trondheim.

The results from the evaluation showed that the proposed solution provides high usefulness as a tool in daily maintenance work operation.

Sammendrag

Den økende utbredelsen av bygningsinformasjonsmodeller i byggebransjen åpner for applikasjoner rettet mot vedlikeholdsarbeidere. I denne oppgaven er mobil utvidet virkelighet og lokasjonsbaserte tjenester benyttet for å utvikle en applikasjon rettet mot vedlikeholdsarbeidere med tilgang på bygningsinformasjonsmodeller.

Bygningsinformasjonsmodeller inneholder informasjon om hvert objekt i en bygning, med millimeters presisjon. Effektivitet i arbeidsflyt kan hjelpes ved å ha tilgang til slik detaljert og oppdatert informasjon på en håndholdt enhet. En slik løsning fører til at vedlikeholdsarbeidere slipper å bære rundt på plantegninger over hele bygningen. Ved hjelp av mobil utvidet virkelighet blir vedlikeholdsarbeideren presentert en visualisering av objektet, uten behov for ytterligere tolkning. Den håndholdte enheten brukes for å legge objektet over virkeligheten på sin rette plassering. Lokasjonsbaserte tjenester benyttes for å motta informasjon om presis plassering av objektet.

Applikasjonen blir evaluert for å undersøke anvendbarheten i hverdagen til en vedlikeholdsarbeider. To tester ble gjennomført. Den første ble gjennomført på Universitet i Tromsø, og den andre ble gjennomført på Norges Teknisk- og Naturvitenskaplige Universitet i Trondheim.

Resultatene fra evalueringen viste at den foreslåtte løsningen gir høy nytteverdi som verktøy i daglig vedlikeholdsarbeid.

Problem description

The CampusGuide provides a platform for wayfinding to different rooms at the NTNU campus, supporting both in-door and outdoor navigation. In another project at NTNU augmented reality solutions are created to visualize information of interest in a geo-located manner.

The task relates to integrating functionality from both these type of solutions, in combination with building information models, making it possible for maintenance workers to explore buildings, based on positioning of the user.

A prototype shall be developed and evaluated in a rigorous manner. The project is expected to follow a design science research approach, producing and evaluating an artifact (e.g. an App) in a scientifically sound manner. Code to be produced should be made available under an open source license. It is preferred that the project report is written in English. The results from a good thesis should be possible to use as a basis for developing a scientific publication.

Supervisor: Professor John Krogstie, IDI, IME, NTNU

Preface

This thesis concludes my Master of Science at Norwegian University of Science and Technology (NTNU). The research was carried out from the fall of 2012 to the spring of 2013, and conducted partially in Trondheim, and partially in Tromsø. The project was supervised by professor John Krogstie, and the thesis was submitted to Department of Computer and Information Science (IDI), in the Faculty of Information Technology, Mathematics and Electrical Engineering (IME), at the Norwegian University of Science and Technology (NTNU).

My supervisor John Krogstie has provided great guidance, with a flexibility exceeding my expectations. A sincere thank you for this. I also want to thank maintenance manager Eivind Jensen for his perspectives on maintenance. Finally, thanks for the massive support I have received from my family and friends which have definitely helped me through this unique experience.

Martin Nagy
Trondheim, May 31, 2013

Abbreviations

API Application Programming Interface

AR Augmented Reality

ARCBA Augmented Reality Context-Based Application

ASS Application Specific Survey

BIM Building Information Modeling

CAD Computer-Aided Design

GUI Graphical User Interface

GNU GNUs Not Unix

GOMS Goals, Operators, Methods, and Selection Rules.

HIG Human Interface Guidelines

HUD Head-Up Display

IME Faculty of Information Technology, Mathematics and Electrical Engineering

IDI Department of Computer and Information Science

IFC Industry Foundation Class

ISO International Organization for Standardization

LBS Location-Based Services

MAR Mobile Augmented Reality

NTNU Norwegian University of Science and Technology

PC Personal Computer

POI Point Of Interest

SD Standard Deviation

SUS System Usability Scale

UIT University of Tromsø

USPTO United States Patent and Trademark Office

VR Virtual Reality

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Chapter 1

Introduction

This chapter is an introduction to the thesis and give an overview of the driving forces behind. The research use aspiring technology in mobile devices in combination with Building Information Models to examine opportunities in maintenance of buildings. The motivation for focusing on maintenance is elaborated in this chapter. Next, the chapter identifies the project definition, and describe the main contributions of this thesis. Finally, the structure of the thesis is presented.

1.1 Motivation

Building Information Models (BIM) increase in availability and leads to opportunities for improving efficiency in the planning, construction and management of building projects [5][62]. Cost-efficient cross-collaboration using BIM is appealing to many companies, leading to expectancy of even wider acceptance of BIM in the coming years [15]. BIM has enabled the use of multiple dimensions. As a result, focus has switched from unidirectional design and planning, to obtain information about every object in the building and their relations (elaborated in section 2.3). Which in turn enable development of applications suited for maintenance.

BIM is currently extensively applied in planning-, construction- and management phases of building projects. Still, 60 percent of the building lifecycle cost is related to building operations [1]. The subsequent building operation phase can also gain greater efficiency from the increased deployment of BIM. The research currently utilizing BIM in an operational context does not focus on building maintenance [26].

Mobile Augmented Reality (MAR) has been applied in a variety of different applications [63]. The current research on combining BIM and MAR mainly focus on the planning and construction phases [60][51](also described in section 2.4).

As little research has been made on how BIM and MAR can be used in a operation and maintenance context, this study examines the field and proposes a solution for a such system.

1.2 Project Definition

This project has investigated a possible implementation of a maintenance tool for mobile devices, when access to building information is available, as well as assessing such a tool.

First, an extensive literature review was executed, to build knowledge on the field of research, and to have a better foundation to identify opportunities for developing a solution. Secondly, the problem was further specified. Furthermore, the continuing research was conducted by following a Design Science Research Approach.

Resulting from the research one artifact was developed. The artifact was a prototype for an application targeting maintenance workers. The application utilized Building Information Models, Mobile Augmented Reality, and Location-Based Services to achieve its purpose. In the end, the application was evaluated with focus on usability and usefulness.

1.3 Contributions

In this thesis a literature review has been conducted with special focus on combination of Building Information Models and Mobile Augmented Reality. Building Information Models for providing access to building data, and Mobile Augmented Reality to enable visualization of the data on a mobile device.

The main contributions of this thesis are:

- Exploration of available technology for mobile devices to contribute in maintenance work.
- Implementation of a prototype utilizing Building Information Models, Mobile Augmented Reality and Location-Based Services in a maintenance work environment.
- Evaluation of such a system as a maintenance tool, focusing on usability and usefulness.

1.4 Thesis Structure

The thesis is organized in the following manner:

Chapter 2 - Background Theory is a collection of the current knowledge in the field of study, with focus on Augmented Reality and Building Information Models. The chapter also cover some examples of research areas combining the two.

Chapter 3 - Research Design and Methodology describes the methodology used to conduct the study, and how the test was performed. In addition this chapter cover usability principles used in the application.

Chapter 4 - Problem Elaboration describes the problem further with assistance from storyboards. Requirements for the solution are derived from this problem elaboration.

Chapter 5 - Presentation of Solution is an overview of the solution, and the chapter is divided into functionality overview and technical details.

Chapter 6 - Results from Evaluation contains all relevant information about the testing on maintenance workers from the University of Tromsø (UIT), and the Norwegian University of Science and Technology (NTNU).

Chapter 7 - Discussion provides a discussion on the most relevant results from the evaluation, and assess the applicability in a maintenance work environment.

Chapter 8 - Conclusion and Future Work concludes the thesis with the current discoveries, and look at possible future improvements.

Chapter 2

Background Theory

This chapter aims at elaborating the current state-of-the-art, and providing enough knowledge to understand the most important parts in the field of study. This chapter start with a section about applications which utilize location. The two applications chosen in this section are relevant for the application created in this thesis, by the use of similar technology (The Historical Tour Guide), and the use of Location-Based Services (The CampusGuide). The next section contain an explanation of Augmented Reality (AR), and how it is relevant for this thesis. Then, a section where Building Information Model (BIM) is explained follows. At the end of this chapter, prototypes which utilize both AR and BIM, is presented.

2.1 Applications Using Location

This section consist of relevant applications which utilize location in different ways. The Historical Tour Guide applies a simple form of Augmented Reality (AR), but it is also relevant for its similarity, such as the use of relevant design principles in an AR application. The CampusGuide application applies Location-Based Services, and the CampusGuide Application Programming Interface (API) is used for retrieval of in-door location at the Norwegian University of Science and Technology (NTNU) campus.

2.1.1 The Historical Tour Guide

The Historical Tour Guide application was developed in a study by Haugstvedt and Krogstie [22]. The study examined the relationship between a Mobile Augmented Reality application (MAR), and the usage of such technology in the cultural heritage sector, by conducting research on technology acceptance. The cultural heritage application was developed, and two surveys was distributed, to identify opinions. The application was evaluated with respect to four factors; perceived usefulness, perceived ease of use, perceived enjoyment, and intention of use. The results from this study stated that the intention of use was directly influenced by perceived usefulness and perceived enjoyment. Using the results as a foundation the study also suggested some practical steps to consider when developing and deploying such applications.

One of the artifacts deriving from the study was the application The Historical Tour Guide. It was developed as an artifact in the research of technology acceptance in the cultural heritage sector, still, the application is relevant for this thesis. Under the development of the Mobile Augmented Reality (MAR) application, general principles of usability was explored in a MAR environment, as described in section 3.3.

The Historical Tour Guide is based on an application developed in a study by Mora et al. [39] named CroMAR[1]. In this study, the application focused on supporting reflection on crowd management of events. Mobile Augmented Reality (MAR) was used to visualize the information gathered, to help participants reflect upon and learn from, the events execution. In the exhibited prototype, gathered information is presented on a mobile device intended to be used out in the field, with the ability to browse information on a temporal axis. The gathered information can come from sources such as; photo captured by a mobile unit, event participants tweeting messages, and applications supporting the crowd management work by recording radio communication during the event. All information accessible to the application is intended for use in reflection of an event.

2.1.2 The CampusGuide

The CampusGuide application was developed at Norwegian University of Science and Technology (NTNU) by Trådløse Trondheim, and was released as a beta in 2011. The CampusGuide application was a result of work in connection to Wireless Trondheim Living Lab [3], following up work on Mobile Student Information System (MSIS) [4] as described by Krogstie [31]. The application was developed to help students navigate on a part of NTNU campus called Gløshaugen[2]. Gløshaugen has a 350,000 m2 floor area, with 60 buildings and 13,000 rooms. The size and complexity of this area result in a need for helping visitors and students to find their way. Most of the other navigation systems can only be used out-door, where a GPS (Global Positioning System) signal is available. In contrast to systems which is limited to out-door use, the CampusGuide can also be used in-door, as it retrieve information about position from more than 1,800 wireless routers spread around the campus. The CampusGuide provides easy to use in-door and out-door directions for the user, as seen in figure 2.1[3].

A comprehensive description of the applied technology in the The CampusGuide Application Programming Interface (API) can be found in the section 5.2.4.

[1] CroMAR: http://research.idi.ntnu.no/CroMAR/
[2] NTNU news: http://www.ntnu.edu/news/campus-guide
[3] CampusGuide pictures: http://www.ntnu.no/aktuelt/pressemeldinger/11/campusguiden/bilder

Figure 2.1: The CampusGuide navigation system in use

2.2 Augmented Reality

Azuma [6] described Augmented Reality (AR) as a technique where users are allowed to see the real world, with virtual objects superimposed upon or composited with the real world. To achieve this effect, AR either use semi-transparent displays, or devices with a front-mounted display in combination with a back-mounted camera.

Augmented Reality has come a long way since the first prototypes in the 1960s, and the use in new application areas have been accelerated the latest years with access to smaller and more powerful devices. This section covers the history of AR, a brief explanation of what the term Mobile Augmented Reality (MAR) include, the techniques AR use to track the user, and how AR can position information as overlays and ensure it is placed correctly relative to the surroundings.

2.2.1 History of AR Technology

In 1968 Ivan Sutherland [57] described a way to create a head-mounted three dimensional display. The system would make objects seem to appear in the space in front of the user. To accomplish this he mounted a display in front of each eye of the user, and projected two different pictures onto these displays. The human eye perceive a two dimensional picture on each eye, and combined, the three dimensional (stereoscopic) effect is produced in the visual cortex in the brain. To create the three dimensional effect Sutherland would project a slightly different picture on each of the screens to make the brain create the three dimensional picture, as seen in fig 2.2. The fundamental significance to create credible three dimensional pictures, was to move the displayed objects according to the orientation of the users head. All displayed objects had to be positioned relative to the real world, making the objects seem to "stick" in the real world.

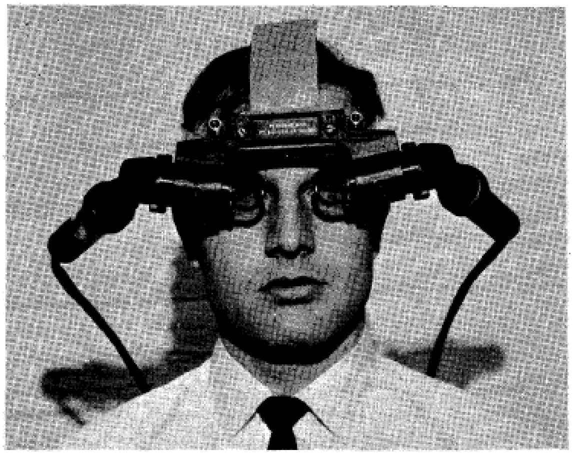


Figure 2.2: Head-mounted system with a display in front of each eye [57]

Milgram and Kishino [37] introduced the "virtuality continuum", helping to illustrate the home of AR, as seen in figure 2.3. The "virtuality continuum" is a graphical representation showing an axis from a complete real world to a complete virtual world. Virtual Reality (VR) is a complete virtual based world, and require a graphical representation of the entire world on a screen. Augmented Reality (AR) differentiates from Virtual Reality (VR) in that it use the real world as a foundation, and only superimpose virtual objects onto the real world, to augment the environment with information.

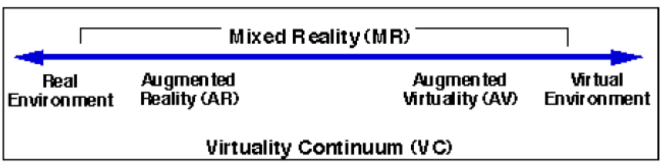


Figure 2.3: Simple version of the virtuality continuum [37]

Development of the technology was continued, but due to limitations in processing power in the 1970s and 1980s, creative ideas was hard to realize in prototypes. In the 1990s, rising progress in development of mobile devices led to a higher rate of progress in AR research.

The term Augmented Reality (AR) was first introduced by Thomas Caudell and David Mizell [12] while working at Boeing. An aircraft consist of many small parts that need to be assembled in a rigorous manner. To reduce expenses and delays in the assembly of parts, they researched approaches for digitalization of assembly guides and wiring lists. By using a Head-Up Display (HUD) mounted in front of the users head, the assembly information could be shown relative to the location of where the assembly was to occur. The concept of HUD technology is seen in figure 2.4.

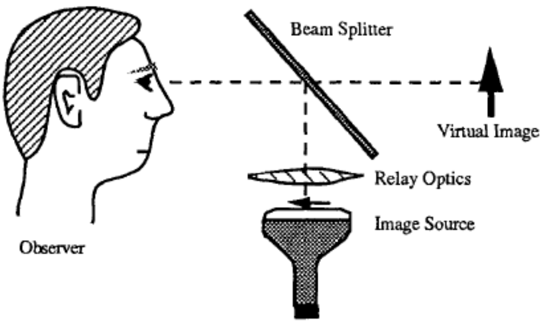


Figure 2.4: The concept of Head-Up Display (HUD) [12]

In the recent years, several advancements have been done in the area of AR [65]. A study by Zhou et al. [65] examines the advancements from the first AR conference in San Francisco, United States, in 1998 (IWAR 98), up until the AR conference in Nara, Japan in 2007 (ISMAR 2007). Since the first AR conference, the most popular topic for research has been core AR technologies such has tracking techniques. An elaboration of tracking techniques is found in section 2.2.3. The second most popular research topics is interaction techniques and Mobile Augmented Reality (MAR). In conjunction with the maturation of AR Zhou et al. [65] expect the focus of AR to move from exploring fundamental technologies, to applying those technologies in real world applications. This expectation is further acknowledged by the initial research focus on AR applications for use in a work environment. An assisting factor for this trend has also been smaller devices and increased processing power.

2.2.2 Mobile Augmented Reality

Mobile Augmented Reality (MAR) is characterized as a technology providing the same features as Augmented Reality (AR), but without the physical restrictions of a research facility or a testing area location. Feiner and Hollerer [18] identified six components necessary to provide true MAR:

Computational platform to process all relevant information, and to compute the visualization of AR objects presented on the display.

Display to present the virtual objects to the user.

Registration of environment. Registration of camera input and head orientation helps to present the AR objects correctly aligned with the real world.

Wearable input and interaction technologies to enable a mobile person to work and collaborate with other users.

Wireless networking for instant communication with other people and central databases.

Data storage and access technology to provide the user with all context relevant data in the environment intended for augmentation.

Early Wearable Computing

With the list of requirements for providing MAR, Feiner and Hollerer [18] also describe a set of challenges that arise. One of the most prominent challenges in a mobile device is the need of processing data, resulting in straining the battery. In the late 1990s devices had increased in mobility, such as getting smaller and consuming less power. With this shift in trends MAR moved closer to realization in wearable computers, as the development is documented by Mann [34], and later extended by Amft and Lukowicz [2].

One solution to MAR and wearable computing is found in the work by Feiner et al. [17]. In this project a prototype of a 3D Mobile Augmented Reality system was created. The desire of the project was to focus on exploring the urban environment, especially the campus area, and retrieve relevant information according to the location and orientation of the user. The prototype consisted of a Head-Up Display (HUD), a handheld computer, and a backpack computer. The combined weight of the system was approximately 18 kg, a system in 1997 still considered a wearable computer, unlike today.

Modern Wearable Computing

Today, the concept of wearable computing is familiarized in mobile devices, such as mobile phones and tablets. On this platform several MAR applications are provided [10].

One of the most recent and highly discussed projects in MAR is the Project Glass from Google[4]. Project Glass aim at giving the user access to all information of Google's services by the help of presenting static information, in addition to utilizing MAR. The device is a set of lightweight glasses with a transparent screen attached to the lens, as seen in figure 2.5 from patent US0D0659741 at United States Patent and Trademark Office (USPTO)[5].

[4]Google Project Glass: http://www.google.com/glass/start/

[5]United States Patent and Trademark Office: http://patft.uspto.gov/

In a similar setup, the efficiency of using wearable computing and MAR technology has been investigated. In a study by Henderson and Feiner [24], a prototype for repair work on a military vehicle was developed. MAR contributed to a significant increase in effectiveness.

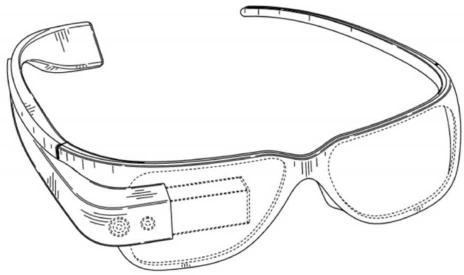


Figure 2.5: Google Project Glass patent illustration

2.2.3 Tracking Location and Orientation

A vital part of Augmented Reality (AR) is to create a credible experience. In AR, objects are superimposed on a real world. To create a convincing superimposed object, the object need to be aligned with the surroundings. To achieve this the users location and orientation needs to be accurately tracked. When tracking the current position and subsequent movement of the user, the application can use different methods to retrieve up-to-date position information. As presented in the study by Hazas et al. [23], and seen in figure 2.6, the accuracy can vary from 1 cm, with an ultrasonic device, to 100 m with a course-grained estimation using the mobile antennas.

The available tracking methods when applying AR in an application on an iPad device, depends on the connectivity features in the iPad. In an unaltered iPad, tracking of the user can be conducted by two methods. The method applied can be a static identificator or a dynamic identificator, as elaborated in this section.

Tracking with Static Identificator

A static tag, such as a QR-tag, is placed on a wall, and the specific location of the tag could be defined in a system database. When the tag is in the visual field of the camera on the device, an accurate location can be determined by registration of the tag. Augmented Reality (AR) objects can also use this as a basis for placing virtual objects in the view.

Using camera and tags for tracking can result in very high accuracy. A challenge arise when the tag is no longer visible due to obstruction or long distance to the tag. Implementing this technique in an application targeted for construction or

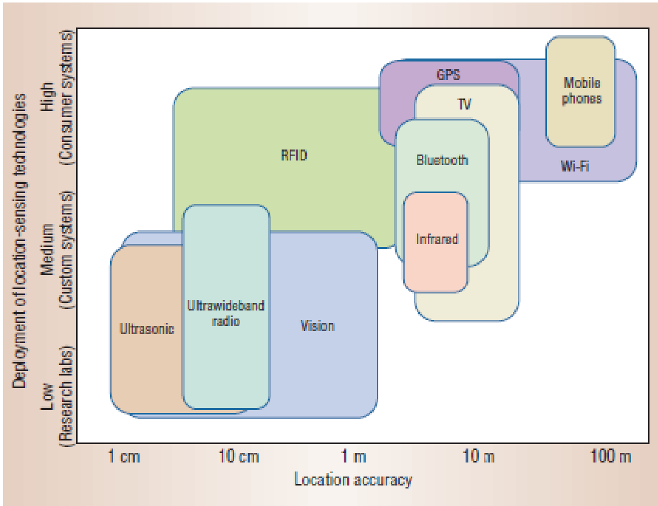


Figure 2.6: Accuracy in methods of location retrieval [23]

maintenance rises another challenge; the walls to place tags on may not yet exist. Advancements has also been done in the purely visual tracking system, without the use of tags [14]. Still, a pure visual tracking system require a lot of processing power, and an extensive database with location and object information.

Tracking using a static identificator is not chosen for the prototype in this thesis, as tags are considered unreliable in a campus and maintenance environment.

Tracking with Dynamic Identificator

Location of the device could be retrieved by using the Global Positioning System (GPS) or wireless network signals. A compass provides the opportunity to find the orientation of the device. The combination of these two techniques are enough to determine the view of the device; where the device is, and where it is pointing. To get AR to operate correctly this information is needed.

Using this tracking technique result in less accurate location and orientation than the static identificator. This is due to two issues; greater margin of error in the retrieved location, and slow response of retrieving changes of location and orientation. As the location and orientation is less accurate, objects placed in the view can get unintended movements, as further described in section 7.3.5.

Tracking using a dynamic identificator is the chosen technique for the prototype in this thesis. The tracking technique do not require any tags, the usage is not restricted to the environments having walls, or any tags being visible to the camera.

2.2.4 Visual Augmentation

The superimposed objects in Augmented Reality (AR) could be presented as 2D (including text labels and pictures) and 3D objects. Feiner and Hollerer [18] states that augmentation is not only restricted to the visual sense. Hearing, touch and smell can also be augmented. E.g. technology such as three-dimensional sound can augment the hearing sense. In this thesis the focus is on augmentation of the visual sense.

To achieve the technical part of the visualization, the software interface OpenGL is utilized, as further described in section 5.2.1.

Objects as Overlays

The information used as overlay on the screen, can be either of 2D or 3D objects. Butchart [10] describes several applications that use either 2D- or 3D objects. Below are a the two techniques described in relation to their distinct properties:

2D object is a text label or a picture. The text label is usually a clickable Point-of-Interest (POI). More information is received at the specific location by clicking on the POI. AR browser applications [10] enable the user to explore the environment, by visualization all POI nearby. Several POIs could be placed within a small area without cluttering the screen, as described in section 7.3.4. Pictures are usually used as a non-transparent or semi-transparent layer on top of an object, such as superimposing an old picture on a new building as described in section 2.1.1.

3D object is usually used when a complex representation is required, in contrast to a simple 2D object. Building Information Model (BIM) construction applications can visualize a 3D model superimposed on the building site, even though construction of the building has not started. Having large 3D objects to visualize can introduce several challenges, as discussed in chapter 7.

Objects Relation to Environment

There are two methods of attachment when superimposing 2D and 3D objects. The attachment method is either relative or absolute to the environment:

Objects attached relative to the environment The object is placed on a point, but can rotate around its own Y-axis. In a situation where the user moves around the object, the object will always face with the front against the user. This is commonly used for 2D objects, such as text tags and pictures. In general, objects of a small size which need to be reachable in 360 degree direction.

Objects attached absolute to the environment The object is placed on a point, but unlike above, it can not rotate around its own Y-axis, causing the object to always face a particular direction. In a situation where the user moves around the object, the object will not move, and the user will have the ability to see the back side of the object. This is commonly used for 3D objects, and also some 2D objects such as pictures which do not need to face the user.

2.3 Building Information Modeling

Building Information Modeling (BIM) is considered to be two things: the process of development in engineering, and the product in the shape of the information model. In this thesis, the term BIM will be used as the latter. The process of development include the use of computers in planning, design, construction and operation of buildings [5]. The product in the shape of the information model consist of objects with properties and relations, which allows visualizations of many different aspects. BIM allow a high detail level and composition of information, which in turn is valuable in assisting decision processes.

In order for BIM to work as intended, the power and significant difference from simple 3D modeling of projects has to be emphasized. BIM can consist of several dimensions of information, that allow storage of the whole lifecycle in construction information. There are five widely recognized dimensions in a BIM[6].

- **0D (zero dimensional)** Model of quantity lists.
- **2D (two dimensional)** 2D visualization of the floor plan.
- **3D (three dimensional)** 3D visualization of the floor plan.
- **4D (four dimensional)** Model of time requirements.
- **5D (five dimensional)** Model of cost requirements.

The BIM can include metadata about every object present, and their relationship. I.e. for a door in a building project, retrieved information can be such as door placement, color, manufacturer, if it is a fire door, sound proofing, cost, mounting manual, and more. More information can also be added later in the lifecycle as more properties are known.

2.3.1 History

A draftsman equipped with pencil and paper has been a widely used tool in the history of civil engineering. In the 1980s, the industry applied computers in their work as a support for digitalization of the 2D floor plan models, known as Computer-Aided Design (CAD). Since then, all other actions which could reduce costs has been sought. The digitalization allowed for further collaboration, and the requirement for more information in the CAD models became a reality. The Internet era provided even more opportunities for easy exchange of building information [48]. As the industry evolved, the pencil and paper have gradually been replaced by a

[6]Statsbygg: http://www.statsbygg.no/FoUprosjekter/BIM-Bygningsinformasjonsmodell/BIM-En-kortfattet-innforing/

computer with a digital model. It was adopted by more participants in the industry, research was given emphasis, and it resulted in the development of BIM. BIM is a standard currently in development. The development and standardization process is driven forward by BuildingSMART[7], an organization which focus on open and neutral standards.

2.3.2 Usages

Accompanied by the availability of BIM a wide range of computer software developers within the construction and maintenance industry utilize BIM [62].

Rendra[8] is a newly started company at the NTNU entreprenurial school. They focus on providing BIM on portable devices, for planning and construction. There are also other companies focusing on similar products, such as Autodesk[9]. All these products are focused on giving a virtual reality visualization on site, not currently providing Augmented Reality (AR). Projects which link BIM and AR are further described in section 2.4.

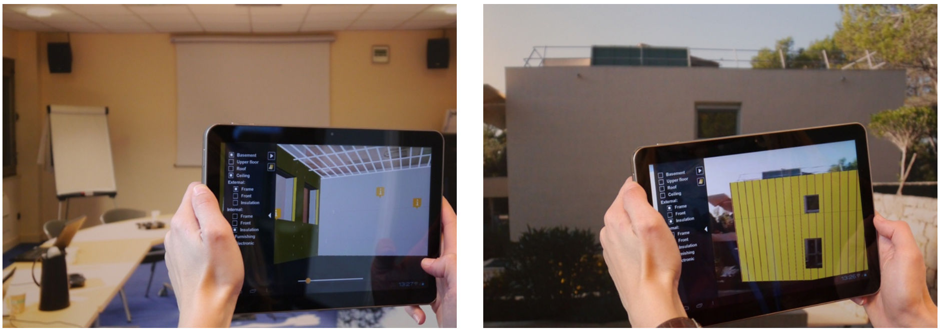
2.3.3 Benefits

Azhar et al. [5] identified the key benefit of BIM as an accurate geometrical representation. By working with pencil and paper, the accuracy of the 2D drawing constructed is dependent on the abilities of the draftsman. The drawing also represent a view from one perspective, i.e. one floor. If changes are necessary, it has to be changed accordingly in every 2D drawing of every floor. BIM consist of information used as a base for the model created, and the redundant work of updating all 2D drawings is removed. The application of computers does also increase accuracy as the occurrence of mistakes is decreased.

In addition, seven other important benefits was determined by Azhar et al. [5].

- **Faster and more effective processes** Easy sharing of information.
- **Better design** Design proposals can be rigorously analyzed.
- **Controlled whole-life costs and environmental data** Better prediction of lifecycle costs.
- **Better production quality** Higher quality in documentation output.
- **Automated assembly** Data can be fed into systems which automate construction of parts.
- **Better customer service** Accurate visualization helps costumers understand design proposals.
- **Lifecycle data** Requirements, design, construction and operational information, are linked and available to support management decisions.

[7] BuildingSMART: http://www.buildingsmart.org/
[8] Rendra: http://www.rendra.no/
[9] Autodesk: http://www.autodesk.com/



(a) In-door (b) Out-door

Figure 2.7: Lifecycle Building Card prototype

2.4 Projects Combining AR and BIM

A lot of research has been conducted on combining Augmented Reality (AR) and Building Information Models (BIM), but currently none of these solutions has been commercialized. This section explore some of the current research.

2.4.1 Lifecycle Building Card

Graf et al. [21] presents a vision of building management tools called Lifecycle Building Card. The concepts presented are theoretical and practical ways to utilize BIM to support maintenance activities.

A prototype utilizing Lifecycle Building Card has been developed by Dr. Sabine Webel and Dr. Ulrich Bockholt at Fraunhofer Institute of Computer Graphics Research. The prototype was showcased at the Hannover Messe 2011[10]. The application support the user in maintenance planning, such as enabling the user to visualize different insulation types with AR, and storing the information in a BIM, as seen in figure 2.7[11]. The prototype does not utilize location-based services in in-door positioning.

2.4.2 Designing and Planning with AR

Tonn et al. [60] describes a solution for supporting design and planning in existing buildings with the use of Building Information Models (BIM) and Augmented Reality (AR). The prototype developed give the user the ability to sample color and materials of existing parts of the building. This prototype show that assessment of color and materials of the building was easier to grasp as it was superimposed on the environment with a 1:1 scale.

[10] Fraunhofer Press Release: https://www.igd.fraunhofer.de/en/Presse/Presseinformationen/Energy-saving-houses-Darmstadt-researcher-becomes-German-High-Tech-Champi

[11] Fraunhofer GHTCA: http://www.fraunhofer.de/en/quick-links/scientists/german-high-tech-champions-awards-in-green-buildings.html

The project conclusion pointed out that there is a major potential in using AR to support color and material design.

2.4.3 Steel Column Inspection

Shin and Dunston [51] proposes a solution where Building Information Models (BIM) and Augmented Reality (AR) are utilized for inspecting steel columns in buildings. The prototype was developed for inspection of anchor bolts in a steel column.

The study indicated that simpler and faster setup of an AR solution can compensate for the lack in accuracy.

Chapter 3

Research Design and Methodology

This chapter start by describing the research questions, and elaborates on how the research is anchored. To find relevant results a structural approach is adopted. The subsection named research approach consist of a detailed explanation of how the study is conducted. Development of a user friendly application requires a frequent reassessment of usability. Therefore, all relevant usability disciplines are covered in depth. Finding results necessitates a way to retrieve those results. In this thesis, two surveys are used to retrieve results, and explanations of them are covered in the last section of this chapter.

3.1 Research Questions

The research investigates the usage of Building Information Models (BIM) in an Augmented Reality (AR) application. The research is focused around answering these questions:

1. Is it possible to present Building Information Models (BIM) relevant for building maintenance workers using mobile Augmented Reality (AR) and Location-Based Services?

   Even though Augmented Reality (AR) have been applied in a wide array of applications on mobile devices, there is still a dominance of AR applications focused on marketing. Today, the use of mobile devices with AR and BIM features has not been successfully applied in a maintenance work environment. Location-Based Services have been utilized to some degree in applications helping maintenance workers to do their work.

2. If yes on 1) Do maintenance workers find this possibility useful?

   Several people argue that AR as a technology have too large barriers to succeed, and could be considered a hype [63]. Others have concluded with this technology having a great potential, even after the initial "wow" factor has faded [10]. This research will figure out to which degree combining AR and BIM technology can be found useful for a maintenance worker.

3. How to assure high usability of such applications?

   There are several factors to consider to assure high usability in applications with AR and BIM. The experiences from the application development, and subsequent evaluation will provide significant insight to this question.

3.2 Research Approach

Conducting a research requires a structural approach. This thesis follow the Design Science Research Approach which seek to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts. Hevner et al. [25] states seven guidelines in which the artifact must satisfy, as seen in table 3.1.

Moreover, he states that the fundamental principle of design-science research, from which the seven guidelines are derived, is that knowledge and understanding of a design problem and its solution are acquired in the building and application of an artifact. Richey and Klein [47] states that the development of an artifact can result in a new tool, a product, or a process. Still, the research must not be mistaken for product development. Ellis and Levy [16] points out the importance to distinguish between research and product development, and defines research as; addressing an acknowledged problem, building upon existing literature, and making an original contribution to the body of knowledge.

In addition to the guidelines Peffers et al. [46] developed a Design Science Research Process Model to provide a better understanding of the process sequence, as seen in figure 3.1. In this thesis the entry point for research is a problem centered approach.

3.2.1 Design Science Research Guidelines

In table 3.1 the Design Science Research Guidelines are elaborated. The guidelines was followed in this project to ensure an optimal research project execution.

Guideline number one states that a viable artifact is to be created. In this project, an artifact in the form of an application will be developed. The application is focused on utilizing Augmented Reality (AR) in a maintenance work environment. The research artifact shall be a usable prototype, runnable on an iPad.

Guideline number two states that the objective is to develop solutions to business problems. The aim is to contribute with research in the continuous evolving area of utilizing Augmented Reality (AR) as a tool in a business environment. In all areas of business today, cost-effectiveness is given increasingly more importance. The outcome of this research will help increase efficiency in the working environment of all kinds of maintenance workers.

Guideline	Description
Guideline 1: Design as an Artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Table 3.1: Design Science Research Guidelines

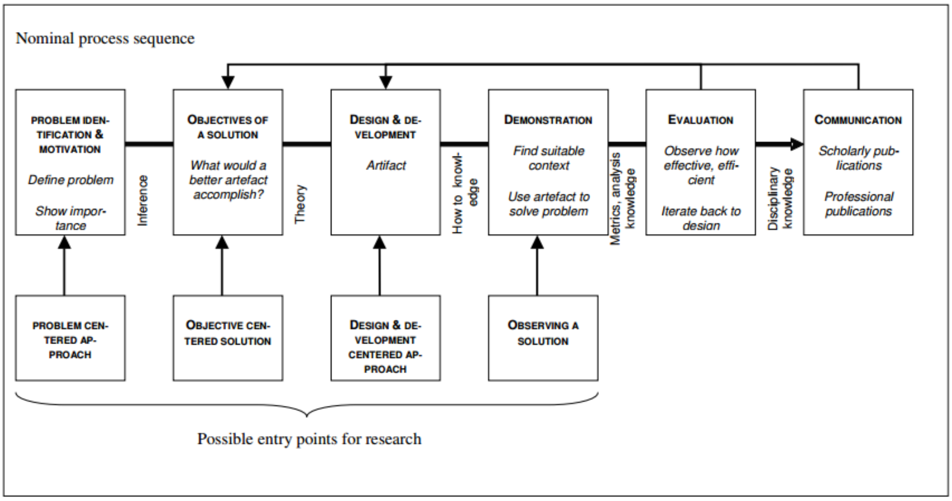


Figure 3.1: Design Science Research Process Model [46]

Guideline number three states that the artifact is to be evaluated in the light of design. As the artifact is an application, rigorous usability tests exists. The application is to be designed and evaluated with respect to well-known usability principles. The application is deployed on an iPad, and utilize Augmented Reality (AR), therefore only the relevant usability principles for this type of application will be selected and applied in the design and evaluation.

Guideline number four states that the research contributions must be verifiable and clear. All necessary documentations is included to support the possibility of repeating the research and verifying the results. By providing a well documented thesis, conclusions are justified. In addition, complete source code to the application, as well as both analyzed and raw results from the surveys are available.

Guideline number five states that the research relies upon rigorous methods in construction and evaluation. The methods in which the research relies upon, are focused around the application and the survey [35]. The application will be constructed and evaluated in conjunction with relevant usability principles, as described in section 3.3. The methods used in construction and evaluation of the surveys are well-known and standardized, as described in section 3.4.

Guideline number six states "the search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment". The research has been conducted with an iterative development in mind to satisfy the sixth guideline. This is illustrated in the fact that the problem description has been revised several times. In addition, the application has gone through the iterative loop of figure 3.1. The application was developed in the "design and development", used in the intended context in "demonstration", evaluated in "evaluation", and revised again in "design and development", then continued in the loop.

Guideline number seven is about communication of the results. To comply with this all research is published in this report, and is also made available online in the master thesis portal DIVA[1] at the Norwegian University of Science and Technology (NTNU).

3.3 Usability Focused Development

Usability is important to focus on when developing applications. In this thesis, the third research question cover how usability can be assured in applications with Augmented Reality (AR) and Building Information Models (BIM), which calls for an elaboration of what areas to consider in the development process.

An utility application with a low degree of usability will compromise desired efficiency in an organization. This is especially present in an utility application intended for maintenance workers. A high degree of usability is a necessity when considering the application is also intended for people with non-technical background, people with non-engineering background, or people with only brief experience with computers and similar devices. The typical kind of users in such an application are elaborated in section 4.1.

There are several approaches for developing applications with high usability. In this section, an overview is given on well-known and widely used usability principles. The International Organization of Standardization (ISO) has a concise definition of usability as described in section 3.3.1. For practical implementations a more specific list of principles is usually desirable. Nielsen [41] defined a list of ten usability heuristics used for evaluation of user interface design. The ten usability heuristics, as well as similar lists of usability principles, are elaborated in section 3.3.3. A lot of research effort has been done on this topic, and the excerpt from the most relevant research is presented in section 3.3.2.

3.3.1 Usability Standard

A widely implemented and specific definition comes from The International Organization of Standardization (ISO). ISO defines usability in the standard ISO 9241-11 as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [27]. The context of use is defined as "users, tasks, equipment (hardware, software and materials), and the physical and social environment in which a product is used".

In this situation the specified users are the maintenance people at NTNU, and the specified goals are maintenance on university building mass. The context of use is in this situation maintenance workers performing maintenance work, using an iPad to acquire relevant building information.

[1]NTNU DIVA: http://ntnu.diva-portal.org

3.3.2 Quality Assurance

Several approaches have been formulated to assure high quality in application usability.

Nielsen and Hackos [43] described five quality components for high usability:

Learnability The system should be easy to learn so that the user can rapidly start getting some work done with the system.

Efficiency The system should be efficient to use, so that once the user has learned the system, a high level of productivity is possible.

Memorability The system should be easy to remember, so that the casual user is able to return to the system after some period of not having used it, without having to learn everything all over again.

Errors The system should have a low error rate, so that users make few errors during the use of the system, and so that if they do make errors they can easily recover from them. Further, catastrophic errors must not occur.

Satisfaction The system should be pleasant to use, so that users are subjectively satisfied when using it; they like it.

Another important aspect of usability is the three items stated by Gould and Lewis [20]. They propose three key principles to consider when designing for usability. The first is about early focus on users and tasks. By emphasizing with the user and associated tasks in an early point of the development, the developer can understand the users rather than only identifying them, which is also supported by Norman [44]. The second is empirical measurement. Applying simulations and prototypes in an early stage of development. Then measuring and analyzing the outcome. And the third is iterative design. Using the result as lessons learned, and return to development for improving the artifact.

When designing the user interface some principles from psychology are found especially useful, and easy to apply in a user interface context. The principle of gestalt theory was first described by Koffka [29], and later applied in visual screen design context by Chang et al. [13]. The etymology of the word is interesting, as gestalt originates from German, meaning "shape, form, or figure". The gestalt principles addresses five items related to the earlier mentioned meaning. The principles are proximity, similarity, figure-ground, symmetry, and closure [53]. They are important to consider when designing the user interface.

Furthermore, evaluation of efficiency in the user interface design is also important. Card et al. [11] proposed GOMS; Goals, Operators, Methods, and Selection Rules. This method evaluate the efficiency from a users perspective. By applying average execution time of users in the model, user behavior can be measured and analyzed. Other measurement studies have also showed the significance of good user interface design [61].

The aforementioned design principles are general and can be applied in a wide range of systems. In addition to those principles, Apple have created the iOS

Human Interface Guidelines (HIG)[2] specifically intended for iPhones and iPads on their iOS platform. The HIG assist to create a consistent user experience in the wide array of applications on their devices. The need for a HIG is supported by a study identifying problems related specifically to usability in the iPad user interface [42].

3.3.3 Heuristic Evaluation

To bring focus on designing for good usability, some heuristic evaluation approaches have been developed.

Nielsen [40][41] well-known principles of good usability will be used as a design guideline in the development process of the application. Some years later Shneiderman [52] proposed eight golden rules to help design and evaluate usability in user interfaces. The application follow the principles of Nielsen's ten principles due to more descriptive items and some overlap of Scheiderman's golden rules. Nielsen's ten principles are as follows:

Visibility of system status The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

Match between system and the real world The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

User control and freedom Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

Consistency and standards Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.

Error prevention Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.

Recognition rather than recall Minimize the users memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

Flexibility and efficiency of use Accelerators – unseen by the novice user – may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

[2] Apple HIG: http://developer.apple.com/library/ios/documentation/UserExperience/Conceptual/MobileHIG/Introduction/Introduction.html

Aesthetic and minimalist design Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

Help users recognize, diagnose, and recover from errors Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

Help and documentation Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the users task, list concrete steps to be carried out, and not be too large.

Tognazzini [59] has also proposed numerous heuristic principles for usability, named first principles of interaction design. The list holds a large number of items, and is rather used as a checklist for user interface evaluation, in contrast to Nielsen's more tangible usability principles.

3.4 Instrument Development

To evaluate this application two surveys and one information form is distributed to all test participants. The purpose of the surveys is to get a foundation to answer the research questions. The first survey is a standardized System Usability Scale (SUS) to get feedback on the general usability of the application. This is done by evaluating the usability in the specified context as described in ISO 9241-11 in section 3.3.1. The second survey is an Application Specific Survey (ASS) which is intended to cover usability factors related to the use of Building Information Models (BIM) and Augmented Reality (AR). The Test Subject Form is not a survey and is only used to collect information about the test participants.

3.4.1 Survey Design

Several studies have shown the relevance for correct survey design[36][49].

How a survey answer is weighed is also important in order to retrieve correct results. O'Muircheartaigh et al. [45] describe the use of response scales, and how the characteristics of the scale, verbal and numeric anchors affect the midpoint and endpoint of the scales.

Studies have also shown that the survey question format is important to consider, to get correct results and not induce biased answers. A study by Krosnick and Berent [32] report that fully labeled branching measures of party identification and policy attitudes are more reliable than partially labeled non-branching measures of those attitudes.

The applied System Usability Scale (SUS) use a 5-point scale, and the arguments is as formulated by Brooke [8]. The arguments in the Application Specific Survey (ASS) has been rigorously formulated to collect uninfluenced results, and also apply a 5-point scale.

3.4.2 System Usability Scale

The System Usability Scale (SUS) is used to assess the overall usability of a system. It was developed by Brooke [8] and originally designed to evaluate an application for people with brain injury. To evaluate the usability a SUS is distributed to all test participants after testing is performed. The survey consist of ten arguments targeting the opinions of the user. The user then has to determine to which degree those arguments cover the opinions when using the application.

Bangor [7] found a correlation between SUS scores and a 7-point adjective scale, indicating that SUS scores could be mapped to absolute adjective descriptors for easier interpretation. The 7-point scale had the scale items; worst imaginable, awful, poor, OK, good, excellent, and best imaginable. The corresponding mean value SUS scores where; 25, not applicable (due to no results), 39.17, 52.01, 72.75, 85.58, and 100.

For test subjects not fully comfortable in English, the survey will be consecutively translated. To assure a correct translation, a translated version[3] of the SUS was used as assistance for the test manager.

The complete System Usability Scale form is found in appendix A.

3.4.3 Application Specific Survey

The Application Specific Survey (ASS) consist of eleven questions to check for application specific issues. The specific questions will highlight evaluation of areas not covered by the System Usability Scale (SUS). The questions relate to usefulness of Building Information Models (BIM) and visualization with Augmented Reality (AR). Like the SUS, this survey also provide arguments which the user need to determine to which degree is correct.

The complete Application Specific Survey form is found in appendix B.

3.4.4 Test Subject Form

The Test Subject Form makes it possible to map subjects conducting the test, and later identify relevant influencing factors.

The complete Test Subject Form is found in appendix C.

3.5 Test Environment

This section provides an overview of the environment on where the tests are conducted. First, the test location is described. The test is conducted in two locations, and each of these locations have various issues to consider. Secondly, the organizations of the maintenance workers are described. The two test environments have different ways of organizing the maintenance workers, and this can influence the test conducted. In the end, the practical execution of the test is elaborated.

[3]SUS in Norwegian: http://www.brukskvalitet.no/maler-for-brukertesting/

3.5.1 Test Location

The evaluation was executed in maintenance departments of two large universities in Norway, the University of Tromsø (UIT) and the Norwegian University of Science and Technology (NTNU). The first test was performed at UIT, on April 29th 2013. The second test was performed at NTNU, on May 2nd and 3rd 2013. Information about the two participating maintenance organizations and the associated test location is found in table 3.2.

The attributes in the table are; test location, date, description, and local adaptation. The latter describes any special adaptations required for the test location.

One special adaptation was made upon testing at UIT. As the CampusGuide only works on NTNU, there is no way of retrieving in-door location using the CampusGuide API at UIT. The solution was found by imitating a in-door location retriever in the UIT test environment. The location is set statically at the test location, not testing the in-door location retrieval part of the application. As a result of this the user can not move during the test, as the location is not dynamically updated.

Test location	Date	Description	Local adaptation
Room B-063 at the NFH building, UIT, Tromsø	April 29th 2013	The room was reserved the whole day for ARCBA testing only	Imitated in-door location retriever, due to lack of CampusGuide
Several, as the offices of the people tested was used, NTNU, Trondheim	May 2nd and 3rd 2013	Testing was conducted in offices with different layouts	Imitated in-door location retriever, due to technical problems

Table 3.2: Test location at UIT and NTNU

3.5.2 Test Subjects

The test subjects are maintenance workers at University of Tromsø (UIT) and Norwegian University of Science and Technology (NTNU).

Maintenance departments in UIT and NTNU are organized in different ways. Maintenance workers at UIT are organized on a person to building basis. The maintenance worker conduct all repair in all fields of specialization. If the maintenance worker come across a job which require further expertise, then a engineer in that field is requested. UIT has a group of available engineers ready to be requested for the specialized job. The group of engineers also plan larger improvements to the building mass.

In contrast the maintenance workers at NTNU are organized on a person to specialization basis. NTNU use a ticket system. In this system a required job is first reported, then executed by an available maintenance worker in the field of specialization related to the reported problem, independently of the building.

3.5.3 Test Execution

The test was executed in two rounds, one at University of Tromsø (UIT) and one at Norwegian University of Science and Technology (NTNU), as shown in table 3.2.

UIT testing was conducted by first approaching all maintenance workers at UIT and telling them about the project and the subsequent test. Then, a confirmation mail was sent out to all participants with information about place, time, and the participant prize. On the testing day the participants visited the reserved room, conducted the test, and then got a piece of cake as a prize for participating. NTNU testing was executed by approaching maintenance workers in the different operating departments, and then conducing the test on available voluntary participants.

In both cases, the test participant was given the iPad with only the instruction "try out this application as a tool for maintenance work". If participants had problems of understanding what to do, the test manager would first step in and give simple instructions, such as "click on the filter and show beams", then give more help if required. If participants had further questions during the test, then the test manager would answer them right away.

The application testing and survey responding was executed in the following sequence:

1. Application test execution
2. Test Subject Form
3. System Usability Scale
4. Application Specific Survey

Participants used 10-15 minutes to test the application, and 10 minutes to fill out the survey.

Chapter 4

Problem Elaboration

This chapter provides a detailed insight into the problem area.

To help describing the problem, personas, scenarios, and storyboards are utilized. A storyboard consist of a persona and a scenario. Personas and scenarios are descriptions of specific users with specific goals in a specific environment. At the start of this chapter two personas are constructed. Then, the scenario is set as a context for the story. Finally, these are used in a storyboard. This is to give an understanding of the operational site, and a typical usage of the application.

In the next sections requirements and use cases are presented to aid prioritizing in the development process, and to move from a problem to an outline of a solution.

4.1 Persona

In interface design it is common to make a persona to give a better understanding of the user of an application [38]. To create a persona, a fictive person is constructed and ascribed a set of skills. The purpose of the persona is to simulate a real situation. Moreover, when the persona acts in a scenario, it is important the persona use the application based on the current skills.

4.1.1 Carpenter Arne

The first persona in this storyboard, is the maintenance worker Arne. He is employed as a maintenance worker, in the operations department at the Norwegian University of Science and Technology (NTNU). Arne is an educated carpenter, and he does supervision, maintenance, and daily operation related to carpentry. He has been called on a lot lately to execute maintenance on the building mass and interior of the building "EL-bygget" on campus. He is 42 years old and consider himself non-technical, as he only has basic computer skills.

4.1.2 Electrician Steinar

The second persona in this storyboard, is the maintenance worker Steinar. He is also a maintenance worker in the operations department at the Norwegian University of Science and Technology (NTNU). Steinar is an electrician, with 24 years of experience, and he does supervision, maintenance and operation of electrical equipment. By working at NTNU in all of these years he has gained a valuable insight to the operations of the electric systems on campus. He feels his services are required on a constant basis all over campus. He is 53 years old, and has a smartphone which he feel comfortable using.

4.2 Storyboard and Scenario

A general description of possible usages in an application can sometimes not give a realistic picture of the actual use. In order to create a better understanding of the possibilities in the application, a storyboard has to be created. A storyboard is a fictive story, and will not describe all aspects of possible behavior. The storyboard is created to tell about a particular situation, and highlights aspects of a likely real life use of the application.

The storyboard consist of a persona, which is the person performing in the story, and a scenario in where the story is performed. In this section, two possible storyboards are described, and each storyboard utilize one persona and one scenario.

Both subsequent storyboards unfolds in the "EL"-building at the Norwegian University of Science and Technology (NTNU).

4.2.1 Attaching a Projector Mount

Carpenter Arne has been given an assignment to install a projector mount to the auditorium EL6. He has brought a ladder, necessary carpentry tools, and a blueprint of the room. All settled in the correct auditorium, he initiates the assignment. He assembles the ladder where he believes the projector is to be mounted. Then he takes a look at the blueprint of the room.

The blueprint is an old and torn paper, which has been stacked in a folder between a lot of other blueprints. This results in faint ink on the print. The old age of the document makes it harder to understand, as some changes have been done in the room without the document being updated. He can see from the blueprint that two parallel beams goes from one side of the room to another, with nothing adjacent to the beams. He select this place for the mounting. Arne climbs up on the ladder, and make marks for the projector mount, and then steps down again.

To confirm the veracity of the blueprint and location to drill, he uses the AR-CBA application on his smartphone. It is loaded with the building information models of the current building. All he do is to pull up his smartphone, start the application, and point the smartphone in the direction of the ceiling. Quickly he discover the absence of a beam at the selected place to drill. As the smartphone always have the most updated model, the blueprint has not been updated accordingly. If he would not have checked, he would have mounted the projector to a fragile ventilation shaft, were there at one time was a beam, and have no place to pull the cables for it. The application confirms that the other beam is correctly stated in the blueprint. Arne revise his plan, and decide to place the projector mount on the other beam instead.

4.2.2 Wet Wall

One day on his routine walk, electrician Steinar, see that the wall is very moist. This wall is located between the auditorium EL6 and an open area. He wonders if someone has spilled water on the wall from the nearby table, or that there is a leak in a pipe inside the wall. As an experienced electrician at NTNU, he knows the possibility for trouble and additional work, if the electrical systems inside the wall gets soaked. To get an overview of the possible outcomes of the situation he needs more information. He do not have the blueprint available for this specific building. The blueprint for this building is safely locked in the office of his vacation absent colleague.

Not long ago NTNU had a similar situation to this. In that case he had to run back to his office, as a leak has to be dealt with fast, and then try to reach his vacation absent colleague. He was redirected from person to person, as this was in the summer, and a lot of people was on vacation. Eventually he was redirected to the correct colleague's private number. With the master key he gained access to the colleagues office. Approximately two hours after he discovered the possible leak, he could determine that there was probably no leak, as all the pipes where not inside the wall at that area.

Back to this day, he suddenly remember that he has brought his smartphone with the application ARCBA, which is loaded with the Building Information Models (BIM) of that particular building, as well as all other buildings on NTNU's campus. He points the phone at the wall, and see right away that there is no pipes in the immediate proximity of the water on the wall. Also, to his relief, the electric components in the wall are located 3 meters away. He determines within minutes from discovering the possible leak, that there is no possibility for a leak at this time, and all all electrical components are safe. He concludes with the water on the wall being students spilling from the nearby table, as last time.

4.3 Requirements

A list of requirements is created to assist in the development process of the application. The requirement analysis describe all the functions for the application to work as intended. All requirements are prioritized to make sure the development process focus on the most important requirements first.

4.3.1 Obtaining Requirements

In the process of designing the requirements, perspectives from current maintenance workers at the University in Tromsø (UIT) and the Norwegian University of Science and Technology (NTNU) were retrieved.

The initial stages of the research required an investigation of maintenance workers, to learn how they currently executed their daily working tasks. Maintenance workers at University of Tromsø (UIT) was mainly targeted for investigation. This was conducted by interviewing the maintenance workers almost daily in a three week period, with a total time interviewing of about 45 hours. In addition, one maintenance worker was followed (with permission) for three hours to learn in practice the challenges he faced. Maintenance workers at NTNU was subjected for interviews for four days, with a total interviewing time of about 15 hours.

The maintenance workers at NTNU had different areas of responsibility, as described in section 3.5.2. In contrast the maintenance workers at UIT had responsibility of the whole building. The interviews helped uncover aspects of the problem, and led to forming the requirements.

Needs uncovered in interviews with maintenance workers at UIT and NTNU:

- During pipe maintenance, having a map of wall content can help planning of maintenance execution.
- Electrical maintenance, where wires possibly are stretched in the wall, currently only rely on local knowledge of the electrician.
- People with responsibilities in the areas of building mass or pipes, think they can benefit from knowing hidden wall content.
- Building mass maintenance do only have access to paperbased blueprints, but a digital blueprint system using iPad is to be introduced in the future.
- Electrical wiring on NTNU utilize to a large degree easily visible cable gates.
- The currently used systems are AutoCAD, Lydia, and PCschematic. Each for one purpose, and with poor cross-application collaboration.
- BIM is currently not utilized in maintenance at UIT or NTNU.
- Daily maintenance operations are usually planned on-site with only analog information available at location (printed blueprint, location assessment, personal knowledge).

4.3.2 Description of Attributes

Below are explanations of the different attributes used in the functional and non-functional requirement table.

ID Defines the requirement type, and the types are shown below:

- FR - Functional requirement

- NFR - Non-functional requirement
- GF - General application functionality
- V - Visualization of information on the screen
- C - Communication functionality
- U - Usability
- T - Target user

Description Offer a short description of the application functionality.

Priority Defines the priority of this functionality. The priority scale has three notches; low, mid, and high.

4.3.3 Functional Requirements

Table 4.1 specifies requirements related to the implementation of the application. All functional requirements are directly linked to features of the application, and by specifying the functional requirements, the development can be planned better. When having a plan, focus can be given to the most important features first.

ID	Description	Priority
FR-GF1	User must be able to log on the application	mid
FR-GF2	User must be able to turn on and off visualization	low
FR-V1	User must be able to choose what information to visualize; doors, windows, etc.	high
FR-V2	Application must visualize the selected information in Augmented Reality (AR)	high
FR-V3	Application must show location of the user on an out-door map	mid
FR-V4	Application must show location of the user on an in-door map	mid
FR-C1	User must be able to share acquired on-site information with people by mail	mid
FR-U1	Application must automatically find the in-door location of the user, enabling instant visualization in the location	mid

Table 4.1: Functional requirements

4.3.4 Non-functional Requirements

Table 4.2 specifies the requirements related to environmental factors. Non-functional requirements focus on how the user think and feel, and how the application is to be used. The non-functional requirements are on a higher level of abstraction than the functional requirements, and do not focus of features in the implementation of the application.

ID	Description	Priority
NFR-U1	Application has to be easy to understand and intuitive to use	high
NFR-U2	Main function has to be simple enough for a non-technical person to operate	high
NFR-U3	User has to understand all functionalities available in the application	high
NFR-U4	Application is tested to work in normal use without occurring errors	mid
NFR-T1	Application has to be adapted for use by adults from 20 to 70 years old	mid
NFR-T2	Application use terms that is understandable for people who is not in the building industry	mid

Table 4.2: Non-functional requirements

4.4 Use Cases

A use case is constructed to help illustrate and validate the functional requirements. The functional requirements are validated by specifying the interactions between all actors, which gives a more detailed overview of the application. The use case is intended to be a more specific description than the storyboard, and is also present to show all possibilities of the application. A use case overview is shown in figure 4.1.

The use cases are based on the requirements derived from interviews with maintenance workers.

The textual use case tables consist of these elements [55]:

Title Name of the use case

Actor Type of participants involved

Trigger The event that starts the use case

Pre-condition Required conditions to be set, in order for the use case to be started

Post-condition Required conditions to set before the use case can be ended

Event flow A normal flow of events in the use case

Variation Variations from the normal flow of events

4.4.1 Start Application

In table 4.3 the ”start application” use case is presented. The application use only one step for the user to be presented with usable information. This result in a low barrier to use the application, which is intentional as the average user is expected to be a novice.

Title	Start application
Actor	User
Trigger	User click on application icon
Pre-condition	IPad is on, and the user is located at a position where a Building Information Model is available
Post-condition	User is enriched with information about the building
Event flow	Steps: 1. Application presents a visualization of BIM, and buttons for management
Variation	Steps: • None

Table 4.3: Use case: Start application

4.4.2 Select BIM

In table 4.4 the ”Select BIM” use case is presented. The application retrieves the Building Information Model (BIM) from a database, and then visualize the selected BIM if the user is in the corresponding location.

4.4.3 Select Visualization

In table 4.5 the ”select visualization” use case is presented. The application has previously stored a BIM, which the user then select what information from to visualize, such as water pipes, electrical wires, and beams.

4.4.4 Share Information

In table 4.6 the ”share information” use case is presented. This view enable the user to share information for easier collaboration with colleagues.

Title	Select BIM
Actor	User
Trigger	User click on settings menu
Pre-condition	IPad is on, the user is located at a position where a Building Information Model is available, and the application is started
Post-condition	The BIM is retrieved from the database, ready to be visualized
Event flow	Steps: 1. Application presents the settings menu 2. User selects which BIM to retrieve 3. User click the button to retrieve selected BIMs 4. Application retrieves selected BIM from database
Variation	Steps: 1a No BIM is selectable due to problems in retrieval of information from the server

Table 4.4: Use case: Select BIM

Title	Select visualization
Actor	User
Trigger	User click on application icon
Pre-condition	IPad is on, the user is located at a position where a Building Information Model is available, and a BIM has been retrieved from the database
Post-condition	User is enriched with information about the building
Event flow	Steps: 1. Application presents the filter menu 2. User selects a category from the list 3. Application visualizes the selected category
Variation	Steps: • None

Table 4.5: Use case: Select visualization

Title	Share information
Actor	User
Trigger	User click on application icon
Pre-condition	IPad is on, the user is located at a position where a Building Information Model is available
Post-condition	User has shared information with a colleague
Event flow	Steps: 1. Application presents the share view 2. User enters; recipient, subject, message, and if current visualization is to be attached 3. User click send
Variation	Steps: • None

Table 4.6: Use case: Share information

4.4.5 Use Map

In table 4.7 the "use map" use case is presented. In certain situations, a map overview can be useful, with relevant in-door and out-door maps.

Title	Use map
Actor	User
Trigger	User click on application icon
Pre-condition	IPad is on, the user is located at a position where a Building Information Model is available
Post-condition	User is enriched with information about the building
Event flow	Steps: 1. Application presents the map view
Variation	Steps: • None

Table 4.7: Use case: Use map

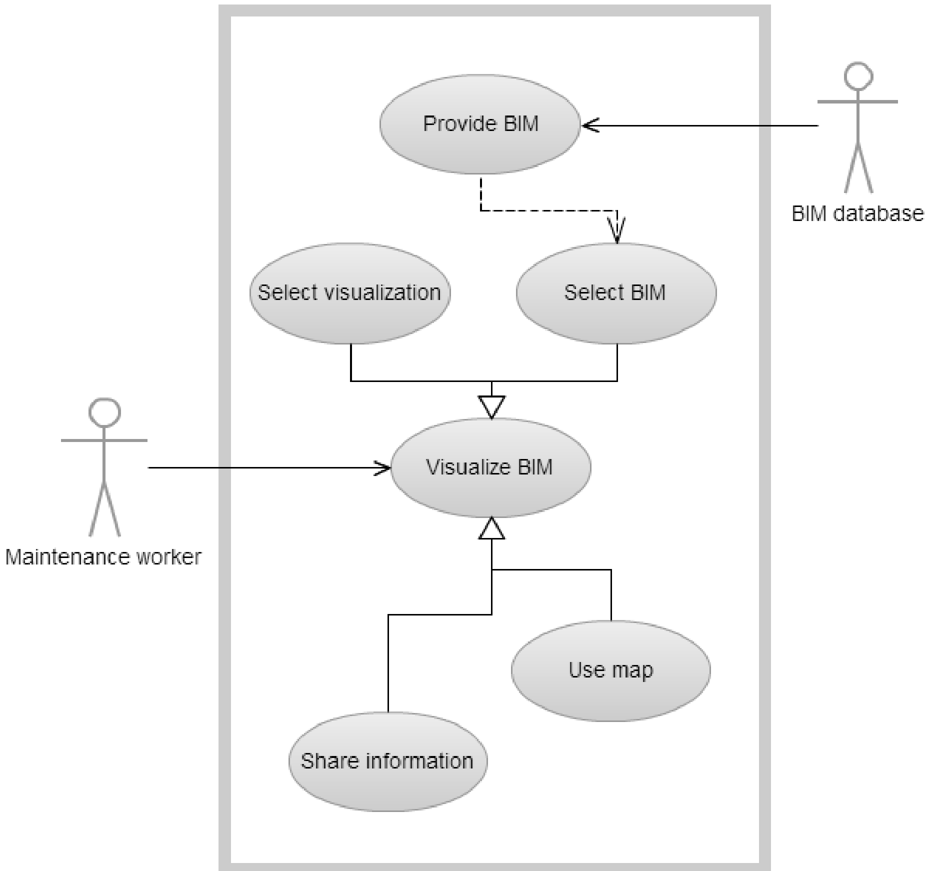


Figure 4.1: Use case overview

Chapter 5

Presentation of Solution

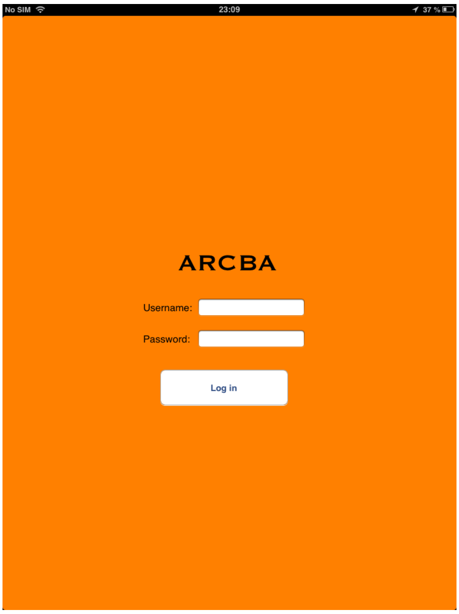
In this chapter the prototype is presented. The prototype is the artifact resulting from this thesis, and it is given the name Augmented Reality Context-Based Application (ARCBA). Building information from a Building Information Model (BIM) is utilized, and with the help of Augmented Reality (AR) technology the BIM is presented to the user for use in a maintenance work situation, as seen in figure 5.6. In use, the user is faced with a range of possibilities to help the execution of a maintenance task. Each of these possibilities are elaborated.

This chapter is divided into functionality overview and technical details. In the section functionality overview, all the user available functionalities are explained. In the section technical details, a detailed description of how the functionality is made operational is provided.

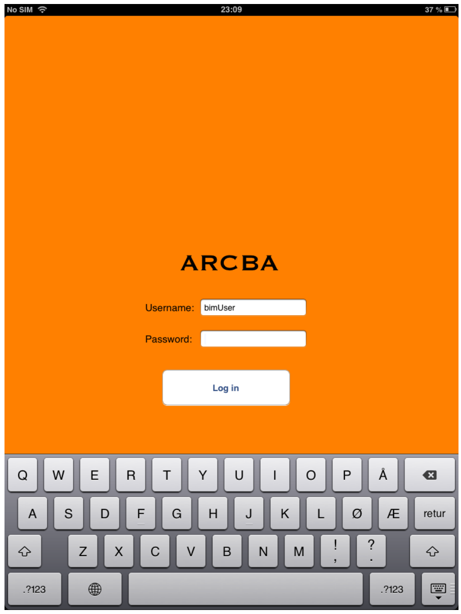
5.1 Functionality Overview

In this section the functionality of the application is described. The functionality encompass all available activities in use of the application, both visible and invisible functionality. The visible functionality is activities modifiable by user input, such as selecting which information in the Building Information Model (BIM) to display. In contrast the invisible functionality is automatic activities not modifiable by a user, such as background retrieval of current position, or switching retrieval technique depending on whether the user is located inside or outside of a building.

The development of the application focused on usability, making the application as simple as possible. This have led to an application which is ready for use immediately at launch, but with access to more options at a click of a button. When starting the application, the user is situated in the start-up view. In this view the user get immediate access to the BIM at the current location, and it is presented on the screen as Augmented Reality (AR). If the user has not used the application previously, login information is also needed to be entered, as seen in figure 5.1. The user have several possibilities in the start-up view. If the user want to filter the presented BIM, then the filter-button is to be pressed. The location of



(a) Login view A



(b) Login view B

Figure 5.1: ARCBA user interface

the user is always known, and the map button show a overview of the surroundings. For application settings, there is a settings-button. Furthermore, the user also have the options to share the discovered information, or to log out.

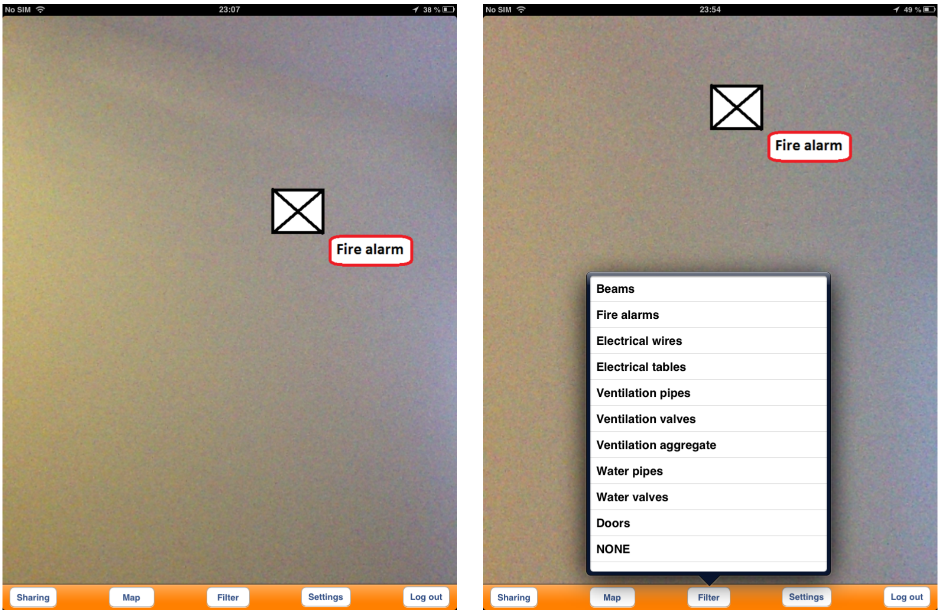
5.1.1 Visualization of BIM

In the start-up view the user is immediately presented with the Building Information Model (BIM) at the current location, as seen in figure 5.2, 5.4, and 5.5. The simplicity of this initial view enable rapid usage of the application.

The user can also select which BIM to use. This is done in the settings view, upon pressing the settings button, as seen in figure 5.3. When a BIM is selected a request is sent to the server, and a correct data model is retrieved. In this prototype only one such model is available, and it is pre-stored in the memory of the device. The pre-stored model does only apply in the specific test location, to ease prototype usability testing.

5.1.2 Filtering Data from BIM

The strength of a Building Information Model (BIM) is related to its extensiveness. It can contain a huge amount of information, such as information about all plumbing, all electric wires, and all doors and windows in a building. As the BIM can



(a) Visualization view A (b) Visualization view B

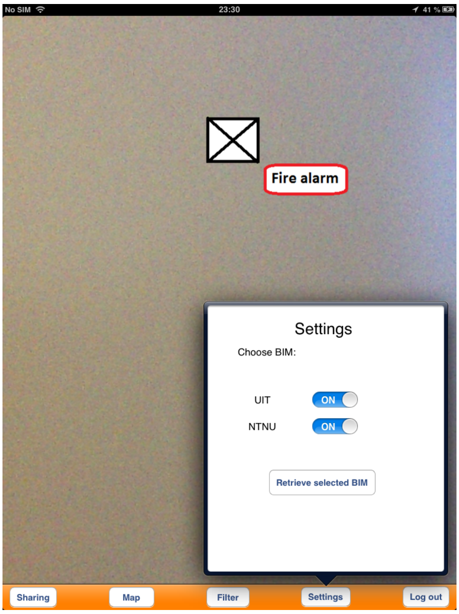
Figure 5.2: ARCBA user interface

contain both relevant and irrelevant information, the user must select the desired information to visualize. In this application the filter view is found upon pressing the filter-button. The filter view provides a simple list where the user can choose between all available visualizations, and the available visualizations are determined by the data located in the BIM. The default visualization is the first in the list.

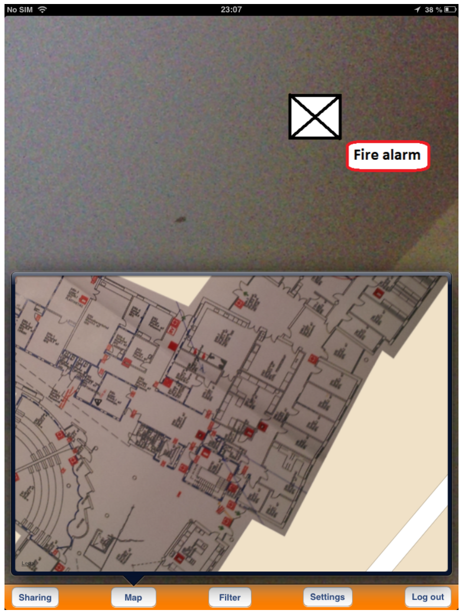
In a normal situation, the application will be closed and opened a lot. If the filter would be reset every time the application was closed, then working efficiency would be affected. To prevent this, the selected visualization is kept as default upon closing the application. There is also a reset button to switch back to the original state.

5.1.3 Map View

Figure 5.3 show usage of the map view. This view is reached by pressing the map-button. The map view consist of a 2D representation of the environment, to show where the user is located, as well as Points-of-Interest (POI). Especially the POI located on the map can help give a greater overview of a maintenance situation. Today's maintenance worker is used to carrying around a large folder of paper maps. By having access to a 2D map in addition to the on-screen visualization, the transition can be eased, as the digital map is more similar to an old paper map, but easier to retrieve. In a situation where a pipe needs to be examined, the



(a) Settings view



(b) Map view

Figure 5.3: ARCBA user interface

Augmented Reality (AR) visualization show the pipe in front of the user, and the user can further check the map to get an overview of the rest of the floor.

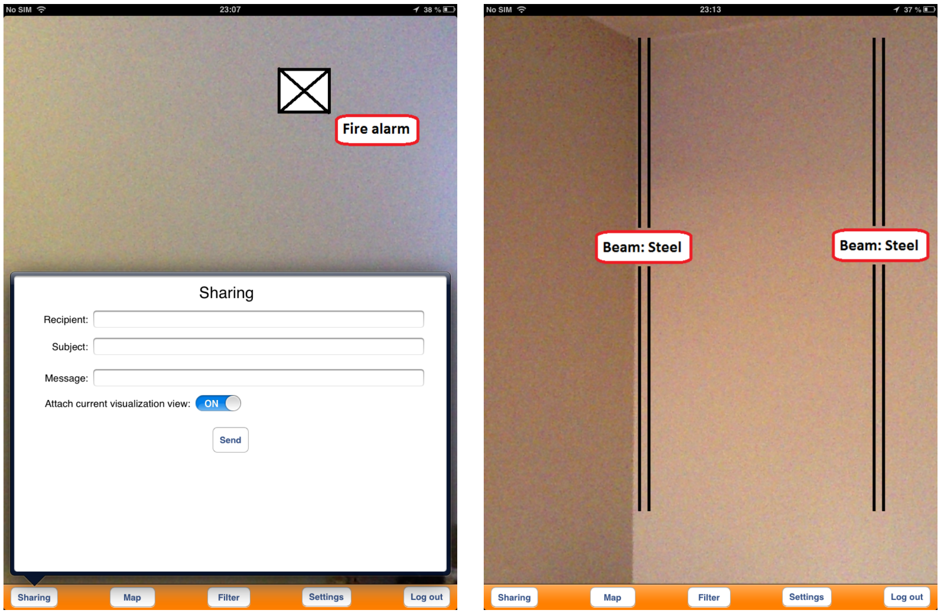
5.1.4 Automatic Location Retrieval

In order for the application to work, a correct location needs to be determined both in-door and out-door. To achieve this the application automatically select the preferred technique in retrieval of location. This functionality is invisible to the user and works automatically in the background.

As described in section 2.2.3 there are two ways of determining the location and orientation, using a static or dynamic identificator. Dynamic identificator is utilized in this prototype, and includes the use of GPS and wireless networks.

In a situation where both techniques are accessible, a strategy is required to avoid errors. The application distinguishes between GPS and wireless network by a prioritization of input. If the user is located out-door then only GPS will be available, and will be chosen as location provider. When the user is located in-door, in many cases both a inaccurate GPS signal and wireless network signal will be available. In a such situation the application will use the wireless network as preferred location provider. If only a wireless network is accessible then this will be selected.

Technology used to provide location:



(a) Sharing view (b) Visualization view C

Figure 5.4: ARCBA user interface

In-door location use the Application Programming Interface (API) of The CampusGuide to determine the position. The API is further described in section 5.2.4.

Out-door location use the device' built in GPS to determine the position.

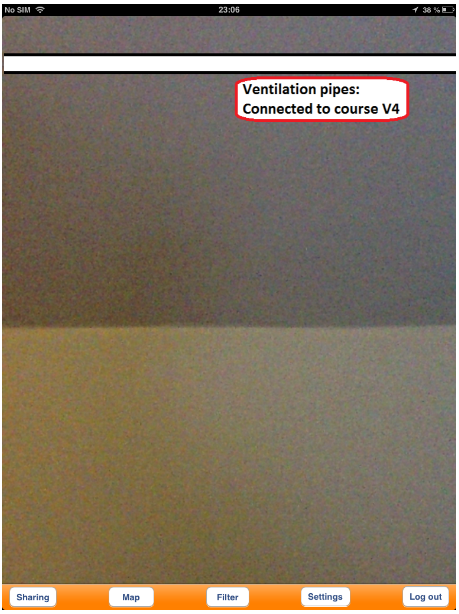
As mentioned in 7.3.5 there are also several challenges related to retrieving correct information about the orientation of the device.

5.1.5 Information Sharing

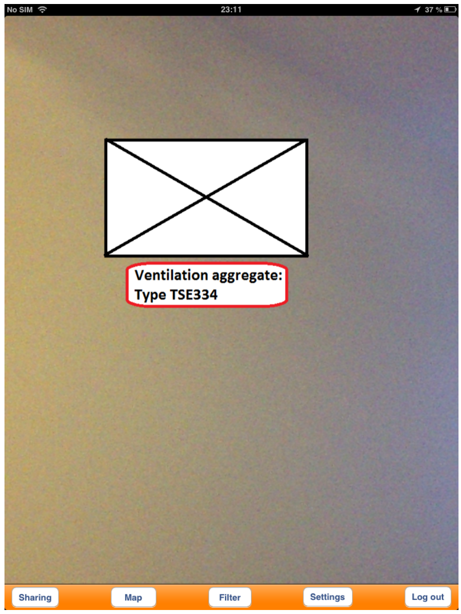
To increase the possibility for collaboration, a simple sharing function has also been implemented. The sharing function is found by clicking on the share button, as shown in figure 5.4.

In a situation where the user have found a maintenance issue which needs to be addressed, the share function can be applied. In this function the user can create a message describing the situation, and add a recipient of the message. The camera is also enabled and a picture can be taken, to further help explain the issue. When all relevant information is attached the message can be sent through e-mail to the appropriate person.

As described in 3.5.2, the organization structure varies between organizations. The organization structure at UIT where maintenance workers have greater fields



(a) Visualization view D



(b) Visualization view E

Figure 5.5: ARCBA user interface

of responsibility, may especially benefit from easy sharing of information with co-workers and getting a second opinion. And by sharing information at an early stage, the planning work can start earlier, and the maintenance can be conducted at an earlier point.

5.2 Technical Details

This section describes the technical composition of the application in a detailed manner. The previous section had an usage focused approach by describing functionalities related to usage. In this section the focus is rather on how the application is composed in a higher level of detail. This section include information about the programming language used, an overview of the application architecture, the programming paradigms applied, and the frameworks and Application Programming Interface (API) utilized.

5.2.1 Programming Language

The application is written in Objective-C, which is the native programming language for iOS applications. The language is derived from the programming language C. It is a object-oriented language, which utilize instances of classes, also

(a) In use A

(b) In use B

Figure 5.6: ARCBA user interface

known as objects. In addition extensions in Objective-C include the use of Smalltalk syntax[1].

5.2.2 Application Architecture

In this section important parts of the application architecture and operation is described.

Automatic Reference Counting

The application is created to work with the Xcode features Automatic Reference Counting (ARC) and Storyboard. ARC is an automatic memory management, and liberate the programmer from dealing with addressing memory issues. Storyboard is a graphical tool to enable easier development of the Graphical User Interface (GUI). It gives the programmer an overview of the different views and graphical objects in the GUI and their connection.

OpenGL

The software interface OpenGL is utilized to achieve efficient visualizations of Augmented Reality (AR) objects on the screen. OpenGL is a platform independent library to help the device draw 3D models[2].

Application Orientation

An iPad application can be created intended for use vertical, horizontal, or both. If the application is intended to be used both vertical and horizontal, then both of the corresponding Graphical User Interfaces (GUI) need to be created. In use the iPad will seamlessly switch between the GUIs depending on how the iPad is oriented. The orientation is determined by a built-in gyroscope which recognize how the iPad is being held by the user.

The ARCBA application was developed for use mainly in the vertical position. For maintenance workers, the size of the iPad have both advantages and disadvantages. A benefit is increased readability of maps, but because of the size the device can also be inconvenient to carry around. A smaller device would open to be used with only one hand, instead of the currently two hand manageable iPad. The application was also developed to be used mainly vertical to be more similar to a possibly smaller device in the future. A possible solution is the iPad mini with a 7,9 inch screen or iPhones with a 4 inch screen[3][4].

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[1] Apple developer: http://developer.apple.com/library/mac/documentation/Cocoa/Conceptual/ProgrammingWithObjectiveC

[2] OpenGL: http://www.glprogramming.com/red/chapter01.html

[3] IPad mini: http://www.apple.com/no/ipad-mini/overview/

[4] IPhone: http://www.apple.com/no/iphone/

5.2.3 Programming Paradigm

There are many ways of developing an application, that could end with a similarly resulting application. This development process focused on creating code that is easy readable and understandable. To achieve this, the development process consisted of utilizing well-recognized programming paradigms. In contrast, a code which is hard to read and understand is commonly known as "spaghetti-code", because of the its unstructured nature[5].

This section elaborates the Model-View-Controller (MVC) principle, a programming paradigm utilized to create comprehensible code.

Model-View-Controller

The application utilize the Model-View-Controller (MVC)[6] paradigm as elaborated by Burbeck [9]. As seen in the figure 5.7, MVC is a software-architecture paradigm that separate the code; handling data, showing data, and making changes in data. By using this paradigm, the code created is more independent and not linked so strongly together, allowing parts of code to be replaced without major recoding.

An overview of the different parts in MVC:

Model holds the data

View is a visualization of the data

Controller is closely linked with the View and handles changes of the View.

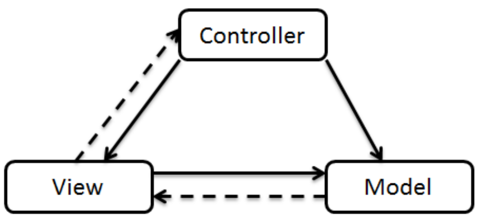

Figure 5.7: Model-View-Controller

5.2.4 Framework and API

Frameworks and Application Programming Interfaces (API) are utilized in this application to reduce time in the development process. Frameworks and APIs are pieces of code developed by others to solve a specific problem, and to liberate the programmer from remaking code which already exist. A framework is an amount of code ready to be used as is or customized for the programmers needs. The API

[5]Spaghetti code: http://sourcemaking.com/antipatterns/spaghetti-code
[6]MVC: http://msdn.microsoft.com/en-us/library/ff649643.aspx

is an interface helping with communication between software. The Park framework contribute with AR visualization, and the CampusGuide API is used to determine the location in-door at NTNU.

Park Framework

PARK is an application in the iOS Developer Library which demonstrate usage of Augmented Reality (AR) on Apple iPhone and iPad[7]. The application is used as a basis for ARCBA as it is open-source, use mobile augmented reality and is ready for further development. The original framework had to be adapted to work with ARC and Storyboards.

The main functionality of the application is a live camera feed with overlaying labels according to a specified position. The application utilizes the iPad's WiFi connection, digital compass and gyroscope to compute the current position and direction of the user. When the iPad direction is changed, the labels on the screen are moved accordingly, and the screen is repainted. The labels and positions are hard-coded into the application.

CampusGuide API

To locate the user in an in-door environment, the CampusGuide's Application Programming Interface (API) is used[8]. It can provide a position with 5-10 meters of accuracy. The CampusGuide API consist of a pollable address which the application use to retrieve information.

To retrieve a position a sequence of steps are executed. First, the application sends a request for position to a specified address (`http://app.campusguiden.no:8080/position`). Then, the CampusGuide API handles the request on its own server. The IP-address of the device is validated if connected to a NTNU network domain. If this test passes, the estimated location of the device is determined through distance to routers it is connected to. Then, the application retrieves information about the users position.

The CampusGuide API is currently only available on NTNU's campus in Trondheim, as described in section 3.5.1.

[7] Apple pARk framework: http://developer.apple.com/library/ios/samplecode/pARk/
[8] The CampusGuide: http://www.campusguiden.no

Chapter 6

Results from Evaluation

To evaluate the application a test focusing on usability and usefulness was conducted. This chapter presents the results from this evaluation. First, the demographic data is described. Then, results from the System Usability Scale (SUS) and Application Specific Survey (ASS) are elaborated. In the end of this chapter the reliability and validity of the results are investigated.

The tables in this chapter consist of several attributes. Description and item are details and properties of the question. N is the number of instances, % is the percentage of instances. Min and max reflects the minimum and maximum value of the instances. Mean is an arithmetic mean value, which is derived from adding all values, and dividing on the total number if instances. The median show the central distributed value, and the standard deviation (SD) is used to show the distribution of all the values by squaring the variance. Also, the term computer and PC (Personal Computer) is used interchangeably.

And the SUS and ASS both use a 5-point scale, from ”strongly disagree” to ”strongly agree”, which is represented by the numbers 1 through 5.

6.1 Demographics

This section is divided into two categories. Participant information aim at examine the demographic profile of the test participants. Participant skillset includes the users experience in smartphones, tablet and computer. By collecting this information, questions can be linked with age or level of skills of respondents. This will in turn give a greater understanding of the answer as it is seen in the context of the user.

6.1.1 Participant Information

Table 6.1 provides information about the participants gender, age, university affiliation, field of responsibility, and if the user is in a leadership position.

The results show that the participants are divided almost equally between the operation department in University of Tromsø (UIT) and Norwegian University of Science and Technology (NTNU), and consists of males only. Table 6.2 show that the participants age varies from 26 to 64, with a mean of about 45 years, and a median of 43 years. The largest single field responsibility of the respondents are carpentry and ventilation, with equally many at 15.8%. All maintenance workers at UIT have multiple fields of responsibility. 31.6% of the respondents are in leadership positions, and can do low level decisions regarding implementation of a such system.

Description	Item	N	%
Gender	Male	19	100.0
	Female	0	0.0
Age	20-29	2	10.5
	30-39	1	5.3
	40-49	10	52.6
	50-59	5	26.3
	60-69	1	5.3
University	UIT	10	52.6
	NTNU	9	47.4
Field of responsibility	Carpentry	3	15.8
	Electro	2	10.5
	Pipe	1	5.3
	Ventilation	3	15.8
	Multiple fields	10	52.6
Leadership position	Yes	6	31.6
	No	13	68.4

Table 6.1: Participant information

Description	N	Min	Max	Mean	Median	SD
Age	19	26	64	44.89	43.00	9.660

Table 6.2: Processed age

6.1.2 Participant Skillset

Table 6.3 provides information about smartphone, tablet and computer ownership and the participants self perceived skill of these.

The results show that 89.5 % have a smartphone, 57.9% have a tablet, and 100% have a computer, either at home or at work. A tablet has a different physical appearance than a smartphone, but in use it deviate very little from a smartphone. This indicate that most of the participants have access to and is familiar with relevant equipment for this application. Participants assessment of own skills is rather constant on all devices. Table 6.4 show a mean value on smartphone of 3.32, tablet of 3.26, and computer of 3.53. With a corresponding SD of .820, .933, and .772. This indicate overall average skills on smartphone and tablet, and just above average on the computer.

Description	Item	N	%
Smartphone ownership	Yes	17	89.5
	No	2	10.5
Smartphone skill	Very good	1	5.3
	Good	7	36.8
	Average	8	42.1
	Poor	3	15.8
	Very poor	0	0.0
Tablet ownership	Yes	11	57.9
	No	8	42.1
Tablet skill	Very good	1	5.3
	Good	7	36.8
	Average	8	42.1
	Poor	2	10.5
	Very poor	1	5.3
Computer ownership	Yes	19	100.0
	No	0	0.0
Computer skill	Very good	1	5.3
	Good	10	52.6
	Average	6	31.6
	Poor	2	10.5
	Very poor	0	0.0

Table 6.3: Participant skillset

Description	N	Mean	Median	SD
Smartphone skill	19	3.32	3.00	.820
Tablet skill	19	3.26	3.00	.933
PC skill	19	3.53	4.00	.772

Table 6.4: Processed skillset

6.2 Perceived Usability with System Usability Scale

This section describes the results from the first part of the evaluation, the System Usability Scale (SUS). Brooke [8] developed a method of calculating a total usability score from the SUS. This is also covered in this section.

6.2.1 Result Description

Table 6.5 and table 6.6 show results from the ten usability questions in the distributed SUS.

SUS Q1 "I think I would like to use this system frequently" get a mean value of 3.63, indicating a desire above average to use the system daily in a maintenance situation.

SUS Q2 "I found the system unnecessarily complex" get a mean value of 1.84, indicating that Augmented Reality (AR) technology and the few functionalities available are not complex to use.

SUS Q3 "I though the system was easy to use" get a mean value of 4.32, and a SD of .671 with 89.5% choosing "agree" or "strongly agree", indicating that the functionalities was easy to understand.

SUS Q4 "I think that I would need the support of a technical person to be able to use this system" get a mean value of 1.74. The answers is polarized between 89.5% choosing "strongly disagree" or "disagree", and 10.5% choosing "agree".

SUS Q5 "I found the various functions in this system were well integrated" get a mean value of 3.47 and median of 3.00, resulting in "undecided".

SUS Q6 "I thought there was too much inconsistency in this system" get a mean value of 2.26, and a median of 2.00. The SD of 1.240 however suggest high disagreement between the participants.

SUS Q7 "I would imagine that most people would learn to use this system very quickly" get a mean value of 4.26, indicating a low barrier to start using the application.

SUS Q8 "I found the system very cumbersome to use" get a mean value of 1.53, with 89.5% choosing "strongly disagree" or "disagree", indicating conformity in the system not being cumbersome.

SUS Q9 "I felt very confident using the system" get a mean value of 3.84, a median of 4.00, and a SD of .688. This show a high unity of answering the statement with "agree".

SUS Q10 "I needed to learn a lot of things before I could get going with this system" get a mean value of 1.79, and a median of 2.00. Even though most participants disagree with the statement, two participants agree with the statement. This show that the application is still a prototype and require further work.

6.2.2 Calculated Score

The calculated SUS score is obtained by following a method developed by Brooke [8]. The questions is divided into two groups, and each scale item score will range from 0 to 4. First, odd numbered questions are added together by each item contributing with score position minus 1. Second, even numbered questions are added together by each item contributing with 5 minus the score position. Finally, the two groups are added together and multiplied by 2.5. The calculated score will then range from 0 to 100.

As seen in table 6.7 the participants calculated SUS scores has a mean value of 75.92, which is quite good [7] given the fact that the application is still a pro-

	Strongly disagree		Disagree		Undecided		Agree		Strongly agree	
ID	N	%	N	%	N	%	N	%	N	%
SUS Q1	0	0.0	2	10.5	7	36.8	6	31.6	4	21.1
SUS Q2	6	31.6	10	52.6	3	15.8	0	0.0	0	0.0
SUS Q3	0	0.0	0	0.0	2	10.5	9	47.4	8	42.1
SUS Q4	9	47.4	8	42.1	0	0.0	2	10.5	0	0.0
SUS Q5	0	0.0	2	10.5	9	47.4	8	42.1	1	5.3
SUS Q6	5	26.3	9	47.4	2	10.5	1	5.3	2	10.5
SUS Q7	0	0.0	1	5.3	2	10.5	7	36.8	9	47.4
SUS Q8	12	63.2	5	26.3	1	5.3	1	5.3	0	0.0
SUS Q9	0	0.0	0	0.0	6	31.6	10	52.6	3	15.8
SUS Q10	9	47.4	7	36.8	1	5.3	2	10.5	0	0.0

Table 6.5: System Usability Scale results

ID	N	Mean	Median	SD
SUS Q1	19	3.63	4.00	.955
SUS Q2	19	1.84	2.00	.688
SUS Q3	19	4.32	4.00	.671
SUS Q4	19	1.74	2.00	.933
SUS Q5	19	3.47	3.00	.697
SUS Q6	19	2.26	2.00	1.240
SUS Q7	19	4.26	4.00	.872
SUS Q8	19	1.53	1.00	.841
SUS Q9	19	3.84	4.00	.688
SUS Q10	19	1.79	2.00	.976

Table 6.6: Processed System Usability Scale results

totype. The SD of 12.338 also indicates that majority of the participants find the application above average in usability.

Description	N	Min	Max	Mean	Median	SD
Calculated SUS	19	57.5	92.5	75.92	75.00	12.338

Table 6.7: System Usability Scale total score calculated

6.3 Perceived Usefulness with Application Specific Survey

This section describes the results from the second part of the evaluation, the Application Specific Survey (ASS).

6.3.1 Result Description

Table 6.8 and table 6.9 show results from the questions in the distributed ASS.

ASS Q1 "BIM is currently available for the building I manage" get a mean value of 1.53, indicating low availability of BIM in the buildings managed by the participants.

ASS Q2 "This university is currently using BIM in other projects" get a mean value of 1.53, indicating low utilization of BIM, or little knowledge about BIM being utilized at the university.

ASS Q3 "The app eliminates the need of bringing blueprints with me" get a mean value of 3.74. 68.4% "agree" or "strongly agree" with the statement, but 31.6% still "disagree" or are "undecided".

ASS Q4 "The app eliminates the need of knowhow (tacit knowledge) of an experienced maintenance worker" get a mean value of 3.00, a median of 3.00, and a SD of 1.054. This result in the majority being "undecided", and the rest being spread on the entire scale.

ASS Q5 "I find the app to be a relevant tool for my daily working routing" get a mean value of 3.47. The SD of 1.124 show that there is not total cohesion of the participants, but 57.9% of the participants still consider the application to be a relevant tool. This is further supported by the above average mean value in SUS Q1.

ASS Q6 "I find the app to be a relevant tool for substitutes in my position" get a mean value of 3.58, indicating a slightly higher acceptance of the application being a relevant tool for substitutes rather as a daily tool for the maintenance workers themselves.

ASS Q7 "The app could help me find the relevant building information" get a mean value of 4.05, a median value of 4.00, a SD of the low .621, with 84.2% "agree" or "strongly agree" with the statement. The conclusion derived from these numbers is a strong consensus of the application's ability to offer relevant building information.

ASS Q8 "I believe I could get use of this app in the future" get a mean value of 4.00, with 42.1% choosing "strongly agree", indicating a future for this application. The 21.0% "undecided" probably reflect on it still being a prototype.

ASS Q9 "I believe the successor in my position could get use of this app in the future" get a mean value of 3.79, a median value of 4.00, and a SD of the high 1.134. The numbers indicate a future for the application, but the 10.5% choosing "strongly disagree" or "disagree" should be investigated in further work.

ASS Q10 "The accuracy of position and orientation of the app is not a problem" get a mean value of 2.95, which result in "undecided". The SD of 1.129 show high disagreement between the participants, an this is supported by the entire scale from strongly disagree to strongly agree being used.

ASS Q11 "How do you think this application should be improved to better help you in a daily maintenance work environment" was an open field for writing suggestions. Even though only seven of nineteen people chose to fill in this field in the evaluation, every participant shared thoughts around possible improvements, and most of these thoughts have been incorporated in this thesis.

6.4 Validity and Reliability

Validity is given when the questions measures what is intended [58]. In reproduction of this evaluation some of the lessons learned should be considered.

Brooke [8] argue that the score of each question in the System Usability Scale (SUS) is not meaningful on its own, because of the extreme nature of the statements, and the possibility of misinterpretation. In this evaluation the argument is not fully complied, as each question is evaluated. Still, the argument is considered to reduce possible misinterpretation.

When using a 5-point scale from strongly disagree to strongly agree, the questions should be formulated as extreme statements. In retrospect, questions ASS Q1 and ASS Q2, should have taken this more into account by being formulated differently, or using a 5-point scale from "not at all" to "to a large degree". The questions aim at investigating to what degree Building Information Models (BIM) is known to maintenance workers, and the presence of BIM in their work.

Questions SUS Q6, ASS Q5, ASS Q9 and ASS Q10, all have a SD on or above 1.124. Such SD reflects highly disagreement between the participants, also supported by all of these questions utilizing the entire scale from "strongly disagree" to "strongly agree". This can be interpreted as low precision of the question itself, and that participants does not fully understand the question.

	Strongly disagree		Disagree		Undecided		Agree		Strongly agree	
ID	N	%	N	%	N	%	N	%	N	%
ASS Q1	12	63.2	4	21.1	3	15.8	0	0.0	0	0.0
ASS Q2	14	73.7	2	10.5	2	10.5	0	0.0	1	5.3
ASS Q3	0	0.0	2	10.5	4	21.1	10	52.6	3	15.8
ASS Q4	2	10.5	3	15.8	8	42.1	5	26.3	1	5.3
ASS Q5	1	5.3	3	15.8	4	21.1	8	42.1	3	15.8
ASS Q6	0	0.0	2	10.5	7	36.8	7	36.8	3	15.8
ASS Q7	0	0.0	0	0.0	3	15.8	12	63.2	4	21.1
ASS Q8	0	0.0	2	10.5	4	21.1	5	26.3	8	42.1
ASS Q9	1	5.3	1	5.3	5	26.3	6	31.6	6	31.6
ASS Q10	2	10.5	4	21.1	8	42.1	3	15.8	2	10.5

Table 6.8: Application Specific Survey results

ID	N	Mean	Median	SD
ASS Q1	19	1.53	1.00	.772
ASS Q2	19	1.53	1.00	1.073
ASS Q3	19	3.74	4.00	.872
ASS Q4	19	3.00	3.00	1.054
ASS Q5	19	3.47	4.00	1.124
ASS Q6	19	3.58	4.00	.902
ASS Q7	19	4.05	4.00	.621
ASS Q8	19	4.00	4.00	1.054
ASS Q9	19	3.79	4.00	1.134
ASS Q10	19	2.95	3.00	1.129

Table 6.9: Processed Application Specific Survey results

Chapter 7

Discussion

Interesting results emerged from the application evaluation, indicating positive response to all research questions. This chapter provides a discussion of each research question, and the results from the evaluation are analyzed in regards to both opportunities and challenges.

Building Information Models (BIM) and Augmented Reality (AR) offer a lot of possibilities, and combining them can lead to more challenges that need to be addressed. Several studies have discussed general limitations of using AR applications [65] [30]. In this chapter the most important challenges regarding the application is presented.

7.1 BIMs Relevance for Maintenance Workers

The research indicates a strong possibility to present relevant Building Information Models (BIM) for maintenance workers, using Augmented Reality (AR) and Location-Based Services. The research reveal a list of relevant objects in a BIM. In the end of this section the challenge of lack in available BIMs is elaborated.

7.1.1 Relevant Objects in a BIM

Initial investigative interviews with maintenance workers revealed objects that should be present in a Building Information Model (BIM). Relevant objects appeared to be information about; beams, fire alarms, electrical wires, electrical tables, ventilation pipes, ventilation valves, ventilation aggregate, water pipes, water valves, and doors. In addition all associated attributes were requested, such as type and special properties. The prototype was developed with this in mind, making these objects available in the prototype on evaluation.

The evaluation demonstrated that maintenance workers were satisfied with the available objects of the BIM, and found the BIM relevant for maintenance work in the prototype. This was further supported by the Application Specific Survey (ASS), and especially ASS Q3 and ASS Q7, as seen in table 6.8. ASS Q3 got

68.4% in "agree" or "strongly agree" of the statement "the app eliminates the need of bringing blueprints with me". ASS Q7 got the even stronger 84.2% in "agree" or "strongly agree" of the statement "the app could help me find relevant building information".

7.1.2 Lack of Available BIM

However, a majority of the buildings at University of Tromsø (UIT) and Norwegian University of Science and Technology (NTNU) does currently not have BIMs available. With this in mind, two solutions are possible:

- Creating a BIM at the current building
- Only using the application at buildings which have a BIM available

The first option would require major investments, in many cases excessing the potential savings of such an application. The second option have a greater chance of being implemented. A large quantity of construction companies focus on applying BIM in their construction process. This leads to an increase in the number of buildings constructed with a related BIM. This option will result in few additional costs to apply the application.

7.2 Usefulness of Application

Results from the prototype evaluation indicate high usefulness for maintenance workers. Table 6.8 presenting the results from the Application Specific Survey (ASS) show that ASS Q5, ASS Q6, ASS Q8, and ASS Q9 indicate interesting results. In the end of this section the challenge of cross-application collaboration is addressed.

7.2.1 Maintenance Workers Assessment

The evaluation demonstrated that maintenance workers find the application very useful.

In ASS Q8 with the statement "I believe I could get use of this app in the future" 42.1% of the participants chose "strongly agree". The question was formulated with "in the future" to get the participant to incorporate the application being a prototype and still require some more work. This is still a strong indicator of the perceived usefulness.

In ASS Q9 the statement "I believe the successor in my position could get use of this app in the future" got the strong 63.2% in "agree" or "strongly agree". This question was asked as current maintenance workers may have a higher tolerance of getting accustomed to new tools, and with a mean age of about 45 years, many may not be comfortable in using digital tools. This seem to be supported by correlating the data from the evaluation. A negative correlation was found in AGE and SUS Q1, with a Pearson correlation coefficient of -.534, and it is significant at the 0.01

level (2-tailed). This means the older the participant is, the less the participant want to use the system frequently. Also, a positive correlation was found in AGE and SUS Q4, with a Pearson correlation coefficient of .477, and it is significant at the 0.01 level (2-tailed). This means the older the participant is, the more likely the participant need support of a technical person to use the system. These results are interpreted as younger people seeing higher usefulness of the application, and are more likely to use it.

7.2.2 Rapid Resolution of Situation

As described in section 6.3.1, the lower score of ASS Q5 than ASS Q6 indicates that maintenance workers value the usefulness of the application higher for substitutes in their position.

This is also supported by the first comment in appendix E. One maintenance worker suggested high usefulness of the application for security guards. Security guards may face situations such as where a valve need rapid closing to prevent water damages. The problem require rapid handling, but the security guard usually have poor knowledge to solve the situation. To solve the situation the security guard is forced to look through blueprints, interpret them, and find the corresponding valve in the building. If the daytime maintenance worker is not reachable by phone, and help the security guard, then a such task can cause serious damage to the building mass.

7.2.3 Cross-application Collaboration

The programs currently applied in NTNU's operation department have a limited ability to do cross-application collaboration. Different programs use different file types, and the possibility to import and export between is to some degree possible, but with large limitations.

The limitations became apparent when conducting informal interviews with the maintenance workers, as elaborated in section 4.3.1. A maintenance worker described several situations were they had a person sitting with two applications side-by-side, manually reading from one application, and drawing the same information in the other. This type of job would only take seconds in applications with full cross-application collaborations.

As described above, the challenge of collaboration between applications and systems is present [15], and calls for focus on file exchange functionality rather than limitations for user data. BIM is a step on the way to overcome the challenge of cross-application collaboration [56] as it is an increasingly spreading standard that support file exchange functionality [54].

To ensure high usefulness and easy cross-application collaboration the application utilize the standard BIM.

7.3 Ensuring High Usability

The experiences made from developing this prototype could be used as a guideline for similar applications in the future as most participants found the application very easy to use.

SUS Q3 from table 6.5 show that 89.5% chose "agree" or "strongly agree" to the statement "I though the system was easy to use". This is also supported by the reversed question SUS Q8. The application also got a mean SUS score of 75.92. That is a high score, considering the application is still an early prototype. Users find this way of combining Building Information Models (BIM), Augmented Reality (AR), and Location-Based Services, easy to use.

The users of the prototype assess themselves to have average skills on devices, but find the prototype intuitive and easy to use. In the end of this section three challenges of usability is presented; filtering issues, information noise, and accuracy in orientation of device.

7.3.1 Previous Experience of Users

The participants reported to have average skills in smartphones, tablets, and computers. The mean value of smartphone and tablet skills was reported to be 3.32 and 3.26. The computer skills was some higher with a mean value of 3.53. Still, with this relatively modest self-assessment of skills, 89.5% chose "agree" or "strongly agree" to the statement "I though the system was easy to use". To ensure high usability for all participants, the application has tried to comply to a large extent with the usability guidelines described in section 3.3.

7.3.2 Intuitive User Interface

Early in the evaluation phase, the amount of maintenance workers not understanding basic English became evident. This lead to making sure all surveys distributed was also in Norwegian. Even though the application was completely in English, none of the participants experienced major problems using the application.

The language barrier was not an issue when using the application, as participants understood the basic functionalities. This indicates an intuitive user interface. The high intuitiveness can be explained by users being able to recognize usage patterns from applications they have used before. Also, the easy start of the application help the users to get going. The application is started, login information is entered, and the user is immediately presented with relevant information. This discovery need to be considered when developing the application further, to keep the intuitiveness. If the application get too complex the application need to be available in the native language of the users.

7.3.3 Filtering Relevant Information

The Building Information Model (BIM) can consist of a large amount of information, from where doors are located, to how a pipe is bent, all in millimeter precision.

Filtering of information is vital to select only the relevant information to visualize on the display. Filtering of relevant information is done by selecting desired category of information to visualize. If the user is presented too many categories, then the list could affect the efficiency. The size of the BIM will determine if the available categories to choose from is too many.

Reducing number of categories could be solved by at least two ways. Having a static list with predefined categories, or having an automatic selection of categories defined by a preset search term.

7.3.4 Information Noise

Virtual Reality (VR) is a visualization of a whole world, controlling all visualized information on the screen, as described in section 2.2.1.

In contrast, Augmented Reality (AR) use the camera feed as a foundation, and superimpose information on top of it. If the camera is pointing on an area with many intrusive physical objects, a lot of unnecessary information can be shown in the camera feed. This can cause the view to be cluttered with information noise, resulting in interference for the user. Livingston et al. [33] identified issues regarding multiple layers of information in the field of visualization.

To reduce the chance of information noise affecting the usability, buttons and AR objects need to be clearly separated from the intrusive physical objects.

7.3.5 Accuracy in Orientation

One of the challenges that arise when visualizing a Building Information Model (BIM) using Augmented Reality (AR), is the precision in position and orientation of the device. To create a credible visualization the BIM needs to be in the correct relative position on the screen. To achieve this the application needs to know the exact position and orientation of the device.

Determining orientation with visual detection, both of QR-tags and physical objects, has been researched. None of those technologies are applied in the application in this thesis, due to problems also described in section 2.2.3.

A margin of error in accuracy is present when using the CampusGuide API (in-door) or GPS (out-door) to determine the position. The CampusGuide API have 5-10 meters of accuracy[1] depending on location of the routers in the building. The GPS also have 5-10 meters depending on several factors, such as obstacles around the user, the direct visibility of satellites, as well as weather conditions.

The challenges in accuracy appear on the screen as lagging objects, causing unnatural movements. Azuma [6] describes the lag in registration as dynamic errors. If lagging objects appear to much then the lack of credibility will destroy the AR experience.

The results from the evaluation suggest that the accuracy of the prototype is not a problem. ASS Q9 from table 6.8 get a mean value of 2.95, which indicate "undecided". Still, the accuracy could vary in different locations, causing different

[1] CampusGuide: http://www.campusguide.no/

results. Maintenance workers also added during evaluation that an application like ARCBA does not need to compete with on-wall measurement devices with millimeter precision, as the presented information is more important the the exact position. Still, the precision should be attempted to be kept at not more than 30 cm.

A study by Glanzer et al. [19] showed that using a Building Information Model (BIM) can increase in-door position accuracy, by excluding less probable positions of the user, based on the BIM. This method is not applied in this application.

Chapter 8

Conclusion and Future Work

In this chapter the research questions are assessed in relation to the results. A conclusion is stated and the future work is identified.

8.1 Conclusion

This research has investigated how an application for maintenance workers could utilize Building Information Models (BIM), Augmented Reality (AR), and Location-Based Services. The research relate to how a combination of these technologies could aid maintenance workers in their daily operation. A prototype was developed and evaluated to assess the possibilities and the challenges. The research focused on answering these questions:

1. Is it possible to present Building Information Models (BIM) relevant for building maintenance workers using mobile Augmented Reality (AR) and Location-Based Services?

2. If yes on 1) Do maintenance workers find this possibility useful?

3. How to assure high usability of such applications?

To investigate the first research question a prototype was developed. The prototype used BIM, AR, and Location-Based Services to evoke opinions on how these technologies could be applied for maintenance workers. As described in section 7.1 it is clearly possible to present BIMs relevant for maintenance workers using these technologies.

The second research question was examined by analyzing the users perceived usefulness of the prototype. As described in 7.2, results from the evaluation revealed maintenance workers assessing the prototype to having a strong degree of usefulness in a maintenance work environment.

The third research question was examined by analyzing the users perception of the prototypes usability, and how known challenges affected this. As described in section 7.3, high usability of such applications is achieved through creating a intuitive user interface that follow the general usability guidelines. The results also show that the known challenges are not so prominent as estimated.

Before starting with this thesis, my assessment of AR was a fun technology with no other applicability than marketing and games. This view was based on the currently known lack of availability of AR in business applications. From conducting this thesis my view have changed dramatically. I have learned the advantages AR can give an application, and the power of combining it with BIM and Location-Based Services, as described in this thesis.

This thesis concludes with the presence of major advantages when applying BIM, AR, and Location-Based Services, and the evaluation show that maintenance workers are highly positive to such a solution. The thesis has also provided a example of a solution in the developed prototype.

8.2 Further Work

This section highlights possible approaches for subsequent work with this thesis.

As the application is still an early prototype, more work is required for it to become as intended. The application could be developed to be ready for release, and possible extensions of functionality could be looked into. In addition, a way to incorporate the application more as a tool could be examined.

8.2.1 Further Prototype Development

The initial idea was to create the prototype close to a releasable application. As the thesis proceeded, the amount of work was gradually revealed, and this idea become improbable. The prototype development focus changed from being a releasable application to being an early prototype. The early prototype would appear as the releasable solution, and could be used to research the usability and impact of the features in a maintenance work environment.

Development of full Building Information Model (BIM) compatibility in Augmented Reality (AR) turned out to be a task greater than the allocated time for this thesis. To solve this, the BIM is imitated by using static images as information for the AR. The CampusGuide API for location retrieval did also not work as intended during the tests, and the location was set manually when conducting both tests.

Further development of the prototype should focus on finalize the aforementioned tasks, and then complete all requirements.

8.2.2 Application Release

The application could be developed to a point where it is mature enough for release as a daily tool in a maintenance environment. To get there the application need to be developed for release, and tested rigorously. The application should also be able to be integrated with existing systems.

Commercialization could also be examined by using Kleef et al. [28] success factors for Augmented Reality (AR) business models.

8.2.3 Extend Functionality

The functionality could be extended to also include the possibility for updating changes in the application by maintenance workers. When carrying out maintenance work the systems need to be updated with the latest information. Current maintenance systems at Norwegian University of Science and Technology (NTNU) do also suffer from updating issues. NTNU have solved this by hiring a person exclusively to update maintenance work afterwards in the computer systems.

Other functionality could be exploring the social aspects of Augmented Reality (AR) as described by Schmalstieg et al. [50] with AR 2.0, or including 4D Building Information Models (BIM) as described by Woodward et al. [64].

8.2.4 Incorporate as a Tool

The application could also be incorporated more closely as a maintenance work tool. One such solution could be to utilize modern wearable computing as described in section 2.2.2. A combination of Project Glass from Google[1], and a compliant version of the application in this thesis, which utilize Augmented Reality (AR) and Building Information Models (BIM). The possibility to present relevant information to a maintenance worker in such an easy way, without even requiring frequent hand interaction, could open for higher efficiency in maintenance work.

[1] Google Project Glass: http://www.google.com/glass/start/

Appendix A - System Usability Scale

The System Usability Scale (SUS) presented is from the work of Brooke [8], and is further explained in section 3.4.2.

System Usability Scale

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Appendix B - Application Specific Survey

The Application Specific Survey (ASS) presented is distributed to all test participants.

Application Specific Survey (ASS)

	Strongly disagree 1	2	3	4	Strongly agree 5
1. BIM is currently available for the building I manage					
2. This university is currently using BIM in other projects					
3. The app eliminates the need of bringing blueprints with me					
4. The eliminates the need of knowhow (tacit knowledge) of an experienced maintenance worker					
5. I find the app to be a relevant tool for my daily working routine					
6. I find the app to be a relevant tool for substitutes in my position					
7. The app could help me find the relevant building information					
8. I believe I could get use of this app in the future					
9. I believe the successor in my position could get use of this app in the future					
10. The accuracy of position and orientation of the app is not a problem					

11. How do you think this application should be improved to better help you in a daily maintenance work environment?

____

____

____

Appendix C - Test Subject Form

This form is distributed to all test subjects executing the application testing.

ID	Question	Response (Yes/no/description/ 1-5 worst-best)
Q1	What is your gender?	________________
Q2	What is your age?	________________
Q3	Which university do you work for?	________________
Q4	What is your position?	________________
Q5	Do you have a smartphone, either a private or at work?	________________
Q6	What are your skills on using the smartphone?	________________
Q7	Do you have a tablet, either a private or at work?	________________
Q8	What are your skills on using the tablet?	________________
Q9	Do you have a computer, either a private or at work?	________________
Q10	What are your skills on using the computer?	________________

Appendix D - Digital Attachments

In this appendix a link to the application source code and the raw survey results is presented.

D.1 Source Code

The source code is available from the hosting service GitHub, on the address `https://github.com/marnag/Context-AR`. The code is licensed as open-source, under the GNU public license.

D.2 Raw Survey Data

The survey data is also available from the hosting service GitHub, on the address `https://github.com/marnag/Context-AR/tree/master/survey`. The survey data file is named spss_data_washed.sav, which is readable in the software IBM SPSS Statistics[2].

This file contains all retrieved data, except the property "leadership position" and "age". This data is scrambled in the file, because a presence of these data in combination with the few instances in "field of responsibility" could be used to violate the anonymity of the data.

[2] IBM SPSS Statistics: http://www-03.ibm.com/software/products/us/en/spss-stats-standard/

Appendix E - Comments

The following comments are feedback and suggestions received in initial investigative interviews and during the evaluation phase.

1. **Maintenance worker at UIT:** This application can be used for security guards, which need to do step-in maintenance work, such as finding valve for closing water supply in a leakage situation at night. The valve can be situated around in the whole building, and todays solution is to find the maintenance office and interpret the blueprints.

2. **Ventilation engineer at NTNU:** Even though this application is just a prototype, I really like it and see a need for it in our daily work.

3. **Ventilation engineer at NTNU:** Good idea! When we need to figure out a K-value for a system today to do measurements of air distribution, we need to either disassemble the ventilation system and find the K-value on the inside, or find the K-value somewhere in the correct documentation for that specific system. This kind of application could easily reduce the time from 15 minutes to 1 minute.

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