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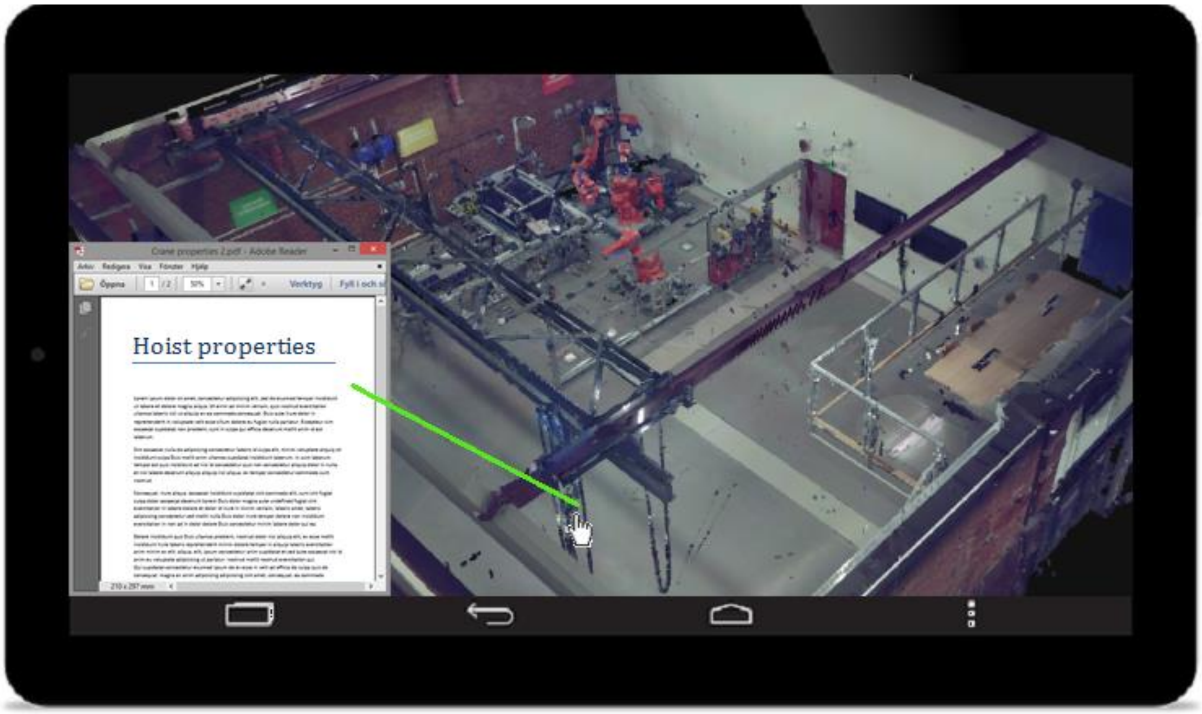

VISUALISING INFORMATION SYSTEM WITHIN PRODUCTION ENGINEERING

Master's thesis in Production Engineering

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Gothenburg, Sweden June 2015

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Visualisation of the possible new information system, with a point cloud section of a workshop at Chalmers, displayed on a touch pad.

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Abstract

At the company GKN Aerospace all planning processes for installation of machines, currently rely on 2D drawings of the layouts and architectural buildings, these often show not to be fully updated and even provides incorrect information to some extent, which leads to several problems, some severe costing up to 2 000 000 SEK in unpredicted work. Taking in consideration that when a machine is installed, it is not seldom that it stays in place for 25 years, layout planning and other machine related work concerns should be as thorough as possible from a cost perspective as well as to avoid future problems.

The objective of the master thesis described in this thesis, is to further develop earlier research made on the uses of point clouds of workshops, this by making an empirical study at a company, supported by a literature study on the area of research. The aim of the project is to deliver a function specification, of the characteristics that would be of best use to its end users. This function specification should be seen as first stage in a possible implementation of a new visualising information system, using point clouds of the workshops at the company. The main stakeholder as the end users for the new visualising information system, was identified to be the department of Machine Maintenance Engineering, and the new information system is meant to improve the planning of new layouts in the workshops as well as the daily maintenance in the workshops.

The methodology used in this thesis include an empirical study at the company, a literature study with the objective of gaining inspiration and extending the project team's knowledge in the field of 3D laser scanning, research of technology already in use and research methodology. By broadening the knowledge on cognitive support and on how to correctly select and interview the personnel chosen, the empirical study with direct observations, interviews and meetings could be analysed together with the literature study, which further on led to the composure of a function specification and a demo.

The function specification served as a base for the development of the demo, which demonstrates how the functionalities could be accomplished in a new visualising information system. This thesis presents a benefit analysis of possible savings with a new visualising information system at the company. The conclusion made by the project team is that a new visualising information system of this sort would save money, time and work effort at the company, as well as contribute to a better work environment.

Acknowledgements

The project team that assembled this master thesis, wants to use this section to thank for the help and commitment of the knowledgeable people that were directly involved in the success of this investigation. We thank our supervisor Erik Lindskog at Chalmers, for the effort and support put into this project, Johan Vallhagen at GKN Aerospace for putting this investigation on the map, and giving us access to the correct personnel, and our examiner Björn Johansson at Chalmers for making this investigation possible.

We would like to give a special thanks to the Machine Maintenance Engineering Department, for the enthusiasm shown for the outcome of our investigation, and the effort put into making sure that we had all the correct and necessary information, as well as access to all the personnel we asked for. We would also like to thank all the personnel at GKN for the time spent in meetings and interviews and for giving us the opportunity to do direct observations.

This work is a contribution in the project *Methodology for Visual Production Development* which is funded by VINNOVA (Swedish Agency for Innovation Systems) and the NFFP6 program.

Terminology

In this Master Thesis, a couple of terms that can leave room for interpretation are used frequently. In order to avoid misunderstandings, these terms will be explained below, in the context of this thesis.

Cloud storage
Is a type of service, where users store and manage files online. Having the files online, allows the users to access them from anywhere they find themselves, and also speeds up the processing time when working with heavy files, due to that just the data viewed is being downloaded.

Cognitive support
Regards the area of how to best design support for the worker, in order to provide ultimate conditions to correctly interpret the task and its status. Cognitive support has the aim that it should be hard to do things wrong and therefore it contributes in the avoidance of errors, danger, confusion, irritation and mental overload.

Demo
This thesis presents a demonstration (Demo) that is a representation of how the functions in the Function specification could be accomplished in the possible information system.

End product
Product that this project is intended to deliver a pre-study for, will be the final information system implemented at the company. The end product is intended to be used on a daily basis of the entire MME department.

End users
Users of the new visualising information system that this project has elaborated a function specification for. It will include workers with different responsibility areas at the Machine Maintenance Engineering department, such as project leaders for equipment acquisition, machine maintenance managers and mechanics and electricians in the daily maintenance work.

Function specification
The function specification in this thesis, is a compilation of all collected data and theory into functions that the new visualising information system should have.

Information system
Refers to a system with complementary hardware and software that collects and shares stored information in databases. It can be all kind of information, such as machine manuals, instructions for operators and mechanics, production data, maintenance data, logistic data etc..

Machine Maintenance Engineering (MME)
Department that is working with both; planning new layouts in the workshops and planning of how the maintenance in the workshops should be carried out. Approximately 60 employees are working at the MME department.

Multi-touch
Refers to the ability of touching a touchscreen with more than one finger at a time, which is used to achieve advanced functionality within the software. Predetermined gestures with two or three fingers often correspond to different navigation functionalities within the software.

Point cloud
Is a set of data points in a coordinate system. These points are usually defined by X, Y and Z coordinates in a three-dimensional system, and the points are often intended to represent the surface of an object.

SAP
Is the information system currently used at the company. SAP, or SAP SE (Systems Applications Products Societas Europaea), is a German software company that delivers full-scale Enterprise Resource Planning systems to companies, corporations and government agencies.

Stakeholders
People that will be affected by the outcome of this project. More specifically they include; the project team, Machine Maintenance Engineering department at GKN Aerospace, Johan Vallhagen, supervisor at GKN Aerospace, Erik Lindskog, supervisor at Chalmers.

Tablet
Is a mobile computer with a touchscreen display, which allows the user to control it by finger gestures substituting the mouse and keyboard of the traditional computer. The Windows tablets that are used by the mechanics at the company today, has approximately the size of an A4 paper, and are equipped with a protecting enclosure.

The company
This project has been carried out in collaboration with GKN Aerospace, which will in this thesis be referred to as the company.

User interface
Is the space where interaction between human and machine occurs, and the aim is to allow effective operation and control of the machine by the human, and at the same time the machine should feedback information about the process. A user interface should be designed to be user friendly, efficient and intuitive in order to provide minimal input for the desired result.

Visualisation
Refers to visualisation within software systems. When visualising information systems, the aim is to ease the user’s perception of the information given. Instead of only textual information, it should be a visualising support for the user with images and/or animations in combination with colour coding’s or separating shapes.

Visualising information system

This project's goal has been to develop a function specification for a new visualising information system at the company. This new visualising information system should be an innovating information system consisting of both an overview of the plant in 2D and a total 3D-view of all the workshops with embedded information of machine properties, surrounding equipment properties, correct dimensions, what media that runs in tubes, instructions for workers with opportunity to edit, etc.

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1 Introduction

In this section an introduction for this thesis is presented, in order to give a background for the project and to explain the aim of it, as well as its delimitations.

1.1 Background

GKN Aerospace Engine systems (Trollhättan, Sweden) develops, designs, and manufactures various advanced components for jet engines. GKN Aerospace has today a complex information system, called SAP, which is not designed to fit all its users. The company has as well problems with not having correct, and up to date information stored in their system, this due to that many of the drawings of the workshops are old. Some are converted from physically paper drawings and information might have gotten lost, and some are not and are to found in folders. Additionally, project planners of new layouts in the workshops have expressed the need of a visualising tool when they discuss layout problems in meetings, 2D drawings are not preferable during layout planning, especially not when considering problematic height issues.

When the information system is not user friendly, there is a risk of details being missed in the documentation and misinterpretations by the user. With an information system that is hard to navigate, in addition to that the information stored is sometimes incorrect, the mental work load on the workers becomes larger due to that the workers will keep as much information as possible in their mind. With an improper information system the communication between staff will be weaker and the work more time-consuming.

3D laser scanning of the workshops at GKN Aerospace can be used for visualisation in a new information system that will increase awareness and facilitate improvements at the company based on economical, supportive, and social factors. This project has consisted of a development of a function specification for a new visualising information system, customised to serve its end users properly. The new visualising information system should render the workshops of GKN Aerospace in 3 dimensions and provide the user with correct information of the workshops, e. g. measurements in all directions, embedded information of equipment properties and instructions for maintenance. In this thesis, GKN Aerospace will be referred as the company.

1.2 Aim

The aim of the project is to identify the stakeholders that are in need of a new visualising information system, and to deliver a function specification for such a system using point clouds. The aim also includes an explanation of how the new visualising information system would be beneficial to its users.

1.3 Research questions

- What target group is in need of a new visualising information system?
- What is the function specification of a new information system?
- What are the possible benefits with a new information system?

1.4 Delimitations

The project consisted of identifying a target group and elaborating a customised function specification for a new visualising information system. The benefits, which the company could get by the functions in a new visualising information system, were analysed by the project team. This thesis also consists of a demo, which shows how the functions in the function specification could be accomplished in a future information system. Due to the restrictions of putting point clouds of the company's workshops online, and that the project team used an online tool for making the demo, the demo is made of point clouds of a workshop at Chalmers.

The project will exclude the creation of the new information system and any programing involved, as well as, if it will be compatible with the company's present information system, called SAP. This project will neither consist of the implementation process of the new system, nor any evaluation of it, by its end users. Suggestions how to further develop the new system, can be read about in the section 6 in this thesis.

1.5 Thesis outline

The theory presented in chapter 2 in this thesis should be considered as the basis for the rest of the thesis, therefore it was chosen to be presented before the methodology in chapter 3. The methodology for this project is conducted with regard to the theory.

In chapter 4 Result of data collection, the empirical research at the company with observation, meeting and interview material included, is presented. The main points from the gathered material are presented at the end of each section respectively. The theory section together with the empirical research stated in the result of data collection, have contributed to this thesis solution which is presented in chapter 5.

The discussion of how this project has been carried out is presented in chapter 6 and it is described how the project team has reasoned and why different paths in the project have been chosen. After the discussion, the project team declares their conclusion in chapter 7.

2 Theory

The theory in this thesis is a literature research with regard to current technology within the field of this project, as well has to scientific methodologies and concepts that have empowered the performance of this project.

2.1 Virtual tools for production systems

This part of the literature research will concern different aspects of virtual tools within the field of production technology.

2.1.1 Virtual technology

Traditionally used tools for creating virtually environments of production systems often encounter problems like, too low level of details and lack of correct measurements. Inaccuracies in the virtual environment, which can lead to that wrong decisions are made in the planning stage (Lindskog, 2014). This enlightens the importance of a rightful course of action when it comes to the development of a new all-covering visualising information system.

To deal with the situations that can occur when working with 2D models, that to some extent can give inadequate information, a tool called Virtual Reality was engineered. Virtual Reality has the aim to give the user a 3D virtual environment with real time data, and give the user the possibility to make correct and rapid decisions based on the visualising 3D virtual environment (Lindskog, 2014).

2.1.2 CAD

Computer aided design (CAD) is a proven and commonly used tool in the product development industry. It is a tool that is popular, since it allows for the visualisation of the product, make quick changes in its design for simpler objects, look at the mechanics and piece relations within, all this this without ever having the cost of making the physical product (Rohrer, 2000). CAD systems also have different capabilities to analyse the products features like measurements, Finite element methods (FEM) and others depending the chosen software (Madsen, 2011) quality of products are increased since design errors are reduced, CAD also improves communication due to visualisation and standardized engineering drawings and better visualisation of the measurements in these (Narayan et el, 2008)

2.1.3 3D laser scanning

Although CAD design is a proven concept in designing products, it is a very time consuming and complex job to make a CAD drawing of an existing building and all its properties, which leads to a diminished level of detail and accuracy. This is where a 3D scanner would be useful, since using a 3D laser scanner would significantly reduce the man hours required to digitalise an existing building and allow for a simple, highly detailed and realistic digital view of the factory (Lindskog, et al. 2012).

Laser Scanning is a technology that was first used in workshops in the late 80´s, where it was used to scan workshops and get an updated image to compensate for poor documentation, but was extremely expensive, lately it has not only become more accurate but the price has decreased with development, which has increased the interest over this technology Figure 1. The laser scanner works by emitting a laser beam rotating 305º Figure 2, when this beam reflects back to the machine it uses the reflected beam to give the position, colour and intensity of the target, each beam representing one point. The scanner itself rotates 360º Figure 2 emitting millions of beams and by adding each individual point generated by the laser together, it forms a spherical point cloud, each point typically having a coordinate in the Cartesian plane (XYZ) (Randall, 2013). The result of the 3D scan will be an image that is realistic and precise +-2mm, this depending on the scanner chosen (Optical Survey equipment, 2015). A very useful feature is that there is software that allows for hybrid utilisation of point clouds and CAD objects, and even transforms point clouds into CAD objects.

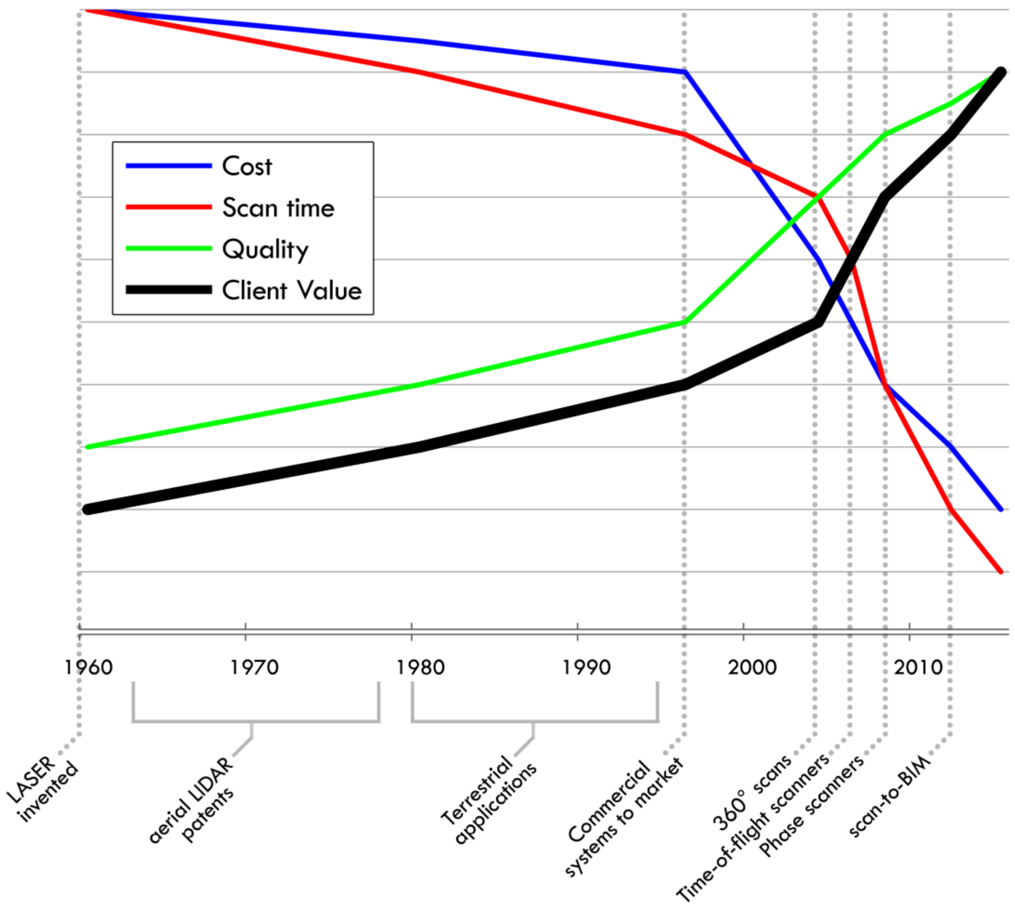


Figure 1 Laser scan development (Randall, 2013)

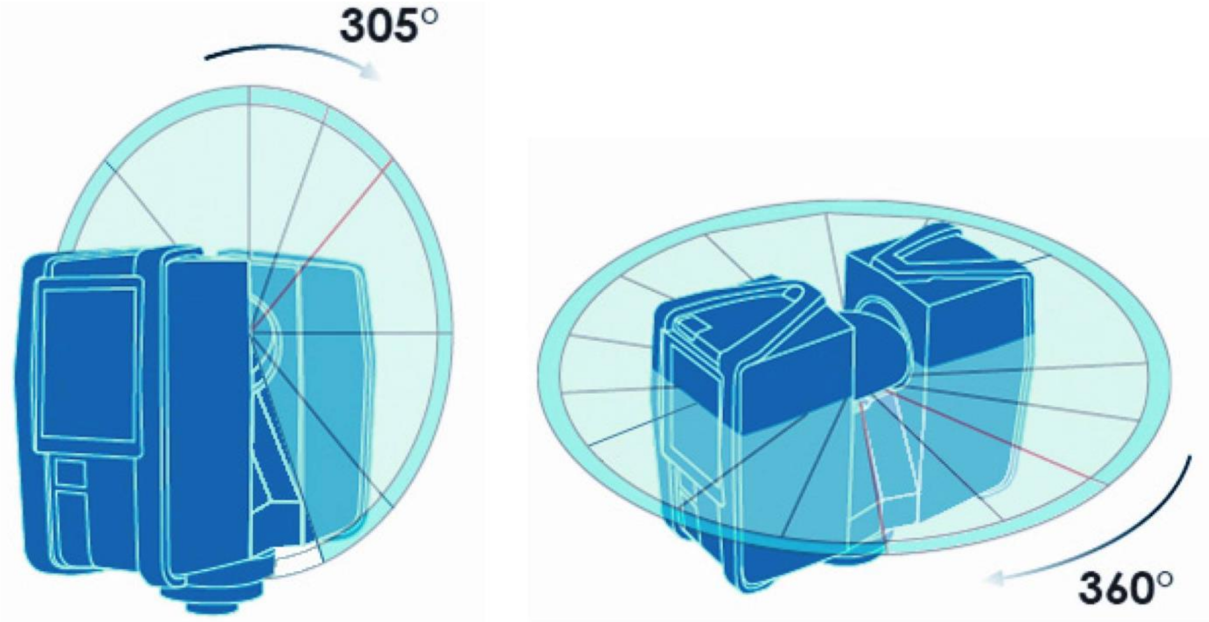


Figure 2 Rotation axis and degrees of laser scanner (Faro instruction booklet)

2.1.4 Information storing and sharing

Point clouds can be extremely large and require powerful and costly computers to manipulate them and work with them. Storing the point clouds in a server, which allows for users with the right authorisation to access, manipulate and view the desired parts of the cloud, reduces the computer's processing time and improves the user friendliness. This works by that the user only downloads the part of the point cloud that is of interest, instead of the entire file. This reduces the need for space and processing capacity of the individual computer, and removes the risk of losing the information if the individual computer crashes. (Gupta, 2015)

Lately cloud storages have gained relevance and have started to be used instead of internal servers both by companies and private people (Gupta, 2015). Cloud storage is a type of service, where users store and manage files online, so the user never sees the servers. Having the files online, allows the users to access them from anywhere they find themselves, and by not having the files on their own computer it removes the risk of losing files if the computer is damaged. Cloud storages have many advantages but as everything it also has disadvantages.

With the advantage of having access to ones data from everywhere, there is the limitation that, everywhere where one wants to access the file from, has to have an internet access, which is one of the disadvantages of the system, since there can be accessibility problems due to unreliable or no internet from certain places, as well as one makes themselves dependent on the internet and susceptible to internet shortages, which will keep one from accomplishing the job. Also to access the cloud storage one needs a computer, which depending on the operating system can show compatibility problems with the software's being used, so cloud storages also have their limitations (Kremian, 2014).

With the cloud storage a company can outsource part of the IT-department, this will reduce the need of space that is used for servers and all the equipment involved, and time that is used to manage it. By outsourcing it, one gives up direct control over the data storage and places it in the cloud storage which can be a risk in itself since unpredicted costs can rise, like the cost of migrating the data to the cloud storage, and although cloud storages encrypt their files and have security as one of the main advantages, companies might not feel confortable on outsourcing the security of their data (Kremian, 2014).

2.2 Building information modelling

The technology of Building Information Modelling (BIM) has been a great source of inspiration throughout the whole project, following there is a research on the topic.

2.2.1 Applications of BIM

BIM is a development in the Architecture, Engineering, Construction (AEC) industry that started its journey about ten years ago, and has had the aim to provide a virtual 3D model of an entity with all its related information (Lin, 2014). BIM is meant to provide the user with accurate geometrical visualisations and can give more time-effective processes, and is said to be able to give an average investment return of 634% in building construction projects (Azhar, 2011).

Some of the benefits of using BIM, it gives the users a better way to communicate issues of a project related to the facility, this because virtual rendered views and animations of the facility can quickly be visible, as well as mechanical and electrical perspectives (Hardin, 2009). BIM can be described as database of knowledge of a facility in a digital format, it is formed to be able to store the knowledge in a 3D CAD environment, as well as allow continuously updating (Lin, 2014). A further description of BIM is "a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward" and is given by the National Building Information Modeling Standard Committee (National BIM Standard, 2015). BIM is an object-oriented 3D CAD technology that renders a facility's precise geometry, all relevant data of constructions and fabrications, and also a big amount of engineering data through the life cycle of the facility (Lin, 2014).

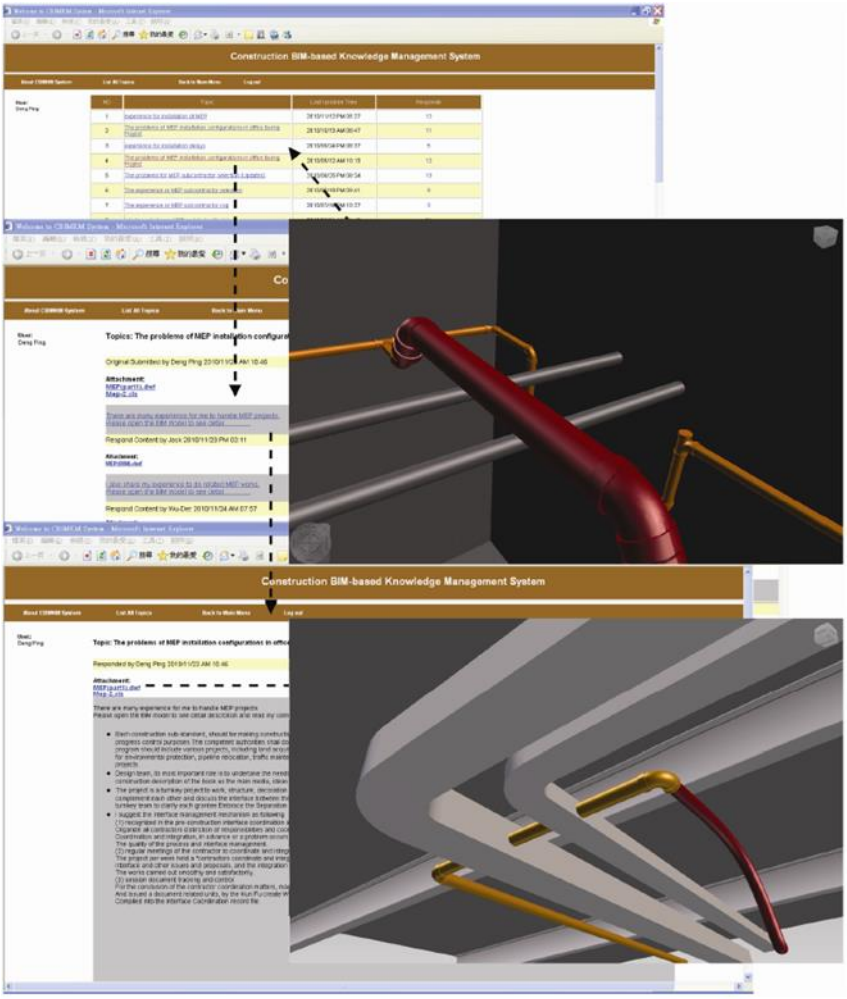


Figure 3 Information about the pipes in a facility, in a BIM software (Lin, 2014)

A well-chosen BIM technology gathers all the facilities information into one database, which facilitates collaboration between all appropriate users. As the BIM software allow continuously updating, it can be programmed so that changes made in the BIM software will affect all related drawings and data to a correct new state. Project documents and building information data are attached to the elements in the 3D CAD environment. In the BIM software, advanced analysis can be done with regard to clash detection, energy efficiency, structural analysis and simulation (Lin, 2014).

2.2.2 Clash detection

When designing structures of a building, there is often a need for detecting possible sections where items may meet difficulties to fit properly. Clash detection is a software feature in several 3D CAD programs which can detect collision between interior assets and walls, poles and pipes etc. and report detected clashes automatically (Rex and Stoli, 2014). Clash detection in BIM software can foresee upcoming possible collisions during the construction phase of a building project, and there are examples of when this clash detection feature has been able to save both time and money (Eastman et al., 2011).

2.2.3 Possible pitfalls with BIM

Integrating a totally new information system with 3D CAD environments like BIM at a company that has until now, only been working with 2D drawings, will not just be a major change for the system, it will also demand a new way of thinking for the employees. When the technology changes, so will the practices and functions of the workers using this new technology, and it’s only appropriate to not expect everything to function as it has in the past. When the information will become much richer and more robust, it is important for the management to change in its way of thinking in order to be able to fully utilise the new system’s potential (Hardin, 2009). As mention earlier, the meetings with the stakeholders of this project has given the input of an existing concern for that an exchange of information system at the company could result in lost information.

2.2.4 BIM for existing buildings

BIM is today a common tool present when projecting new buildings, and updating of pre-existing BIMs also occurs to some extent. When BIM creation is done for new buildings, it is done in an interactive way with commercial planning software which allows continuously updating to an “as-built” BIM. Despite an increasing BIM usage in new buildings, implementations of BIM for existing buildings with no pre-existing, old BIM accessible, are still a rarity in the AEC industry. One reason might be the low participation in BIM of facility managers, owners, deconstructors and related consultants (Volk et al. 2014). However, there are examples of when a BIM creation of an existing building has been developed successfully, e.g. in Sydney Opera House and in campus buildings (Volk et al., 2014).

When investigating the feasibility of developing a correct BIM for an existing building, the first step is usually to look for an old, outdated BIM for the facility that can be amended. If there is no old BIM existing at all, different technologies for capturing data are to be considered. To choose the right capture technology, the level of details for the desired functionalities in the BIM needs to be stated. Research has been done in the field where 3D-scans of the facility with point clouds, have been fed into a BIM software. “Scan-to-BIM” refers to the recent development within processes where the user should be able to get an automated BIM model from 3D-scannings with a high level of detail, which in turn should enhance the application of BIM in existing buildings. Further developments within this field, is to include scanning technology which can analyse materials and properties, with material recognition, radiography, magnetic particle inspection and possibility to identify tags installed during reconstructions (Volk et al., 2014). Detection technologies like these could improve the transformation of point clouds into a BIM model.

Functionality requirements determine not only level of detail, thus also the size of data volume which can be influencing the processing time and effort for the computers that the BIM software is to be worked on. The image- and range-based point clouds for the scanned facility has to be aligned and merged into a coordinate system, and then cleaned from noise, irrelevant parts or information. With a demand of a high level of detail, the computing time can still be unreasonable, and then a solution can be to outsource the heavy databases and computing processes to cloud servers which can enable faster operations in the BIM software (Volk et al., 2014).

2.3 Grounds for lean thinking

The science of lean production has been present during evaluation of different procedures at the company, and with regard to this follows here by an introduction to the topic.

2.3.1 Specify Value

Everything starts with the definition of value. The value in lean thinking, is the value given by the customer to a specific product (object or service), this product will have a specific end and will be supplied at a specific price. The product will be exactly what the client wants, no more no less, or else it will be considered muda (which in Japanese means waste) (Black, John, 2008). The people responsible for producing and engineering the product, shouldn't think about what is possible to do with the latest technology, but what is possible to do with technology that has already proven itself. By using the latest technology, one has the risk of producing a product that is to expensive, which would not satisfy the final customer. Risking customer satisfaction should never be put at stake, since they are the ones that demand a company's product and services (Womack, et.al, 2003).

2.3.2 Value stream mapping

In lean thinking a way to find sources of waste is to identify the Value Stream. A Value Stream is a detailed analysis of all actions involved to output a specific product, for a can of beer for example the most complex part is the production of the can itself, the value stream map starts with the mining of the raw product all the way to the transformation into a can. The analysis of the value stream will show that along the stream there are three types of action.

1. Actions that create value as the customer sees it
2. Actions that are required but add no value (Type one muda)
3. Actions that are not required and add no value, these can be immediately eliminated (Type Two muda)

The aim of this, is to reach perfection, to do this one should strive after eliminating all muda within the organisation (Womack, et.al, 2003).

2.3.3 Muda (Waste)

A way of justifying changes is to identify sources of waste that can be eliminated by change. According to lean thinking there are seven sources of muda (Arunagiria, et al., 2014).

<u>Overproduction</u>
Production of parts that are not actually demanded. This demand comes from the process ahead in the production line or from the customer order. Overproduction will lead to lines before the process ahead or lead to excess Inventory. Lean, basis its theory on a pull system, so a product is only ordered when there is a demand for it.

Inventory

Name that describes excess products, which includes finished products waiting to be demanded by the costumer, and too much work in process (WIP), all these lead to a stop in the cash flow. A company has inventory mainly for security reasons and limit the consequences of a production stop, like a machine breakdown or other unforeseen events. Inventory is expensive but sometimes a necessary evil and it requires skill and experience to decide its sizes, in the lean mentality one should aim for a pull system, and this requires having a “small” inventory or nothing at all.

Waiting

Waiting for action to happen, machine not working, operator waiting for a machine to finish, waiting for product from upstream. A source of delay can be the loading and unloading of the machine, time it takes to change a tool in the machine or a machine breakdown.

Motion

Excess movement to fulfil a task that leads to delays, unused resources e.g. employees time, skill, experience, injury.

Transportation

Describes movement/transport to or from the facility. Centralised production means that the finished product can be far from the customer, and the factory’s location can be far from its suppliers.

Rework

Describes the extra work that one has to put into the process, rework can be caused by human or/and machine error and will lead that product needs to be inspected again, and possibly have to be discarded.

Over processing

Describes the action when a product goes through a non value adding activity, simplifying the work procedure will naturally reduce these and speed up the procedure. The problem should be tackled by identifying each procedure a product goes through, all these should add value to the work object and should not be able to be accomplish automatically, the activities that don’t fit that description should be removed from the procedure or if they are a requirement e.g. bureaucratic procedures, a more effective method should be investigated to complete them.

2.3.4 People as a resource

Production companies tend to rely on technology upgrades to improve their production and eliminate their waste. Many times they forget to improve the resource that they already have people. The reason companies tend to forget this, is that it is a simple solution, but the simple solution is not always the easiest to accomplish. It has been seen that companies that take full advantage of their personnel’s capacity tend to reach a leaner production and stretch goals. By stretch goals it is meant that it is not only the production that becomes lean but the company has a whole. No company can become lean without utilising the full potential of its team (Black, 2008).

2.4 Design for human

During the late 90’s, sick leave increased among the personnel, which led to higher interest for the work environment at companies. Reasons for work environment degradation, was said to be caused by slimmed-down organisations, reorganisations, increased concentration of core-activities, higher working tempo and time-pressure (Bohgard et al, 2009). In addition to these, less time spent on adapting to new technologies, and education on how to meet these new standards for the employees, have all affected negatively the work environment.

In current years different theories have been developed to face this problem, and how to change the negative development of the work environment towards a positive direction. These theories have all the same aim, to accomplish a work environment that is motivating and supporting, and hopefully leads to engagement, increased competence and company loyalty in reward (Berlin and Adams, 2014 (b)).

2.4.1 Stress contra boredom

Workplace stressors are not only time dependent. Bad communication, insufficient support, high demands and personnel conflicts are important as well, and it’s what we call negative stress. Positive stress on the other hand, is when a worker needs to accomplish a challenging task within limited time-span, but feels confident that it can be accomplished by the means available. When the worker is able to feel satisfied with his/her performance, and as such be ready for the next task or challenge presented (Berlin and Adams, 2014 (b)).

Negative stress has a damaging impact on the work environment, so has a too low workload and a low stimulating degree from the work tasks. Boredom in the work environment leads to lower concentration in the task, and can contribute to mistakes. Boredom is often a result of a mismatch between the worker’s competence and the task demands. To counteract boredom, it is important to correctly assess the worker’s competence and exploit their full potential at work (Berlin and Adams, 2014 (b)).

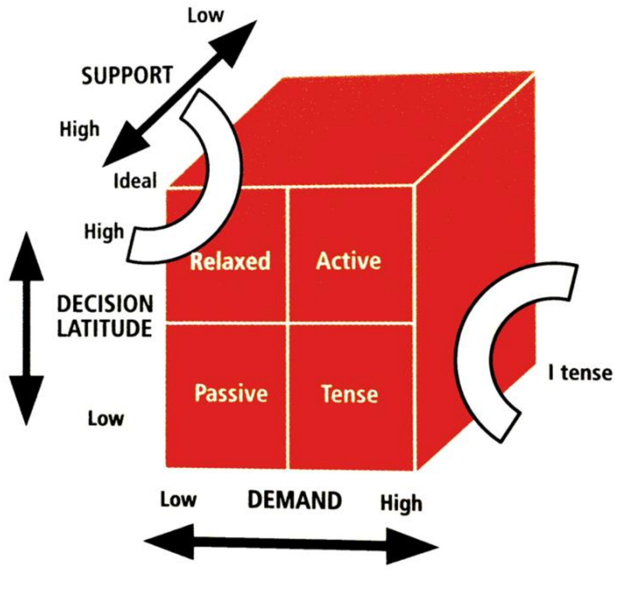


Figure 4 Demand-control-support model (Karasek and Theorell, 1990)

2.4.2 Demand, control, support

A model that well describes what factors that are important when developing a good work environment, is the demand-control-support model made by Karasek and Theorell (1990), and it takes decision latitude, demand level and support level into consideration. Decision latitude is a measurement of what authorities the worker has, i.e. what degree of freedom the worker has when it comes to taking own decisions. The demand level, represent the size of demands placed on the worker, and the third dimension, is what degree of support that is available to the worker. All these three aspects play a big role when designing a good work environment. As it can be seen in the model in Figure 4, a worker with high demands in combination with high decision latitude, together with good support/means to meet these demands, is an active worker without alarmingly high tense. If either the support or decision latitude would go down, the worker will get a tense or stressed work environment (Bohgard et al, 2009).

2.4.3 Mental models

To cope with vast amounts of information at the same time, the human brain makes up mental models. This gives the worker an overall picture of what the work task is about, or a picture of the given information as a whole, this saves time in the communication between workers and other information exchanges. Every worker makes their own mental model that will differ from each other's, also when the brain builds this model, one is susceptible to loosing information, or that false information can be remembered when the worker try's to fill up the missing gaps using his/her imagination. This misinterpretation of information can lead to mistakes of different magnitude (Berlin and Adams, 2014). To counteract the formation of wrong mental models, well-structured and pedagogical information should be available to the workers, as well as means and support for clear communication between them.

2.4.4 Design for cognitive support

It is important to keep in mind, that there is no strategy that will fit all companies. The best-suited strategy for each company to reach their goal will depend on its type of business, size, unique requirements, strengths and weaknesses. The strategy should be designed in a way where it will be hard to do things wrong, well suited instructions should be provided to the workers, it could be in paper form, but the trend leans towards providing all the required information electronically

i.e. on computers or common screens in the factory. When instructions and information are stored in databases and available to the workers, attention should be put into the way it is presented. When designing the interface, it should be done in a way that it is easy to find the desired information, doing this will also lead to that the information is updated more frequently (Berlin and Adams, 2014).

When designing the information displays, there are some important facts about the human's cognitive abilities, and limitations that need to be taken into consideration. Several design principles have been elaborated by Bohgard et al (2009) and categorised into four sections regarding attention, perception, memory and mental models, Table 1 presents an explanation of them with a focus on visual displays:

Table 1 Design for visual displays with regard to cognitive support

Attention	Minimise time and effort for finding information All relevant information for the worker should be gathered in the same display, and close to the worker. The information distribution should be ordered, so that all information that belongs together is grouped. The worker should not waste time on searching for information in different places.
	Closeness Sometimes, two different types of information are needed at the same time, e.g. an assembly instruction in combination with a picture of the part, in this case it is useful to divide the screen into two sections of information. Other cases, where one uses different types of information simultaneously, is when one groups associated information by colours, marks or arrows. However, to achieve full focus on one task, there should not be a clutter of different information in the same display.
Design to support perception	Legible displays It can seem obvious, but displays need to have good illumination, high contrast and be easy to handle in order to get the desired viewing angle. Also for portable displays, the battery life is essential.
	Minimise levels of information When different levels of information should be viewable at the same time, too many color differentiations or sizes will lead to confusion. It is recommended to not exceed 5 different levels of information, and take into consideration workers that are colorblind, color differentiations should be limited to red or green together with yellow or blue.
	Prioritise information in a suitable way If it suitable, information should be ordered in a top-down manner. Important information, which needs immediate attention, should be clearly reinforced by flashing, occupying a central location of the user interface, being highlighted in red or increased in size.
	Redundancy The same message visible in more than one way can reinforce clarity, such as using both text and images or colour and shape. A perfect example of this is traffic lights, where both position and colour gives the same message in a clear way.
	Avoid similarity If two different objects have similar names, shapes or colours, misinterpretation and/or confusion can occur. For example if two objects have the registration numbers IFU238 and IFU278, it can be wise to call them just 38 and 78 to clarify the difference.

Design for the human memory	<u>Short term memory and problem solving</u> The human's short-term memory is sensitive, and should generally not be overburdened in daily work tasks. The instructions needed for the task should therefore be presented on-screen, in this way the worker can focus on solving the problem, instead of keeping details in his/her short-term memory. However, the instructions need a well-elaborated design in order to avoid a cluttered appearance, in a worst case, the worker can be forced to store the details in the short-term memory anyway. A rule of thumb, when designing instructions with several points, is that human short-term memory is limited to remember 7±2 objects simultaneously.
	<u>Anticipating signals or statuses</u> Anticipative instructions will ease the workers mind e.g. a visible bar that fills in accordingly to the progress of the task, or by the user interface making the work aware of the next task by showing it in a section of the screen.
	<u>Consistent design</u> Like they say; old habits die hard. When changes are made in a user interface, or a new user interface is to be design, it is convenient, to keep old colour coding, names or reasoning that have functioned in the past, otherwise unnecessary confusion or re-learning will take place. In a worst case, small, but essential changes can be missed if the worker allows to continue in his/her old manner.
Design to support the worker's mental model	<u>Illustrated realism</u> The user interface should be designed, in order to render the reality as good as possible. If the user interface should give information about different units in a factory, the units should have the same order or layout as in reality. This will combine the worker's mental model of the reality, together with the instructions that belong to each unit.
	<u>Movable objects</u> Dynamic information on-screen should render the real dynamic flow in the workshop. This eases the worker's mental model of how the actual system works.

2.4.5 Elaboration of a new system

Vink et al. (2005) writes about participatory design at companies, which is a concept with the aim of letting all users have a large input through the whole design process. It is important to involve all participating employees from high-level management down to operators, including maintenance, design engineers, health and safety workers, trade-unions and branch organisations. The end users of a new design in the workshop have unspoken knowledge, as they are working in the workplace or piece of equipment on a daily basis, they are more aware of any problems experienced and more able to give specific advices regarding design modifications. However, middle management, or even top management, should also be involved in the participatory design, given their power for decision-making. After and during every step in the participatory design, all participants are kept informed of the results of every step.

Step 1. Preparation
A meeting is held with all participants and stakeholders of the project. The meeting should bring up the aim of the project, the strategy to get there, and possible outcomes.

Step 2. Analysis of current state
A study should be done, that will investigate the current state by interviews, observations, questionnaires, or simulation studies. The aim here is to get a benchmark of how things are done today.

Step 3. Selection of improvements and design
When identified problems and needs has come to light by the analysis of current state, a requirement specification should be elaborated. All the participants' requirements and wishes should be taken into account. A good way to make sure that everyone can give their opinion, is to organise a forum where ideas and improvements can be suggested by different people. Based on the requirement specification, simulations of possible new designs could be visualised by 2D or 3D animations and be further discussed with all parts.

Step 4. Pilot study testing the solution
In this step, a prototype with the suggested improvements should be tested. A pilot study should be made, where the solution derived from step 3 should be tested and evaluated by all participants.

Step 5. Implementation
A central meeting with all participants should be held, to inform what solution the project has led to. Education and training regarding the new concept should be offered to the end users. The new design/concept is implemented in the workshop.

2.5 Stakeholder identification

Stakeholder is any person/company that has a direct involvement in a project, or a person/company that is anyway affected by the project, in the stakeholder group are also people with an interest for the project (Phil Rabinowitz, 2014). An important step with any project is to correctly identify the stakeholders, which can be a complex and long process, which requires collecting enough information about each candidate to make sure the right choice is made.

2.5.1 Stakeholders Categories

Projects arise when someone sees that there is a problem that needs to be solved, and from the moment that the problem is put on the table to that it is solved it will affect different stakeholders, there are several ways to classify the different stakeholders, according to Jonker et al (2010) stakeholders are divided into 5 different groups:

Problem Creators
Are the people with enough authority to create a problem and put it on the map in order for it to be solved. They are responsible for defining the problem, but as soon has this is done and clarified, the problem is transferred to another stakeholder so it can be solved.

Problem Sponsors
Are the people responsible for keeping the problem on the agenda, they make sure it doesn't disappear before it is solved, but they do not contribute with anything to solve it.

Problem Owners
Are the people responsible for solving the problem, when the problem is created it is directly assigned to a owner. An interesting fact about the owners of the problems is that it can be beneficial to have a couple of problems in your hands when you are discussing for a budget for example.

Problem Solvers
Are the people responsible for examining the problem and eventually come up with procedures to solve it. They are not always responsible for solving the problem itself since some companies entrust consultants to do this.

Problem Subjects
These are the people the problem affects, the ones that the problem is about. These subjects are usually not involved in the formulation of the problem or the solving of it.

2.5.2 Identifying Stakeholders

An important fact when identifying the stakeholders is that one should go beyond the obvious choice of a stakeholder and remember that all changes made, will have an effect over people that weren't stakeholders at a first glance. Also, it is important to remember that projects can both have positive and negative outcome for the stakeholders (article). To better identify stakeholders one needs to go throw a knowledge gathering process, this to better understand the way the company at stake works and a better knowledge of the methods of work of does involved, to do this there are several methods that can be used:

- Brainstorming: Is ideal to get ideas in an informal way, it encourages out of the box thinking, and even ideas that can at first seem unappropriated can turn out to be the first step to reach a creative solution (Phil Rabinowitz, 2014) and this case find the right stakeholder.
- Collect names from informants in the company: This can be done by having meetings with people from different departments in the company, and lead these conversations towards the objective of your project, and whom would be interested of the project and whom would be the Stakeholders.
- Get suggestions from identified Stakeholders: Once Stakeholders start to get identified, meetings with these regarding the project will lead to ideas and personnel that can be interested and affected by the outcome, this will help to pin-point the other possible stakeholders.

2.6 Interview approach

In this section the theory behind the performed interviews at the company, is presented.

2.6.1 Information gathering

To gather information is essential, and literature studies will give one an understanding about the field of research. Interviews on the other hand, are a vary important tool when it comes to getting a perception on the reality of the factory and its workers, with interviews one may get useful information on the work methodology used, facility problems and with luck even pin point the root of the problem (Qu & Dumay, 2011). Generally, interviews are divided into three general methods: structured, semi-structured and unstructured interviews (Wilson, 2014).

2.6.2 Structured interview

Is a method of interviewing that involves a list of questions that the interviewee will answer with short precise answers, it doesn't allow for developed answers but will keep the general methodology standardised since all the questions are the same and in the same order for all the interviewees. This will give the same type of answers which facilitates analysis but there is the risk that if the wrong question is made, one will be analysing an answer that might not be useful (Wilson, 2014). It is a method that can be easily used by an untrained interviewer, although there is a risk that an untrained interviewer will not ask the questions in a standard way, risking to put words in the interviewee's mouth affecting the goal of standardisation and unbiased answers.

2.6.3 Unstructured interview

This is a type of interview that is more comparable to a conversation with guidelines (DiCicco-Bloom & Crabtree, 2006), this can lead to a more relaxed environment and for a relationship to be built between interviewer and interviewee. As in a conversation, the answers will vary and develop depending on the interviewee, and responses can uncover unexpected facts. A disadvantage with this type of interview method in relation to the structured, is that due to the conversation nature of this method, the experience of the interviewer will possibly have a direct impact on the quality of the information collected. To save the conversation a recording device should be used, analysing it can be a time consuming effort, and it can be problematic if the interviewee does not allow for the recording device to be present. (Wilson, 2014).

2.6.4 Semi-structured interview

It's a method of interviewing that lays between the structured and un-structured, and is the most used interview method of all three (Alvesson and Deetz, 2000), it's a flexible method that although it is considered structured one can use probing (A sign, can be a nod or a sound that suggest the interviewee to continue to develop the answer) this can be very useful for the interviewer. The interviews format is that the interviewer has a set of questions from which investigator will guide the interview, and by the use of probing, the interviewer will be able to keep the conversation in the right course, and develop interesting answers which has the unstructured method can uncover unexpected situations. This interview method, requires some experience from the person doing the interview to avoid placing words in the interviewees' mouth, standardisation is hard to accomplish due to that the answer to questions will lead into different directions depending on the subject, due to this, the information will also be harder to analyse and compare (Wilson, 2014).

2.6.5 Guidelines when making semi-structured interviews

When using the methodology of semi-structured interviews, one is able to lead the interview into different directions, so there are many aspects to take into consideration when preparing for them.

Firstly, one should be prepared and have facts in hand before starting the interview, this can both ease the flow of the interview, and give the interviewee confidence in the interviewer. According to Häger (2007), good knowledge about the interviewee's situation and work, can impress the interviewee and create better contact.

Though it is important to have good insight in the workers daily duties to ease the interview, Häger also brings up the value of not putting the words in the interviewee's mouth during the interview. It is a fine line between letting the interviewee know you have done your homework before the interview, and not being too busy telling him/her what you know, and hinder the interviewee to have their say. An example of this could be when interviews are done in the sports world, and the sport journalists are often a little overwhelmed by their own excitement and can give the interviewee questions like How does it feel to have taken this silver, aren't you happy at all? Will it take long to get over this huge disappointment? Because that's what it is, right? The interviewer tries to show compassion and understanding, but at the expense of not giving the interviewee the chance to give his/her opinion of the matter, and the interview becomes worthless (Häger, 2007).

2.6.6 Formulating open questions

It is essential to be aware of how a question should be formulated, the question shouldn't be leading in any direction, like the example given above, it should be formulated in an open and easy way, and the question should not be able to be answered with just a yes or no. An open question demands the interviewee to express and describe the issue, and it often begins with an interrogative, like What? How? Why? If an interview is supposed to give an employee's opinion about a firm's closure, the interviewer may instinctively want to ask the question You have fought for the factory's survival, but now it is going to close. Does it feel like a failure?, but a question like You have fought for this factory's survival. How did you react when you got the message of its closure? will probably give a richer answer (Häger, 2007).

2.6.7 Encourage the interviewee

If the interview is meant to be about the future, like the case of this project investigating the possibility for a new information system, it could be of relevance to make hypothetical questions to encourage the interviewee to come up with suggestions. Easy tools to give the interviewee the chance to express his/her mind even more, is to give the attendant the question How do you mean? or to just be silent and wait for the interviewee to carry on his or her reasoning. Häger (2007) also enlightens the value of being observant and to listen carefully, not seldom can the attendant questions formulate themselves like It seems like you think that...? or You say that it can be confusing, how do you mean?.

2.6.8 The interviewee's concern

If the interview is starting to get into sensitive territories and the employee/interviewee is becoming uncertain if he/she can reveal all relevant details, it can be suitable to offer anonymity for the interviewee. Another option is to offer the interviewee the ability to read and approve his/her parts before it get published. Furthermore, the interviewee should always get the information about who the interviewer is, for whom he/she is working, how it will be recorded, why the interview is being arranged, where and how it is going to be published, and the approximate length of it, all this prior to the interview taking place. (Häger, 2007)

2.6.9 The disposition of the interview

Häger (2007) means that a winning concept for an interview is to start with something everyone agrees upon, then deepen into the matter, and in the end ask for a further explanation from the interviewee. The circumstances will of course influence the interview's approach, additionally the interview can also be ended by a conclusion, reflection or by a future vision.

3 Methodology

In this chapter, there will be a presentation of the methodology used to reach the purpose and aim that was set up for this master thesis. The methodology consisted of a wide literature study, an empirical research and an elaboration of a function specification with a demo, based on studies and research.

3.1 Research approach

The main stakeholder for the new visualising information system was not predetermined, but was something that was identified after the start-up meetings at the company, together with early literature studies within the field of the project. Considering the input given by the upstarting stakeholder meetings, a literature study of what visualising information systems there are in the market today was conducted. What parts the literature study and the empirical research have consisted of, can be seen in Figure 5.

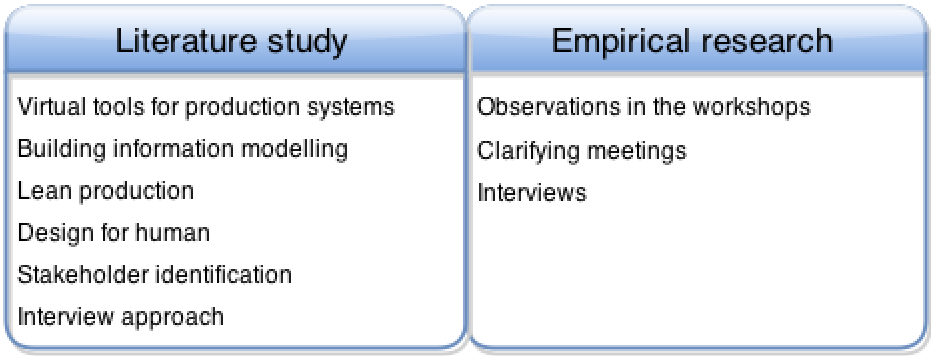


Figure 5 Included parts in literature study and empirical research

The aim of the literature study was to make a benchmark of what technologies exist within the project's field, and to investigate technologies available in the market today as well as in what way a new information system can improve the company's work procedures. The literature study also included an investigation of how a new information system should be designed to best serve its user, as well as how to identify stakeholders and in what suitable way the interviews should be carried out.

The empirical research has consisted of data collection from stakeholders and other informative sources at the company, all of which were of relevance for the projects purpose. The aim of this was to both get an understanding of the working procedures and to collect data for the investigation, this in order to pin point possible improvements. With the objective of getting as wide input of data as possible, the different methods; observations, meetings and interviews, were all performed and evaluated one by one. After each observation/meeting/interview the project team evaluated the information gathered which was summarised into main points.

When the literature study and the empirical research were finished, the project team analysed the outcome in order to be able to determine what functions the new visualising information system should have. When the function specification was established, the project team developed a demo of how the function specification could look like as a system.

The performance of this project was inspired by the first parts of Vink et al.'s (2005) methodology for participatory design at companies, which can be further read about in the theory section 2.4.5 in this thesis. The project has only used the first three steps *Preparation, Analysis of current state* and *Selection of improvements and design.*

3.2 Data collection

This section will explain the methodology of how the data collection in this project has been conducted.

3.2.1 Literature study

The data collection for the theory section of this thesis has had the aim to be a pre-study with technologies and methodologies within the field of this project. The pre-study should in turn, be a basis for the project, in order to be able to reach the final aim, which is the function specification for a new visualising information system. The theory gathered in this thesis has been retrieved from different sources, including scientific articles, books, university theses and reliable websites.

3.2.2 Snowball sampling for the empirical research

The data collection for the empirical research was collected from subjects that were selected using the *snowball sampling* methodology, this to gather the necessary information for the investigation, within the limited time.

Snowball sampling is preferably used when the research is limited to a subgroup, it is a non-probability sampling technique and functions like a chain referral. When a subject is chosen, the researchers use observations, meetings and interviews with these to ask for assistance to select and come in contact with further people that could possibly have an input. (Explorable, 2009).

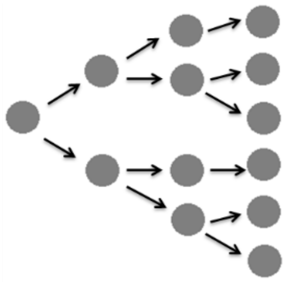


Figure 6 Visualisation of snowball sampling procedure

3.2.3 Observations

In order to get a better comprehension on the working methods of the maintenance workers, observations of the daily work routines in the workshops were carried out. The observations were done during three days and performed by tailing, i. e. not disturbing the mechanics and/or electricians. The project teamed split up in order to being able to observe as much as possible during the days. During the observations/tailings, notes were taken by the team member of how things were done, as well as how the communication between mechanics and electricians were carried out. The aim of the observations was to see things that may be done subconsciously by the workers, and that wouldn't have come to light by interviews.

During the days of observations, there was also room for conversations with the mechanics/electricians. These conversations were found to be very valuable to the project, as the workers shared experiences, thoughts and explanations of their work procedures. All valuable information from these conversations were documented.

3.2.4 Meetings

Under *Interview approach* in the theory section 2.6 in this thesis, it can be read about *unstructured* interviews and *semi-structured* interviews, the meetings performed in this project were done in an unstructured manner.

Several meetings were held by the project team with the company's personnel, these regarded several themes, from working procedures, the current information system to the personnel's own thoughts and ideas. Meetings were held with managers at different levels, with workers and external actors. Some of the meetings were audio recorded and some were taken notes from during the meeting. These meetings revealed a lot of valuable information, and the most important issues are presented under *Clarifying meetings* in the result section 4.2 in this thesis.

3.2.5 Interviews

The interviews made in this project have been carried out in a semi-structured manner, which can be further read about in section 2.6.4. After the identification of the main stakeholder, which was chosen to be the Machine maintenance engineering (MME) department, the interviewees were chosen. The interviewees in this project have been representatives from the groups involved in the acquisition of new machines for the workshops, i. e. managers and engineers, and workers of the daily maintenance of the workshops' machines, i. e.

mechanics and electricians. The common denominator for all the interviewees has been the MME department, which all of them are working for. From the project groups involved in the acquisition of new machines for the workshops, the interviewees have been selected from one of each position in the tree represented in Figure 7:

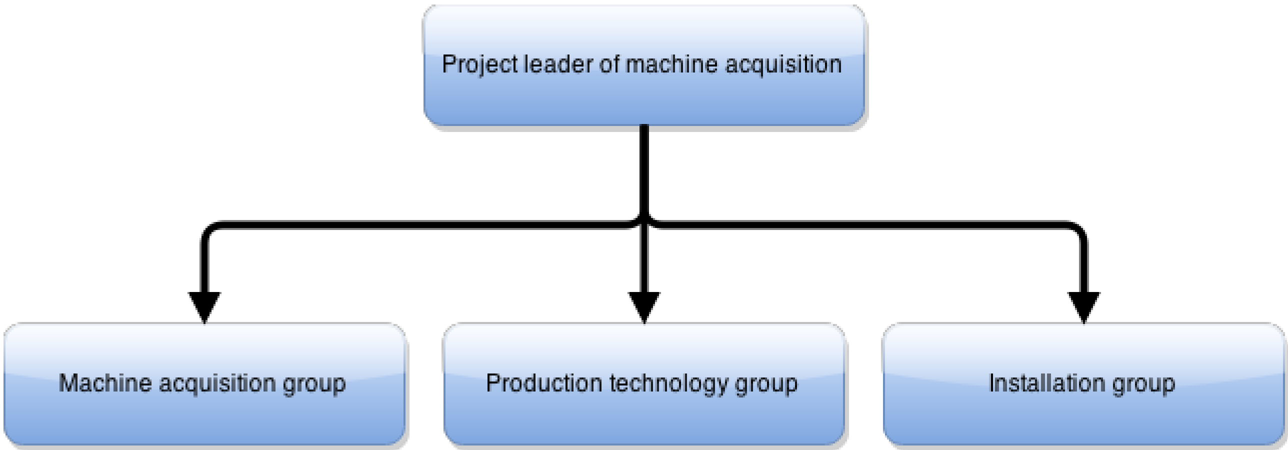


Figure 7 Hierarchical structure at the company when planning new layout in workshop

The aim of the interviews with representatives within the tree in Figure 7 was to investigate which aspects are taken into consideration, when projecting for new machines in the workshops. The plan was to get an input from all the different groups, in order to get their point of view when it comes to challenges and main interests with the project.

The interviews with the maintenance workers were done in regard of finding where time wastes were common, what tasks could profit from a more standardised work approach and a more accessible information system. The interviewees consisted of one electrician and one mechanic.

The questions for the project groups involved in the acquisition of new machines, and for maintenance workers, can be found in appendix A and B respectively. The interviews were carried out at the company, lasted for 30-60 minutes and have been audio recorded. The recordings were processed and what was relevant for the project was sorted out and noted.

3.3 Analysis of collected data

This section describes the part of the project when all collected data was analysed with regard to enable one solution for the thesis. The project team’s performance of scientific methods in order to reach one solution is presented.

3.3.1 KJ method

In order to sort all the collected data in the project, the KJ method was used. KJ stand for Kawakita Jiro whom the method was developed by in the 1960's, and has been used as a management and planning tool ever since. The method has four main steps which are 1) the label making, 2) label grouping, 3) organising into a chart and 4) make a written or verbal explanation (Scupin, 1997).

The project team has carefully gone through all the collected data, including all observations, meetings and interviews at the company, as well as all theory from the literature study. The project team methodically wrote down all the important statements that had come to knowledge, wrote down all statements on individual patches, which were then placed on a whiteboard, without any further classifications. The next step was to look over all different statements and divide them into groups according to their subject, after that, the new labelled groups were organised into a manner that would ease the perception of the project team. The last step was to give the patch groups well describing names, corresponding to the function they would lead to.

3.3.2 Design Specification

When all functions were defined from the KJ method, the project team made a Design Specification. A Design Specification consists of all functions that are defined for the new product, and is made in order to facilitate the design of product alternatives, and it should comply perfectly with the requirements (Roozenburg et al, 1995). The expected outcome from a Design Specification is a structured, hierarchical list of functions.

3.3.3 Design Specification procedure

1. All requirements given by the KJ method were listed
2. The sources of each function were identified, the source to the function were an input from the company, i. e. observations, meetings and/or interviews, and/or input from theory.
3. A hierarchy between the different functions was identified and the requirements were divided into "lower-level" and "higher-level" functions, dependent on the project team's assessment.
4. Finally, each of the functions was controlled to be:
    a. Valid
    b. Possible
    c. Operational
    d. Non-redundant
    e. Concise
    f. Practicable

The elaborated Design Specification was then set to be the project's function specification.

3.4 Elaboration of demo

In order to demonstrate how the function specification for a suitable visualising information system could appear, a demo was made in order to serve as an example on how this could be accomplished. The demo was elaborated using different software’s that had functions that complied with the function specification; the main software used is called NewSpin. The point clouds used for the demo are from a workshop at Chalmers, called PSL (Production Systems Laboratory).

4 Result of data collection

The Machine Maintenance Engineering (MME) department has been identified to be the main stakeholder of this project. They were chosen since the start up meetings with possible stakeholders all pointed towards the same direction, and in conjunction with the theory of *Stakeholder identification* in section 2.5. it was decided that a new visualising information system was required by the MME, in order to achieve better communication, more effective work procedures, and to facilitate layout planning.

Approximately 60 employees are working at the MME department, including engineers, middle management and maintenance workers. The department is handling both planning of new layouts in the workshops and planning of maintenance in the workshops, as well as performing the maintenance.

The staff that figures in the presented observations, meetings and interviews in this report, are named by their position and not by their real names in order to not single out anyone. After each observation/meeting/interview the project team has summarised an evaluation into main points, which further on has contributed to the accomplishment of the function specification presented in section 5.1. More about how the observations, meetings and interviews have been carried out can be read about in the Methodology section 3.2 in this thesis.

4.1 Observations

In this section the transcription of the observations made, is presented.

4.1.1 Tailing observations of two maintenance mechanics: day 1

The tailing observation was done of two experienced mechanics, mechanic 1 (M1) has been working at the company for 25 years and mechanic 2 (M2) for 4 years, but M2 has however longer experience as a mechanic at another company. On the day of the observations, the mechanics were doing a preventive maintenance job (PM) for a machine. The machine was a rather old one in comparison with the other machines of the workshop and had its PM instructions in a folder with text and pictures, and also had an empty field where the mechanics could write notes about missing things in the instructions as well as updates.

M1 and M2 explained that for new machines they have the PM instructions as e-documents instead, available at tablets that they bring to the workplace. The reform with having the PM documents as e-documents instead, first started with having them available at laptops that the maintenance personnel brought to the workplace. Many in the maintenance personnel have been dissatisfied with the new PM e-documents since it was not user friendly and it took time to scroll up and down in the document for the right page. In a physical folder, the different maintenance personnel working on the same machine could keep a pen between the pages where they had the information they wanted. The fact that they are often more than one working on the same machine at a time, and therefore need to look at different pages in the same PM document, causes a time consuming event since different workers need access to different pages and browsing for the right page in an e-document on the laptop does not make it easier.

Due to the complaints of the new PM e-documents readable on laptops, the maintenance personnel have been given A4 sized tablets, to access the PM e-documents on instead. The e-documents have also got improvements, by the addition of hyperlinks which quickly bring the reader to the desired page in the instructions, since the tablet's size is of an ordinary A4 paper it also served its purpose better than the small screen laptop had done. M1 and M2 both agreed on that the new e-documents on tablets have been a progress. However, with the PM e-documents, one does not have the possibility for the maintenance personnel to make notes in it, as the physical folders have.

M1 and M2 explained that another recent progress has been the development of the "Fix och trix-servern", which is a platform where the maintenance personnel, share all their notes and instructions that could be of value for any kind of maintenance made in the factory. The notes and instructions can sometimes be written by hand by a mechanic, and then scanned in to the server, and even manuals of a certain machines or tools, can be uploaded to the server. Back in the days, the maintenance personnel kept their notes in personal folders, they would at times share them, sometimes not, due to the worry of becoming dispensable. The new system called "fix och trix-servern" have all notes and instructions accessible for everyone in a collective manner, this has forced the mind-sets of the maintenance personnel to become more open, and this has also led to that time is saved when searching for instructions.

Grundorsaksanalys (GOA), in English words "root cause analysis", is a rather new working approach for the maintenance of the factory. M1 and M2 explained that when a machine undergoes condition based maintenance, the root cause of why the machine needed the procedure should be registered by the maintenance personnel. This allows for the MME department to investigate the main source of the problem, and plan a PM work for the machine, this to avoid repeating condition-based maintenance for the same reason. After each job done in the factory by the maintenance personnel, 3 - 5 "GOA:s" (explanations of possible reasons to the break down) should be reported into the GOA system which is a part of the company's information system SAP.

4.1.2 Tailing observations of two maintenance electricians: day 2

E1 and E2 are two electricians that have been working for the company for 3 and 5 years respectively. They work with machine maintenance are mostly responsible for doing electrical maintenance, but at times they also do mechanical maintenance.

The procedure observed, was the repair of an automatic electrical shut down of the machines supply. Normally when the door into the machine is open, the electricity supply should shut down, but this hadn't been the case last time an operator opened this door. So the procedure was that a new circuit for the door had to be drawn and installed.

When E1 and E2 arrived to the machine where the job should be done, they soon realised that the drawings they had got from their superior were not the correct ones. This resulted that they had to walk back to their workshop to find the right drawings on their computer. When they had found them they printed all the relevant pages and returned to the machine.

As it was a couple of pages, they had some troubles getting them organised when returning to the machine. The machine was large and the electricians had to work both at the bottom of it and upstairs from its “balcony”. Neither of the places had a workbench, and this was an issue for them since there was no way of placing the papers in an organised matter to facilitate the work that needed to be done.

At one point due to the lack of labelling in the machine being repaired and the instructions, the electricians had to investigate another, similar machine’s cables in order to know which machine’s cables were which, this so they would label the cables in the same way. When questioned how they would update the existing drawings in order to get them the new accurate cable names, they said that they would write the new names on the printed drawings and then give them to the department of maintenance planning for doing the updating.

4.1.3 Tailing observations of one maintenance mechanic: day 3

M3 have been working as mechanic for the company for over 20 years. The procedure observed, was the breakdown of a motor for the hydraulic pump, total reparation time was 2 hours. It started by, when a machine stopped and the alarm started showing on the machine’s user interface, it was indicating that the hydraulics was the source of the problem, there was no sound, and the alarm could only be known by looking at the interface. The worker then set a work order for urgent reparation, the mechanic arrived and by using his experience he listened to the hydraulics and suspected that the problem was in the gear. M3 started by dismantling the motor which took a long time, due to the confined space and protection around it. The problem was the gear where the piece connecting the motor to the machine, had its teeth run out.

To find the spare part, M3 went from the breakdown location to another block of the workshop, to be able to check for the existence of the spare parts, search was done on the computer through the SAP system, the system was divided by machine number, and each machine was divided by sections e.g. electrical, mechanical, hydraulic. The piece should have been registered under the hydraulic section for the machine, but had still not been linked to it, the reason that these situations arise are that the machines are old and parts are being added to the system one at the time.

The piece could have been searched for by its brand name in the SAP system, but M3 didn't have the know-how, so a call was made to the operator responsible for the spare part storage, and he confirmed the existence of the spare part in the storage. The storage for the spare parts is placed in between block A and C, the parts exact location was given by the SAP system. Access to the piece was easy, when the piece was found, it was registered in the system together with work order number, date, operator, piece taken.

4.1.4 Main points from observations

In Table 2 all main points that have come to light during the observations are presented in a concise manner. The sources, who claimed the subject, are lined up for each point.

Table 2 Main points from observations

Main points	Sources
Improved cognitive support for the maintenance workers is needed	M1, M2, M3, E1, E2,
The cognitive support needs improved accessibility	M1, M2, M3, E1, E2,
All cognitive support gathered in one platform would save time	M1, M2, M3, E1, E2,
An user friendly interface would save time and ease the work load on the worker	M1, M2, M3, E1, E2,
If the worker is able to easily edit the instructions in the information system, he/she could save time on the same job in the future	M1, M2, E1, E2,
The information system needs regular updating in order to prevent that new information gets lost	M1, M2, M3, E1, E2,
Embedded information of underlying equipment and parts inside the machines, would be of value in a 3D map	E1, E2,
An indirectly observation was that the layout in the work area was tight, which hindered the lifting work of the new motor, and this matter could be improved by the help of a revealing, visualising information system for the project leaders of the workshops	M3

4.2 Clarifying meetings

In this section the transcription of clarifying meetings is presented. The project team has performed several meetings for the sake of the project, here follows the most fundamental outlines captured from clarifying meetings with managers.

4.2.1 Input from meetings with stakeholders

Meetings concerning the information system today were carried out with different possible stakeholders at the company. Several meetings were with the machine acquisition group and the installation group. A recurring issue mentioned by the stakeholders within the machine acquisition group was that the drawings of the plant/facilities are often not up to date. There have also been problems when the drawings of the plant have been in 2D, and the new machine that has been up for discussion has been modelled in 3D.

Meetings with the installation group, which has access to all the drawings that describe where all different media (air conditioning, electric cables, water, pressured air etc.) are running, have given the input on how the company's information system on this matter is working at the present. The information needed when a new installations is being planned in the workshops, is mainly in the company's overall information system, called SAP, but part of the information can be found in other databases. This matter has led to time wastes in gathering all the needed information from the different databases.

The drawings are almost always in 2D at the company today and are to be seen from above. The problem with this is that, it is impossible to see if there is lack of space vertically in the area where a new machine should be installed. The installation group has been to some exhibitions which have shown 3D information systems handling constructional factors, such as MagicCAD and BIM (Building Information Modelling). However, there have been concerns among the personnel regarding changing into another system, as information could get lost.

Meetings with the machine acquisition group, have given information about possible improvements at the company regarding planning of new layouts in the workshops. There is today a lack of proper drawings of the workshops, which hinders the work procedures and consumes time in the work planning. When the location for a new or existing machine is being evaluated, it is not only the room for the machine itself that is of relevance, but also the space around the machine where trucks, forklifts and employees should fit. One opinion presented by the machine acquisition group was that much time and money could be saved if the drawings of the plant would have the correct data and presented in three dimensions. There have been occasions where preparation work has been done for a machine, which actually didn't fit in reality. During the meetings with the acquisition group it was explained that new machines are usually meant stay in the location where they are installed for 25 years, due to this it is convenient that the location is chosen properly, otherwise it will be an expensive and long lasting complication for the company.

4.2.2 Meeting with a representative at the MME department, concerning the preventive maintenance in the workshops

<u>Preventive maintenance</u>
The MME department at the company, consists of approximately 30 employees that are working with constant improvements for the maintenance procedures. The recent upstarted work with converting all the preventive maintenance work instructions into e-documents, so that they are in the right format for tablets instead of physically folders, has been a comprehensive workload for MME and is still under execution. Presently the protocol that the mechanics and electricians fill in during the maintenance, that confirms that the maintenance has been performed, is still a physically paper.

An e-document for one machine could easily consist of 55 pages including all different maintenance instruction from lubrications to electronics. Many aspects should be taken into consideration, such as how detailed every instruction should be, how many pictures a disassembly should have, and what parts of the instructions that should have hyperlinks. When something is wrong in the instructions, or some part is missing, the mechanics and electricians could either call MME or leave notes in the protocol. All changes in the instructions are then made by MME, this also applies to, when new circuits are made in the factory, which demands updating of the wiring diagrams (which was the case in section

4.1.2). The MME is responsible for updating all drawings and wiring diagrams, but today there is no verification that this is being done for every change made.

<u>GOA leads to new maintenance jobs</u>
When there has been a break down at a machine in the factory a "GOA" is written by the mechanics/electricians (see section 4.1.1 above) and is registered in the SAP system. Every Monday MME has a meeting where all maintenance for the machines is being planned. At these meetings the "GOA:s" is discussed and new maintenance jobs will be planned to solve the root cause to the breakdown of the machine.

<u>Layers of information on a map</u>
MME has today 2D layout maps of the workshops with different layers of drawings, such as machines, electricity centrals and passageways. The layout maps are however rather difficult to interpret and the different layers are seldom used, this due to when layers are taken off, it is difficult to see where and what the drawings are related to. One suggestion from the representative at MME has been to integrate an information layer of where every emergency stop is placed in the factory, this would be useful for when preventive maintenance of these would be done, and would be time-saving.

4.2.3 Main points from meetings

In Table 3 all main points that have come to light during the meetings are presented in a concise manner.

Table 3 Main points from meetings

Main points	Source
A workshop visualisation would ease the communication when new machines are being planned for in the workshops	*The main points presented here, are a synopsis of all the wants that have come to light during the meetings at the company.*
Different layers of information of the workshops visible on a map would ease the preventive maintenance work of certain equipment	
The information system needs regular updating in order to prevent new information getting lost	
All data, such as drawings and equipment properties, gathered in one platform would save time	
A fast and easy way to take measurements, both vertically and in other directions, at the workshops would save time and work effort	
Possibility for making a visualisation of a new location for a machine in the workshop	
Possibility for making a visualisation of how equipment nearby the machine will fit in the new layout	
Possibility for human mannequins' placement in a visualisation of the new layout of the workshop	

4.3 Interviews

In this section the transcription of the interviews made, is presented.

4.3.1 Interview with Project leader/Machine acquisition group representative

R1 has been working for the company for 7.5 years, and in the machine acquisition department for the past 4 years, she has worked on projects in all the facilities except for the military facility. On projects costing over half a million Swedish crowns she works as a project leader for machine investments, where the project leader is responsible for the time plan, that the equipment is ideal for the task, that it produces what it is asked for, it is effective and that it is user friendly. The project leader is also responsible for all the pre-studies, economy surrounding the project, and for gathering the right personnel representatives from the different departments to help with the project's different phases.

The procedures for acquiring new machines have variations, not in the procedure itself but on the outcome and problems that appear along the way. There are two types of acquisitions, totally new machines with a new function, different layout, etc. and new machines that the company has previously acquired; in this case meetings with the people involved in that past acquisition are arranged so that past mistakes will not be repeated.

R1 emphasised that detailed planning is essential before gate R (this is the Design review stage) closes, this to make sure that no changes have to be made after that. If design changes were to be made after this gate, it would be a costly demand, because at this point the machine construction might have reached an advanced stage.

According to R1, poor communication is the usual source of recurring problems, this happens due to the number of people involved, lack of visualisation tools, and out-dated documents. Typical problems occur when digging to install machine foundations, where examples like water pipes that were not present in the drawings are found, or when the workers that are going to use the machine are not involved from first beginning. These are examples where all the information was not gathered for the planning of the machines location or design, leading to unsatisfied operators and late adjustments in the installation of the machine, which are extremely costly.

As a project leader one is involved during the whole procedure for the machines acquisition and installation, and only leaves the project when the machine guarantee gets validated. At this point the project leader passes down the responsibility over the machine to the machine acquisition group.

4.3.2 Interview with Production technology group representative

R2 has been working for the company for the past 25 years, and within the production technology group for almost 20 years. He has had different responsibilities over the years, and he currently is responsible primarily for planning the workplaces surrounding the machines. When installing new machines, he is responsible for the planning and installation of all supporting equipment that means fixtures, NC-programs, hoists, tool cabinets, he also has the responsibility of finding the operators with the right competence to man the equipment. When acquiring fixtures and hoists from external suppliers, R2 is the middle man.

R2 explained that a recurring problem in his work, are the changes made during the planning, as an example he used the flow orientation that can change several times, and explained if he doesn't get the information of the changes on time, inaccurate decisions and wrong orders to suppliers can be made. To avoid that these problem occur in the planning phase, he relies on frequent meetings and on constant communication with all involving stakeholders.

R2 pointed out that when the IAF2 workshop was under construction, many unforeseen obstacles appeared along the way, and one of the biggest problems was when they discovered that the roof was leaking. This resulted in time-consuming reparations and delayed the installations of machines and supporting equipment.

R2 has been involved in 3D-scan project before, and gave an example where due to that there was a 3D-scan of the plant, he was able to notice the existence of cable ladders, which were not represented in the 2D-drawings provided by the facility management.

In another 3D-scan project he has been involved in, one of the biggest advantages was that the 3D-scan of the plant revealed cable ladders that were missing in the 2D-drawings provided by the facility management.

When asked for his point of view on a 3D-scanning project of the workshops, R2 was confident that it could save time if he had such a tool to more accurately plan the placement of the fixtures, hoists and tool cabinets supporting the machine, before the final installation is made. Today the location of the supporting equipment is being determined when the machine is already installed. R2 also concluded that the fact that the machines were in 2D CAD 15 years ago, and currently all the new models are in 3D CAD, the same principle should be applied for the workshops. However, he emphasised the importance of keeping the possible workshop models updated in order to get a valuable improvement.

4.3.3 Interview with Installation group representative

R3 has been working for the company for the past 8 years, and has always worked for the installation group. She is involved in projects in all of the company's facility blocks, and her group is mainly involved with the positioning and repositioning of the machines and all the media flow that is required for the machines to run, what lifting devices for it and the machines foundation. All kinds of data of the workshop are necessary when a new machine should be installed, e. g. measurements of the location, what equipment that surrounds it, and what equipment that is missing for making the installation possible.

During an acquisition project's time plan, the installation group works in close contact with the safety representatives, work environment engineers as well as the project leaders representing the departments involved in the machine acquisition. One of the responsibilities of the installation group is the electrical, pipe and foundation installations, these are outsourced and the different consultants respond directly to the installation group.

During the acquisition of a machine there are different phases of the project, the installation group is involved during the pre-study, layout planning and Installation. For the layout planning they rely on drawings for the different media and current layout of machines. The current system is that they rely on 2D drawings for each media, machine layout and even for the architecture of the building.

Recurring problems occur due to that the drawings are not updated, and the visualisation in 2D is not enough to get a real image and an idea of in which height the different features lay. The existence of non-updated drawings is still reoccurring since not all building drawings have been digitalised. Not having updated drawings lead to problems, examples given were that when digging for a machines foundation water pipes had been found which had to be re-routed, old floors had be found under the existing one and even old foundations. Unforeseen events are time consuming and costly, updated drawings would have a great impact to avoid these.

4.3.4 Interview with maintenance mechanic

M4 has been working as a mechanic for the company for the past 7 years. He works at the blocks C, B, TC and sometimes X block when they need an extra hand. Regarding the work procedures it was explained that there are two different lists of work orders, preventive maintenance (PM) which are added to their work schedule at the end of the previous week and unforeseen breakdowns where jobs are divided among workers in two different ways, own by own choice, or handed to them by their superior depending of the competence needed for the job.

When tackling a job the mechanic has the need for certain tools, spare parts and instructions. He has his own tool box that has the usual tools required, but depending on the job the mechanic might require specialised tools, he will know which ones either by his own experience or by going to the site and deciding at the time which tools he needs. Instructions can be acquired in different forms depending on the job to be done, in PM jobs both the instructions and spare parts are given on the day together with the specialised tools, for the other work orders it is the mechanics responsibility to figure out how to tackle the job.

How to complete a non PM job is completely depending on the mechanics experience and detective skills, many times they ask how to do it to someone that has done it before, to make the procedure quicker. Typical PLC problems and complex jobs can most likely be found on the “Fix & Tricks” database, where jobs, that the worker find complicated are added gradually by the worker themselves, and are organised under the machines number. There are also instruction folders, which many times are in the original language (not swedish or english) so workers rely on the pictures shown, and sometimes Google translate. Currently, instructions are being digitalised and there is a test going on where the workers use tablets to access them, feelings are mixed and many prefer the folder system, since the digital system is still not user friendly.

Finding spare parts was identified by the interviewee as the biggest source of time waste, the reason for this is that not all spare parts have been put in the database and tied to a machine’s name, the procedure of doing this is recent. Currently the parts are added when noticed that they aren't in the database, but only if the worker requests this. This system is highly dependent on the worker's desire to make it work. When spare parts are added, they are not always easy to find, this due to that workers call different parts by different names, so most of the parts are named as the person responsible for this sees fit.

Regarding a 3D system, the wish is that they would have access to all instructions behind a picture of the machine, that they could click on a tube and know which length, diameter and brand, or click on a certain part of the machine and see the part in high detail and in exploded view.

4.3.5 Interview with maintenance electrician

E3 has been working as an electrician for machine maintenance for the past three years at the company, but has longer experience as an electrician at other companies. E3 is operating in 4 out of 6 workshops in the plant. Even though E3 is mainly an electrician, he has also been working as a mechanic when it is needed. Machine maintenance handles different kind of jobs like preventive maintenance (PM), condition-based maintenance (CBM) and unpredicted maintenance.

When a maintenance procedure is planned, it could be either a PM or CBM. In case of a PM, the person responsible for planning it, will have prepared a kit with the required replacement parts, for the mechanic or electrician that would do the job.

For planned jobs there are often attached instructions for the job in the information system SAP, where all jobs are registered. Sometimes the electrician or mechanic need other or additional instructions and drawings than the ones prepared by the planners, in that case, most of the information can be found in the data bases, by searching for the machine number. The tools required for the job are up to the electrician or mechanic to decide and they rely on their experience for this. Every electrician and mechanic has his/her own scooter with a toolbox where he/she can keep the tools. Usually all necessary tools for the job are already in the toolbox and therefore they don't need an additional instruction for which tools to use, E3 explained.

Unplanned CBM for machine breakdowns has no given instructions, and therefore, the success of these repair procedures rely completely on the experience and know-how of the electrician/mechanic. Some instructions for breakdown maintenance are to be found in the "fix och trix-servern" (see also section 4.1.1) this is where the electricians and mechanics write and share instructions, drawings, pictures and manuals. E3 explained that if there has been a breakdown in a certain machine and he got a feeling of that this had happened before, he could search on the machines number in the "fix och trix-server", or for another machine that is of the same model, and get valuable instruction from the server.

E3 clarified that it is up to the electricians and mechanics themselves to add any kinds of instructions to the "fix och trix-server". Some are adding a lot to the server, and some aren't. The reason for this, is that there are no routines or rules for the uploading of instructions made by the machinists and electricians to the server, if this would be included in their work procedure, E3 was positive that the "fix och trix-server" would be a much more complete and useful database.

Searching for spare parts could be a time consuming procedure. Currently, the objective is to organise the spare parts under each machine number and section (electrical, mechanical, hydraulic) many parts are already there but many are still missing. The missing parts are added to the system when the machinists notice that the part is not in the database. Trying to have all parts tied to the machine in a computer system is a recent event (15 years), in comparison to the machines lifecycle (40 years), so this is a work in progress with no deadline.

The physical parts are all in the same building and are organised by shelves and drawers numbers. A part's location could be searched for in the computer, either by the machine identity or by the brand of the piece itself, but not everyone have the know-how on how to do this.

Daily work is organised by a work schedule, which included all planned PM, and a work list of all condition based and unpredicted maintenance. The PM schedule has been organised a week before it is to be done, and is handed out to the workers depending on their competence and availability. Unpredicted maintenance are prioritised depending on the piece that the machine is working on, workers are warned of the occurrence by a phone call, and if a certain competence is needed they would drop their current work and move to that one. Condition based maintenance e.g.(a pump sounds weird) will come up on a general to-do-list, and workers will take it depending on their availability, if the list gets to long the superior will hand out the work to certain personnel as he sees fit.

The area that requires more attention from the maintenance team is the C-block, this is explained by the large number of machines operating there and the complexity of them. A-block has more manual machines; in contrast C-block, is composed by Numerical Control (NC) machines, which require more attention due to the complexity involved to repair them.

Suggestions made by the interviewee, of functions that would be useful for their daily work would be the possibility of having access to a 3D drawing of the machine showing the problem location, (currently a problem is only known from the information on the control screen) but there is today nothing that tells the location of the problem, only the source. It was also suggested, that a tracking system with the possibility of locating the welding units in the factory would be useful, due to that, much time is being wasted on finding them.

4.3.6 Main points from interviews

In Table 4 all main points that have come to light during the interviews are presented in a concise manner. The sources, who claimed the subject, are lined up for each point.

Table 4 Main points from interviews

Main points	Sources
A workshop visualisation would ease the communication between the machine acquisition / production technology / installation group and their collaborators	R1, R2, R3
The information system needs regular updating in order to prevent new information getting lost	R1, R2, R3, M4, E3
All data, such as drawings and equipment properties, gathered in one platform would save time	R1, R2, R3
A fast and easy way to take measurements in the workshops would save time and work effort regarding layout changes in the workshops	R1, R3
Possibility for making a visualisation of a new location for a machine in the workshop would ease the communication between different groups	R1,
Possibility for making a visualisation of how equipment nearby the machine will fit in the new layout would ease the communication between different groups	R1, R2
Possibility for human mannequins' placement in a visualisation of the new layout of the workshop would ease the communication between different groups	R1,
Embedded information of what properties a surrounding equipment have, or information of what media that runs in a pipe in the workshop, would save time and effort	R3,
An user friendly interface would save time and ease the work effort	R3, M4, E3
Embedded information of underlying equipment and parts inside the machines, would be of value for a 3D map	M4, E3
Improved cognitive support for the maintenance workers is needed	M4, E3
All cognitive support gathered in one platform would save time	M4, E3
The cognitive support needs improved accessibility	M4, E3
If the worker would be able to edit the instructions of the job in an easy way he/she could save time on the same job in the future	M4, E3
An equipment tracking system regarding portable units that often are missing, would save time	E3

5 Solution

This chapter presents the accomplished solution for this project. A function specification for the intended new visualising information system is presented, followed by a benefit analysis for what it will provide to the company, and a demo of how the function specification can be obtained in one system.

5.1 Function specification

The information that generated each requirement was acquired from different sources; Interviews (I), Observations (O), meetings (M) and Theory (T).

Requirements 1 – 10 are all ranked as a highly recommended and should be seen as equals. Requirements 11 – 12 are ranked with lower importance, and should be seen as equals.

Table 5 Function Specification

	Feature in the 3D visualising information system	Source	Hierarchy
1	Workshop Visualisation • A visualisation of the workshops to ease the communication during planning of new layouts in the workshops	O, M, I	High level
2	Take Measurements • Be possible to make a measurements (vertically, horizontally and on objects)	M, I	High level
3	Updated information • Editing information regularly so it corresponds to reality, all users should be able to edit instructions	O, M, I, T	High level
4	Machine relocation • Allow to test different machine positions, and give a realistic visualisation of a new layout	M, I	High level
5	Supporting equipment placement • Visualise all nearby equipment necessary for the functioning of a machine, this to get a realistic view of how all the equipment will interact with each other	M, I	High level
6	Embedded information Layers of different information to visualise, for example: • Placement of emergency stops • Medium in tubing • Voltage in electric wires • Lift capacity of hoists	O, M, I, T	High level

7	Gathering all information in one platform • All instructions in one place • List of tools required for a job • Drawings • Machine properties	O, M, I, T	High level
8	Cognitive support for the maintenance workers • Pedagogic instructions in order to ease the workers workload	O, M, I, T	High level
9	Accessibility • Available in a suitable way to all required users	O, I, T	High level
10	A user friendly interface • The new interface should take into consideration the theory about human's mental construction	O, M, I, T	High level
11	Human mannequins placement • Need to see if there is space for human access to machine, and surrounding equipment, this to facilitate the entire work procedure.	M, I	Low level
12	Equipment tracking • Machine location • Welding Machine location	I	Low level

5.2 Benefit analysis

This section presents an analysis of how an information system, with the given function specification, will benefit the company. A thoroughly clarification of what benefits each function would contribute with to the company, as well as who the main beneficiary is for each function, is to be found in appendix C.

5.2.1 Improvements possible in the daily maintenance work

By direct observations of the daily maintenance in the workshops, in addition with the interviews made with maintenance mechanics and electricians, the project team has made the conclusion that much time can be saved in the maintenance procedures. Today there are no standard of how drawings and instructions should be updated, or even written down, neither any standardisation of how to find replacement parts in an easy and time effective way exists.

Most of the maintenance know-how is in the maintenance workers minds, and no instructions are available for many recurring maintenance jobs. However, this issue has led to a stand-alone information system, produced by the maintenance workers themselves. “Fix och trix-servern” is the unofficial name for it, which is a quantity of different PDF-files and word-files written by the maintenance workers and uploaded to a local server at the company. These files are maintenance instructions written by enthusiastic maintenance workers that want to share their knowledge to their colleagues, but as can be understood, far from all maintenance jobs have their instructions put on the server. This observation made by the project team reveals an important and accurate need of a new information system, which enables the maintenance workers to edit and add new instructions of their daily maintenance work. A feature like this in the information system would save much time and ease the mental work load on the maintenance workers.

5.2.2 Improvements possible in the planning of new layouts in the workshops

Currently when planning for the installation of new machines, the company relies on 2D CAD drawings of the factory and architectural drawings, which don't give a height perspective and do not show all required details, due to that they are not updated. This leads to unexpected obstacles, which require re-planning and sometimes re-building on site. The company is conscious of this, and tries to avoid it by having people go to the installation site and make thorough measurements and observations, but even so errors occur, some with more severe consequences than others.

The project team was made conscious by the introductory meetings and interviews with the MME department, that layout planning in the workshops is an over difficult job due to the lack of visualisation tools and to drawings that are not updated nor fully correct. Machines and supporting equipment are many times installed with regard to solutions that are not ideal, and when a machine will be in place for 25 years, all errors that are done will be a long lasting complication, unless larger investments are to be made. Correct planning is therefore an essential part of the process, so that the best possible solution can be found.

The only way to confirm that a visualising information system would be cost advantageous in layout planning, would be to do the same project in two different ways simultaneously, one with a visualising information system and one without, this in order to get a real and empirical proof of that visualisation would be beneficial. Nevertheless, the project team has received examples from a project leader at the machine acquisition department at the company, of when he has felt confident that a visualisation tool would have saved time and money in a project. The examples presented are regarding the installation of a TIG-welder and the installation of a washing machine.

TIG-welder installation example

1. When preparing for the installation of a robot for the TIG-welder, a support beam of the mezzanine happened to be where the robots working area was supposed to be set, this was an unforeseen event since the architectural drawings had not conformed to reality. To solve the issue, the supporting beam was removed, and substituted by two columns. Unfortunately, when it was time to install the machine, the new columns were in the way, since the drawings for the whole layout of the area had been wrong, and the columns were moved once more. The total cost for the rebuilding was estimated to be 130 000 SEK.
2. The control cabinet for the ventilation ended up being situated right behind the toolbox in the work cell, in this situation there was not enough space to perform any service to the control cabinet. This problem was noticed very early on, so total costs to resolve this was of 10 000 SEK.
3. A supporting beam at the entrance of the mezzanine had a very inconvenient placing for the full functioning of the TIG-welder and its supporting equipment, and this was first noticed when everything was already installed. The beam had to be moved at an estimated cost of 120 000 SEK.

Washing machine installation example

In the case of the washing machine installation, the planning team didn't have correct input from architectural drawings and floor layouts, this in addition to that the construction of the washing machine hadn't gone through a fully evaluation. The consequences were that the roof showed to be lower than expected, leading to that the planning team had to rebuild the roof in order for the machine to fit. Besides this, there wasn't space for the machine's cooler and due to where it had to be placed, they had to move a warehouse and build a new one elsewhere. Finally, the space for where the machine was going to be installed was so limited that they had to improvise solutions in order to be able to fit everything. The total cost for the rebuilding was estimated to be 2 000 000 SEK.

Predicted cost savings

The predicted cost that the company could have saved on only these two projects, by having a visualising information system, would be up to 2 260 000 SEK. There are two alternatives for how the company could produce point clouds for the use of a visualising information system. One alternative is to invest in a 3D scanner, an entirely new Faro 3D-S 120 Laser Scanner would cost around 250 000 SEK. However, cheaper equipment can be found and the price will depend on the producer, the equipment's distance accuracy, range, noise reduction, measurement speed etc. (Optical Survey equipment, 2015). The second alternative is to hire a consulting firm to do the laser scan, the estimated price of the work to scan a 1400 m2 workshop, would be of about 200 000 SEK (Rex, D. Stoli, S., 2014). This would include the scan and a deliverance of a filtered point cloud, and would require 150-200 individual scans during a two week period to get the entire work shop. Additionally for the sake of both alternatives, a study would be required to pin point how often the scan should be updated.

5.3 Demo

In the function specification, Table 5, the different functions the desired software should have are presented. In this section it is presented a demo of how such software could look like.

5.3.1 Workshop visualisation

The idea of workshop visualisation is to provide a complete rendering of the workshops at the company with the help of point clouds from 3D scanning. In this demo the point clouds will be from a workshop at Chalmers, but the service will be the same as is aimed for the company.

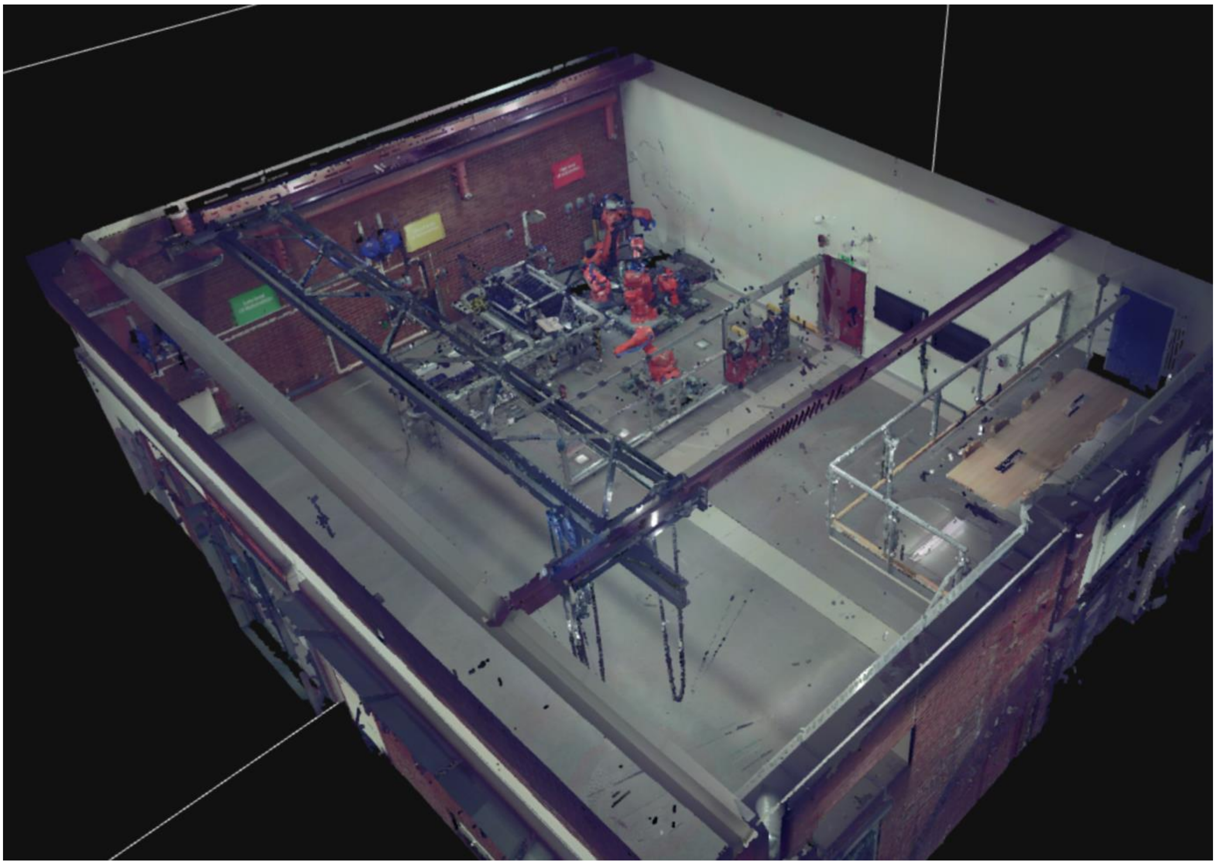
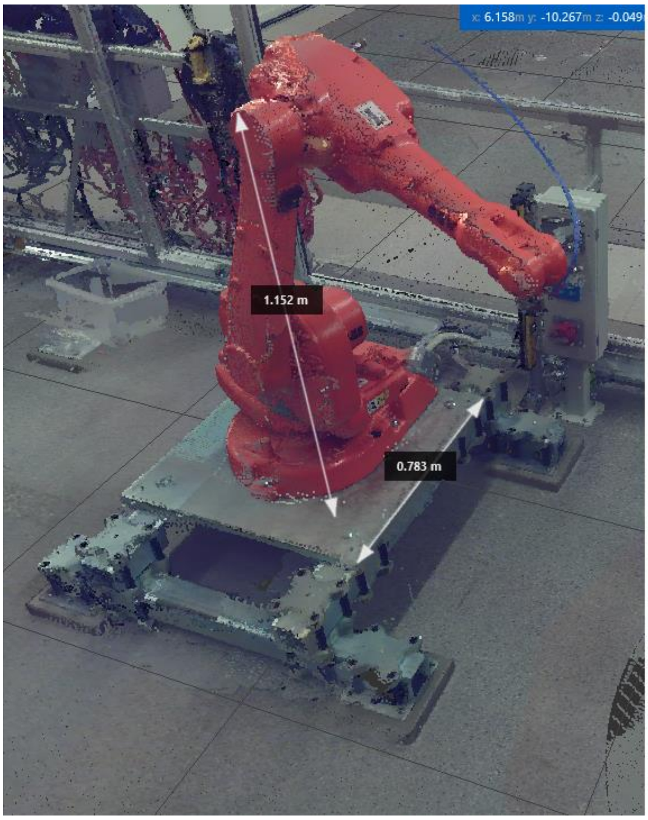


Figure 8 Workshop overview

Figure 8 shows an overview of the workshop and there is ability for zooming in to desired area and get a closer view in 3D. The ability to exhibit any desired part of the workshop in 3D facilitates communication between collaborators and makes sure that everyone considers the same thing in discussions, which hinders misunderstandings.

5.3.2 Take measurements



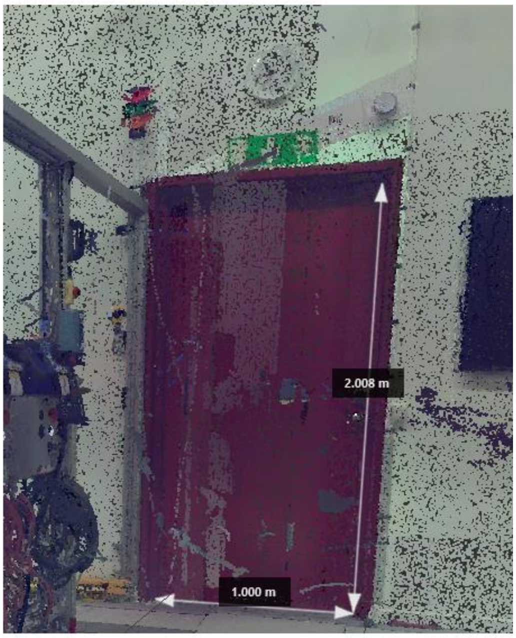


Figure 9 Measurements taken in the software

When zoomed in to the desired area, the user will have the ability to take measurements of equipment or other part of the workshop, in a quick and easy manner. In this example the question has been if the robot would be able to be transported through the door without being dismantled, and the software provides measurements of the robot and the door with an accuracy of ±2 mm.

Using this measuring function, much time can be saved as projecting groups can take decisions without ever leaving the office.

5.3.3 Machine relocation

Machine relocation can consider both new possible layouts in the workshop as well as the communication of how the machine should be moved.

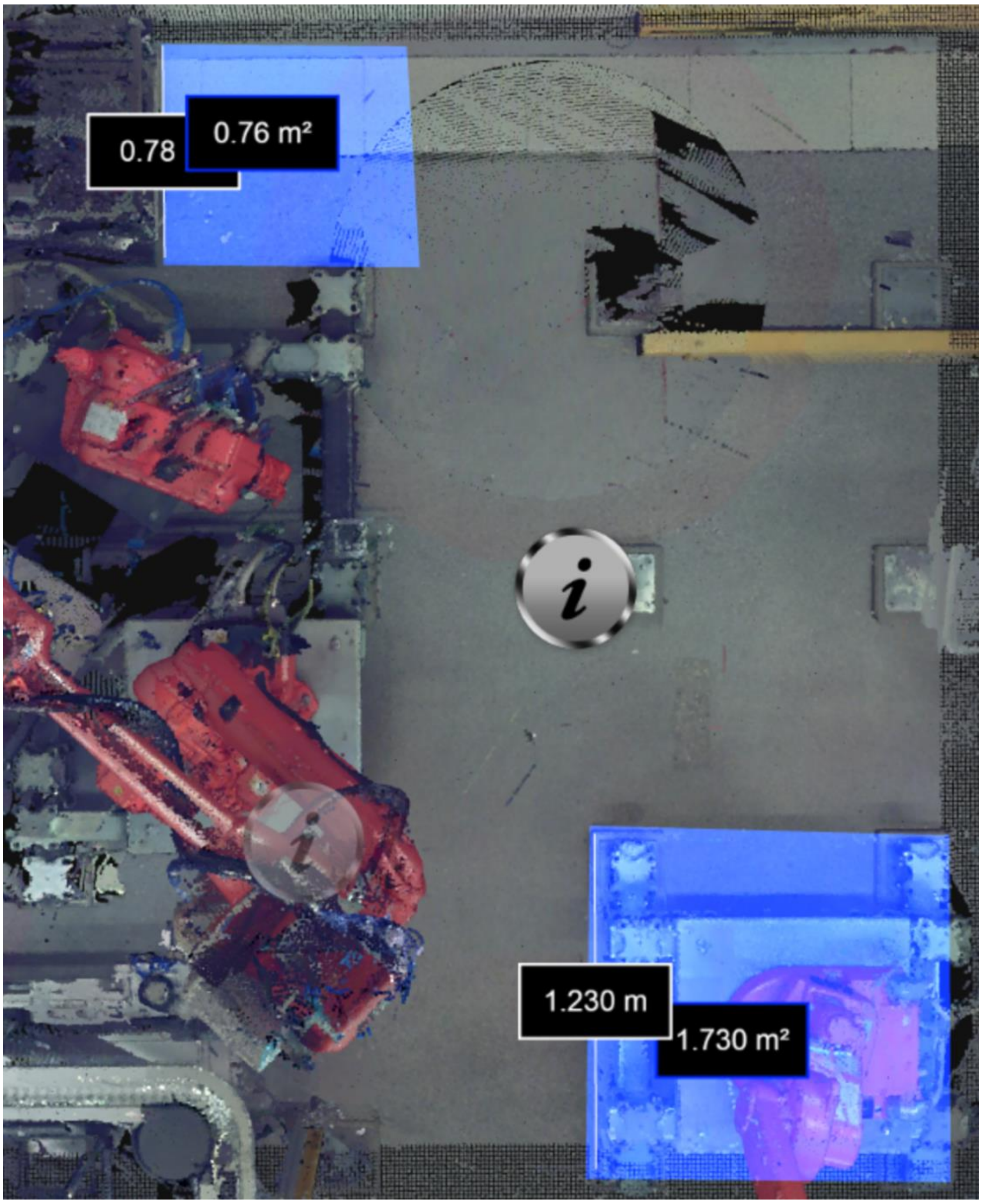


Figure 10 Area estimations in workshop

In Figure 10 an example of when the question have been if a robot will fit in another area, is visualised. Comparison can be made between both area and width of the robot and the area and width of the new place in question. A projecting group could in this example make an immediate decision that a moving of the robot to that place would be impossible.

If the area, on the other hand, would be enough at the suggested place, a “copy and paste”-function in the software would visualise the new appearance of the equipment in the workshop. In Figure 11 a robot from elsewhere in the workshop has been copied and pasted into its new place.

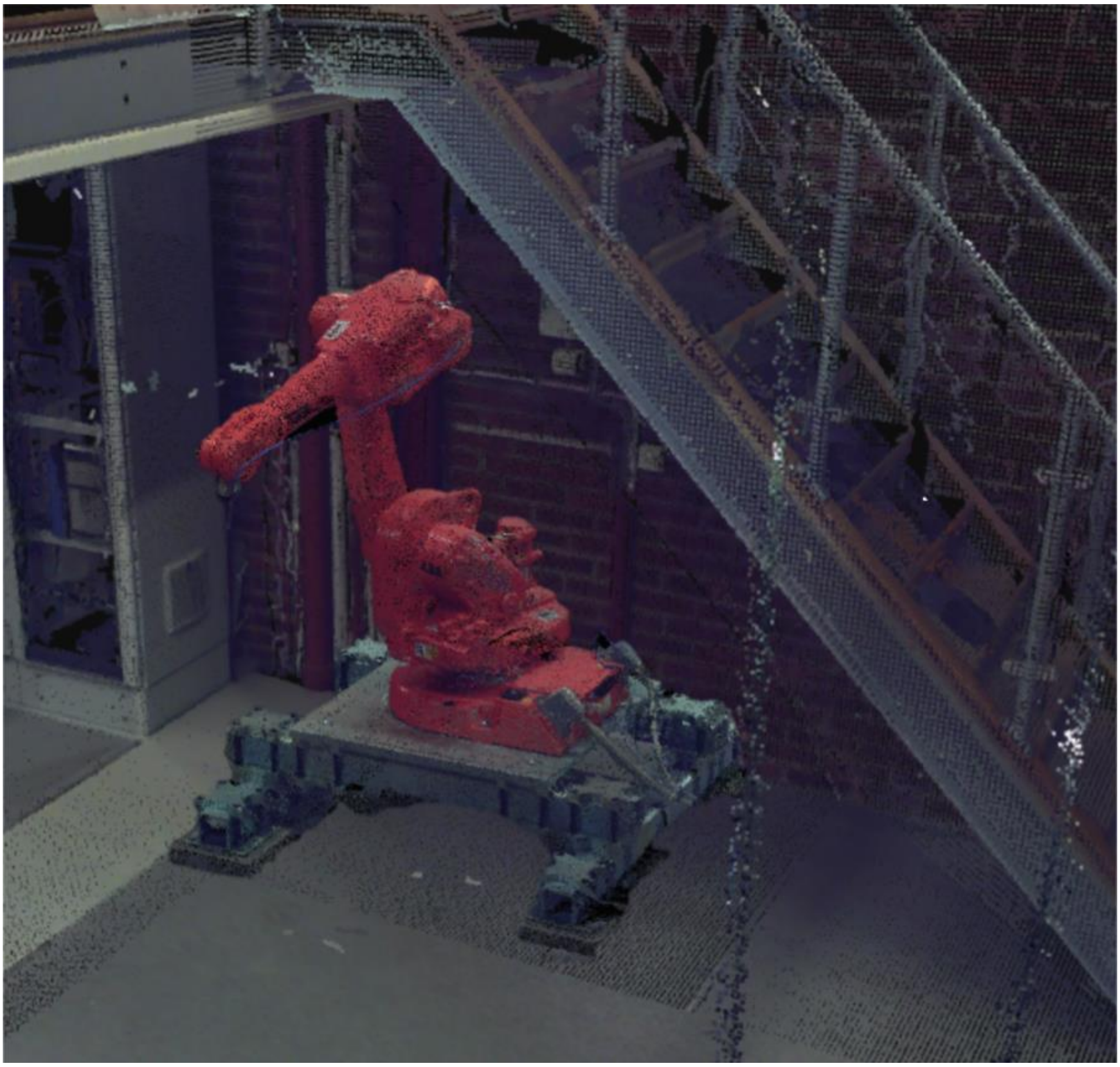


Figure 11 A copy of a robot elsewhere in the workshop pasted into new area

When a new place for an equipment has been established, the planning of the transportation of the object takes place, and in this stage the software will as well serve its users. In Figure 12 an example of how the route for the movement could be communicated to collaborators, is visualised.

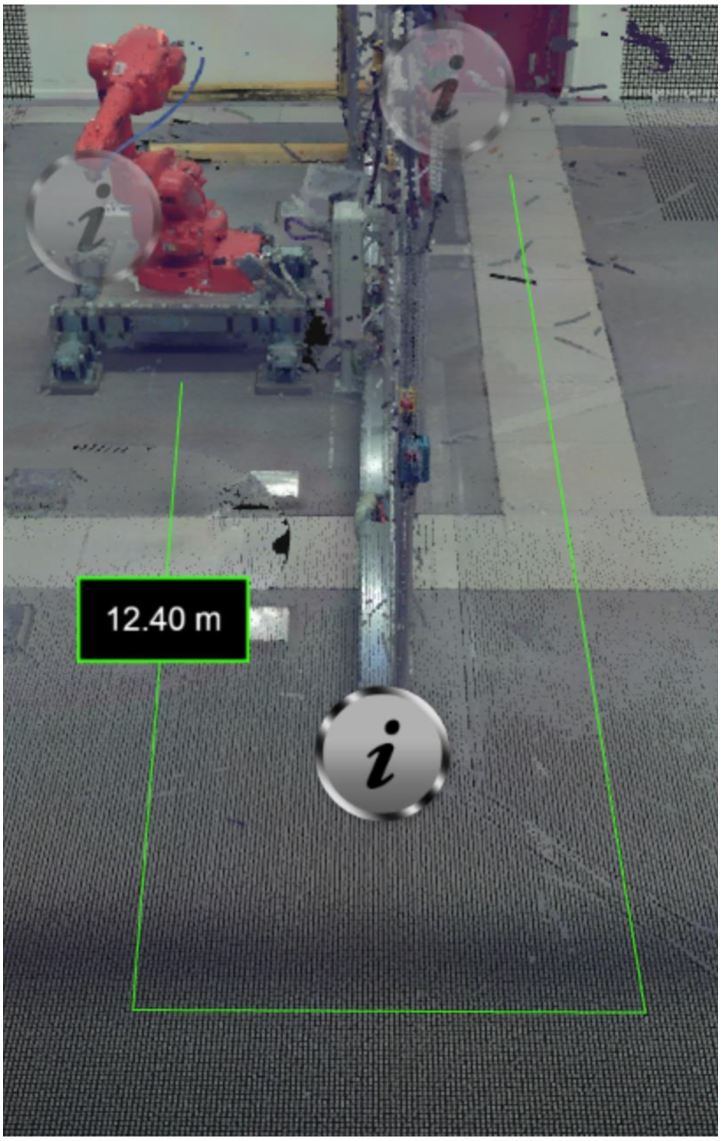


Figure 12 Route for transportation of equipment

5.3.4 Embedded information

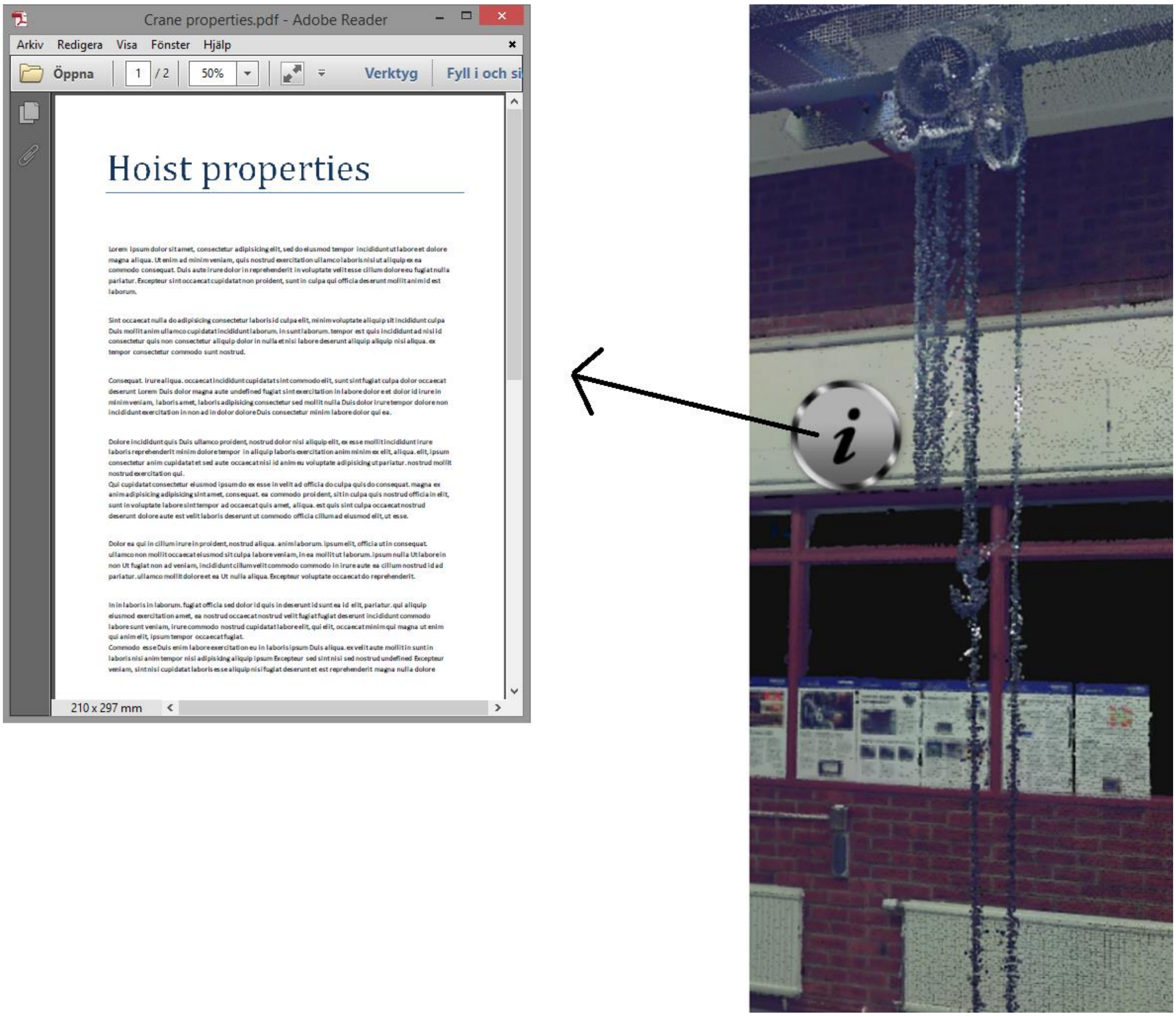


Figure 13 Embedded information of equipment in the workshop

Here is an example of how the software will provide the user with embedded information of the equipment in the workshop. When zoomed in to the desired part of the workshop, the user will be able to click on an equipment to read more about it. If the equipment in question is a hoist, as in Figure 13, the properties that will show can be lift capacity, model, height from floor or other equipment, last performed maintenance work, information of spare parts etc.

5.3.5 Cognitive support for maintenance workers

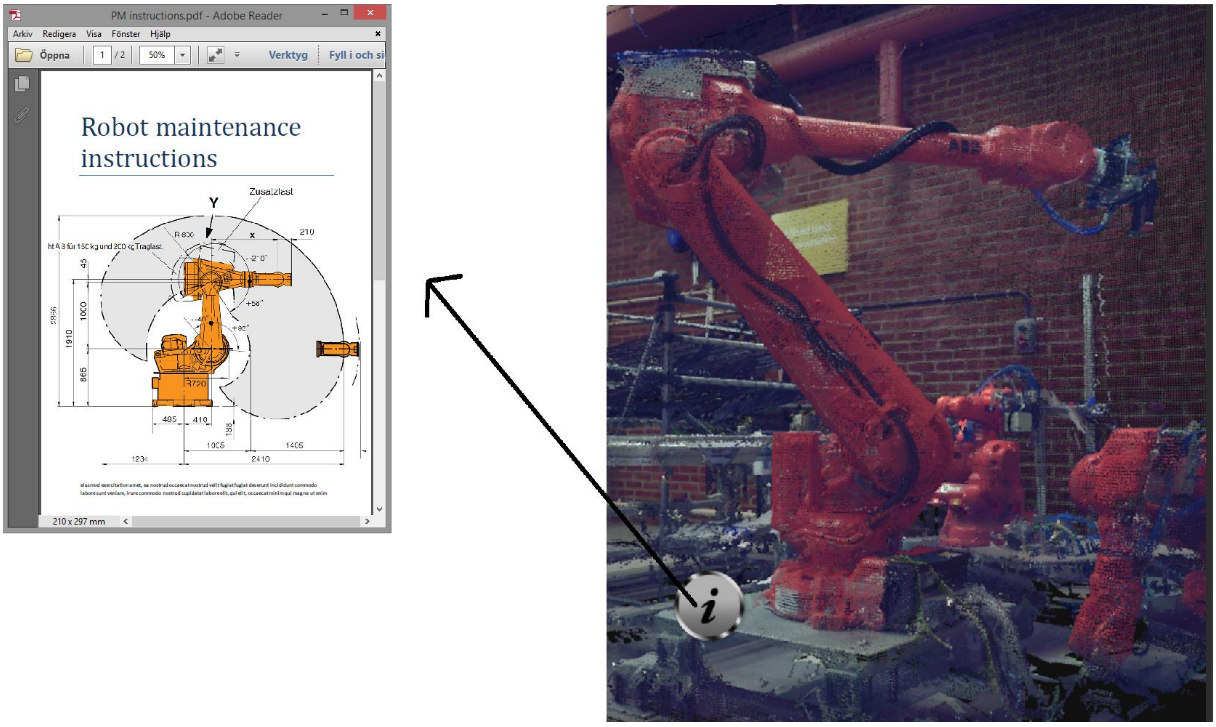


Figure 14 Maintenance instructions provided by the software

Figure 14 visualise an example of how maintenance instructions will be provided by the software, the user will be able to click on the machine to get the instructions of how maintenance of it should be performed. The idea is also to have these instructions editable by the maintenance workers, so new knowledge of how the machine should be serviced will be documented and stored for next time. This feature is inspired by the stand alone-system the maintenance workers at the company have today with valuable information of maintenance instructions for certain machines in the workshops at the company, which they have developed on their own.

5.3.6 Accessibility

It is convenient that the new visualising information system should have good accessibility for all its users. The software that will provide the information system should be accessible on both computers and on tablets. This with regard to that the workers at the MME department use both computers and tablets in their daily work. Figure 15 visualises the software on a tablet similar to the ones the maintenance workers at the company use today.

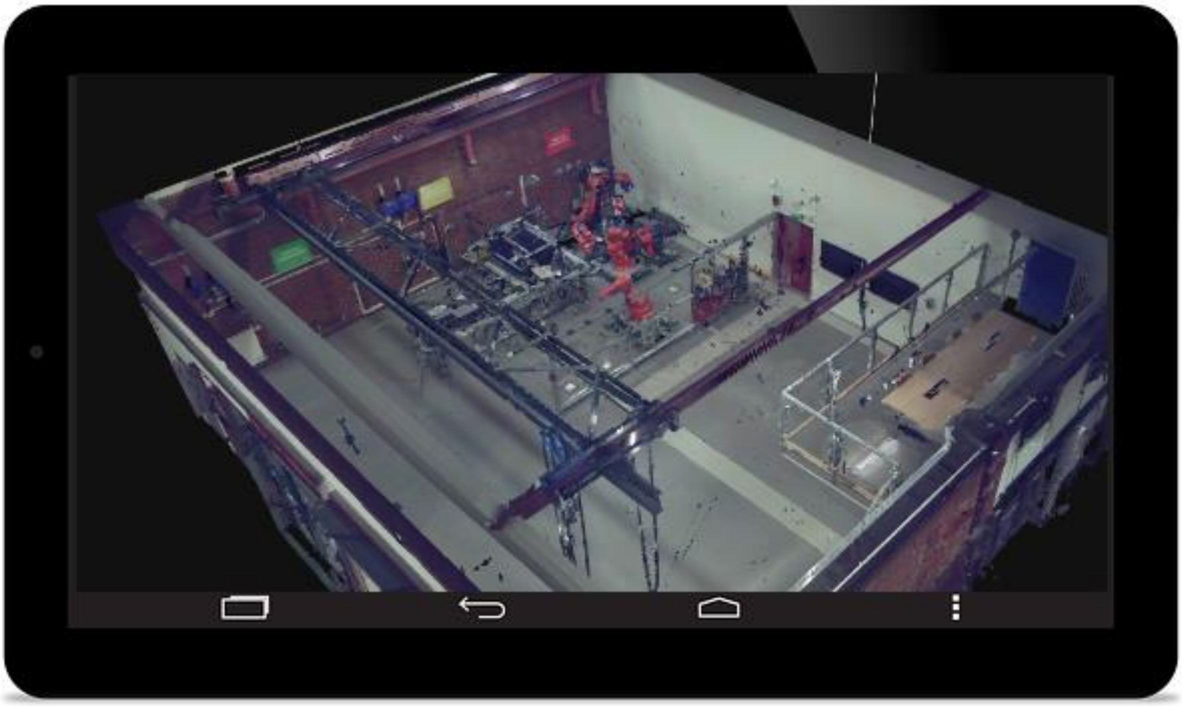


Figure 15 Example of how the visualising information system could be provided by a tablet

The navigation of the 3D view in the software on a tablet will be possible by multi-touching the screen with two or three fingers. Swiping two fingers closer or apart will zoom in respectively zoom out in the software. Swiping two fingers simultaneously upwards or downwards will tilt the view up or down. Rotating two fingers around its own axis will rotate the view. Swiping three fingers simultaneously in any direction will move the view in the same direction without changing angle or zoom.

6 Discussion

This project has had a time limitation, so the project was delimitated to be a preliminary study of what functions a new visualising information system for the company should have, together with a demo of how it could look like. The project team has made a case study of what should be considered for a new visualising information system, and an investigation of what technologies are present in the market today to accomplish this. The theory section of this thesis has been compiled with an empirical study at the company, with observations, meetings and interviews as input, and a function specification was put together. The function specification should be seen as this project's main outcome, but the project team also made a demo of how the specified functions could look like.

6.1 Theory section analysis

A complete BIM for the entire plant of the company would probably be of great value to the company and provide the planners of new workshop layouts with all data necessary for the facility. With a well-chosen BIM software there would also be possibilities for the import of CAD models of machines that are under investigation, and together with clash detect features, and schematics of media in the workshop, the best location for the machine could be determined. A BIM could even provide possibilities for different authority for different users, and give permission to edit information with regard to the user's authorisation. However, there are today very little technology developed with regard to creating BIM for an already existing building, BIMs are mainly being created for new buildings during the construction of the building itself. Taking into account that research in the area of creating BIM for existing buildings is limited, the project team has chosen to not only focus on BIM, but has taken inspiration of BIM technology into the project's development.

A visualising information system with point clouds of the workshops, and embedded information of hidden aspects of the workshops, e.g. underground tubing and properties of machines and other equipment, would be a more cost effective alternative to BIM. The visualising information system should be able to give correct and updated information, and measurements in the workshop could be taken virtually with high precision. The usage of point clouds can be a time consuming process depending on the computers power and the point cloud's size. To avoid that time is wasted on loading the files, it is recommended, that the visualising information system should be put on cloud storage which is further explained in the theory section 2.1.4 in this thesis.

In the theory section 2.3 *Grounds for lean thinking* it can be read about how wastes in the production affect the productivity negatively. The 7 wastes described by lean production, have been a useful tool in order for the project team to identify where the company can improve their working procedures. The science of the 7 wastes has been present throughout the project, during the analysis of the data collection and during the development of the function specification.

The data collection at the company has had as a source, personnel chosen by the use of the Snowball sampling method, which can be further read about in the theory section, there is a risk that the data collection has been based on opinions from a limited group. This matter can in turn have contributed to a function specification that only represents the needs of a small part of the company. However, taking in consideration the time limitations, the snowball sampling was the ideal method for this project which allowed the project team to select a group of subjects, with a high degree of precision in terms of the value for the investigation.

In the theory section 2.4 *Design for human* it can be read how important correct support and pedagogical instructions are to the worker, the appropriate name for this is, cognitive support. When designing a new information system, it is essential that it is being developed with respect to cognitive support, and that the elaboration of the new system should be done in a scientific manner, as the methodology of participatory design of Vink et al. (2005), which can be further read about in the theory section 2.4.5 in this thesis. As this project's aim has been to elaborate a function specification for a new visualising information system, and to present a demo which provides these functions, the end product is not established within this project. Therefore it is important that the elaboration of the end product will take cognitive support, as well as participatory design, into consideration.

6.2 Data collection analysis

The stakeholders for the end product that this project has made a pre-study for, were chosen to be the MME department, this was due to that the start-up meetings at the company all pointed in the same direction, a visualisation tool was desired by the MME department. Therefore, the project team has made the empirical study within the MME department and has designed the function specification to suite the MME department. However, the project team is almost sure that the new visualising information system that this project is aiming for, will be of great value for the whole company and every department.

The interview technique investigation was essential for the project, it contributed for valuable data collection for the project, it supported the project team to form the questions into open questions, and has standard as possible. However, there are room for different interpretations of the answers given by the interviewees, and the transcription from the audio recording into paper can be a source of error. There is also a risk that when two different team members transcribe the audio recordings, there could be discrepancies between the two team members interpretation of these. The same analysis can be made for the interpretations of the meeting outcomes within this project.

For the direct observations, the project team used one team member's perception of the situations given and take notes of the occurrences. This can lead to that there are details missed by the human perception. The choice of the observing method, was made due to time limitation and to being able to cover as much terrain as possible, even though the project team is aware that a video recording would have been a more comprehensive method.

Main points were chosen from the data collection by the help of the theory from the literature study in this thesis. Systematic statements by the personnel at the company have been considered extra carefully. The theory used for the analysis of the data collection was mainly taken from the sections of 2.4 *Design for human* and 2.3 *Grounds for lean thinking*, in addition to that inspiration from BIM technology was always present, which can be further read about in theory section 2.2.

6.3 Analysis of function specification and demo

The function specification is a list of all features that this project has developed with regard to the new visualising information system. A demo has been made in order to demonstrate how the features in the function specification can be accomplished in one system. Nevertheless, it is important to keep in mind that the demo has not been evaluated or tested by any end user.

In the demo it can be seen how a workshop visualisation can be achieved with the help of point clouds of a workshop, and how several of the features presented in the function specification relates to this. However, the point clouds used for the demo are not of the company's workshop, but of a workshop at Chalmers. This is due to restrictions of putting the company's workshop layout online, which was necessary in order to use the program of choice.

NewSpin has been chosen to demonstrate several of this project's function specification; it was a user friendly software to work with and could provide most of the features that the project team was in need of. Nevertheless, New Spin is not developed to support information systems, and is therefore only to be seen as a demonstration tool for this project.

6.4 Further development

For further development and investigation we leave the parts of elaboration of exactly how the new visualising information system should look like, and the implementation of it. The elaboration of the new system could preferably be done by the methodology of participatory design of Vink et al. (2005), with regard to theory of cognitive support, both parts described in the theory section of this thesis.

A suggestion from the project team, would be to order the functions in the function specification by importance for the users, this to secure that no important features would be neglected. A recommendation of how to do this would be to first select the main users of the information system and to form a questionnaire that let the main users order the functions by which they consider to be most valuable. There could also be room for the main users to fill in own suggestions to the new visualising information system. All input from the questionnaires should then be evaluated according to the methodology of participatory design.

Taking in regard that currently there is no software available that can provide all the features in the function specification of this thesis, it is of importance that the development of such software would be a thoroughly process. One alternative would be to dedicate a certain group at the company to programme a customised visualising information system, this if the know-how exists within the company, a second alternative would be to hire a consulting firm to do the job. Nevertheless, if the latter alternative is chosen it is important that an investigation of which consulting firm to hire, will be made.

The project team would like to leave the recommendation that the existing information system, called SAP, should be investigated with regard to if it would be able to be compatible to the new visualising information system. If the new visualising information system would be programmed to be compatible with the current one, much time could be saved when transferring files between them. Compatibility should also be seen as a safety aspect, since direct data transfer would avoid data being lost due to changes in the file format or to human error.

What is less recommended by the project team, but could be necessary if the existing information system can’t be compatible with the new one, is to develop the new visualising information system in an independent manner.

7 Conclusion

From the beginning to the end of this project all arrows pointed in the same direction, the company is in need for an updated visualisation system of its workshops that eases communication and at the same time hinders mistakes. Part of the need comes from when the company installs a machine, and that machine will probably be in that spot for the whole lifespan of the equipment, so when an installation is made it is essential that it will be in the correct place. The target group was chosen to be the MME department.

The empirical study at the company, including meetings, interviews and direct observations, allowed the project team to gather knowledge and pin point functions that were of use for the target group. This was compiled with the knowledge given by the literature study of this project and assembled and put together into a function specification. The function specification reveal a new, innovating, information system that take visualisation, cognitive support, possibility for all information in one platform, different layers of information and possibility for editing information by its users, into consideration. The function specification benefits all its end users, from project leaders that plan new layouts in the workshops to the workers of daily maintenance in the workshops.

The information given by a project leader of new layouts in the workshops, was that there exists a project that has had up to 2 000 000 SEK in costs due to mistakes in planning as a consequence to incorrect information, mistakes that could probably be hindered by the help of a new visualising information system. Direct observations in the workshops, have revealed time consuming processes and inefficient work procedures in the daily maintenance, here a new information system would save time and improve the work environment. The conclusion has been made that the possible benefits with a new visualising information system would be saved time, money and work effort at the MME department at the company.

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A. Interview questions with representative participating in layout planning

What's your name?

For how long have you been working at GKN?

For how long have you worked within the group of Machine acquisition / Installation / Production technology?

What does this mean?

In which workshops are active?

In which phases / gates are you most active?

What is your role when new layouts are being planned for in the workshops?

What demands do you have on a new machine?

What are the problems that usually arise?

How do you handle such problems?

Do you have examples of costly problems?

What are your spontaneous ideas / reactions to the use of point clouds of the factory, and the whole factory as a 3D view, when planning for new machines?

B. Interview questions with Maintenance worker

What's your name?

How long have you been working on machine maintenance?

In which workshops are you working?

How do you get information of what work you should do every day?

How do you know which tools you will need to use?

How do you get your instructions?

If the instructions are incorrect, how do you find the new / the correct ones?

If you are out on a job and realise that your instructions are not enough, what do you do then?

Does it happen that you need to take measurements in the workshops?

When you finish a job, what do you do?

How have you made use of the “fix och trix-server”?

What have you contributed with to the “fix och trix-server”?

Do you have any ideas of how descriptions and drawings could be more accessible?

What would you say is the most time consuming things in your work?

Is there any particular part of the workshop that has been more problematic?

How come?

How could the use of e-documents be better?

Let's say you had the whole factory on Google maps, and the ability to use Street view for it, on a tablet. Do you get any spontaneous ideas on how you could make use of it?

C. Benefit clarification for each function

The main beneficiary and benefit clarification of each function is presented in the table below. If the technology required for the function exists today, or is to be developed for the new visualising information system, will be presented as well.

Table 6 Benefit clarification for each function

Function	Main beneficiary	Clarification
1. Workshop visualisation	Project leaders, middle management, maintenance workers.	A complete 3D rendering of the workshops would be used, this would help with work instructions, and explanations. All employees at the MME department would benefit from the workshop visualisation. Technology for the function exists.
2. Take measurements	Project leaders, middle management.	Possibility of taking measurements vertically, horizontally and of objects. This function would allow for arguments regarding workshop measurements to be settled without ever leaving the office, which would be a time saver and make meetings more efficient. The function can also be used as a tool to make sure that measurements on layouts comply with reality. Technology for the function exists.
3. Updated information	Project leaders, middle management, maintenance workers.	Editing information regularly so it corresponds to reality, all users should have authorization for editing instructions related to their work. This function would serve to always keep the system updated, by the help of standardized work procedures. Scheduled new 3D scanning after layout changes, should be included in the standardized work procedures. Technology for the function is to be developed.

4. Machine relocation	Project leaders, middle management.	Possibility to test different machine positions, and give a realistic visualisation of a new layout, would ease the communication between collaborators. This function would mainly be used in discussions about machine placement, it would automatically remove certain placement options and open the gate to others, the visualising function will save time and lead to more efficient meetings. Technology for the function exists.
5. Supporting equipment placement	Project leaders, middle management.	Visualise all nearby equipment necessary for the full functioning of a machine, this to get a realistic view of how all the surrounding equipment will interact with each other. Technology for the function exists.
6. Embedded information	Project leaders, middle management, maintenance workers.	This function would allow the user to visualise different layers of information, for example placement of emergency stops, medium in tubing, voltage in electric wires, lift capacity of cranes. The user would be able to choose which layers that should be visible on the screen, or have all layers of information accessible by clicking on the object that the user wants more information about. All employees at the MME department would benefit from the function. Technology for the function is to be developed.
7. Gathering all information in one platform	Project leaders, middle management, maintenance workers.	Today drawings, machine properties, maintenance instructions, and other related information are stored at different places such as SAP, the “Fix och trix-server” and physical folders at the company. Gathering all information in one platform, which would be the new visualising information system, would save time for all employees at the MME department. Technology for the function is to be developed.

8. Cognitive support for the maintenance workers	Maintenance workers.	Pedagogical maintenance instructions, with regard to the science of cognitive support should be developed, in order to ease the workers mental workload. When the maintenance workers don't need to keep instructions in their mind, thanks to understandable documented instructions, the workers can start focusing on developing other things in their work. The theory exists, which the development of the technology needs to take into consideration.
9. Accessibility	Project leaders, middle management, maintenance workers.	Availability in a suitable way to all required users. In order for a software to be used, it should be easy to access. The new visualising information system should be accessible both from a computer and from a tablet. Technology for the function exists.
10. A user friendly interface	Project leaders, middle management, maintenance workers.	A user friendly interface encourages to a more frequently usage of the information system, as well as to a more proper usage. The interface of the new visualising information system should take into consideration theory about human's mental construction, i.e. cognitive support. The theory exists which the development of the technology needs to take into consideration.
11. Human mannequins placement	Project leaders, middle management.	Possibility to see if there is space for human access to the machines and surrounding equipment's, this to facilitate the entire work procedure. The idea is to virtually visualise the interaction between human and machine. Technology for the function exists.

12. Equipment tracking	Maintenance workers.	This function derives from a suggestion done by the employees, this when it was explained that there was a lot of time spent on finding the welding machines. The function aims to find the position of, minor portal machines online in the visualising information system. This equipment tracking would be possible by GPS-tracking. Technology for the function exists.