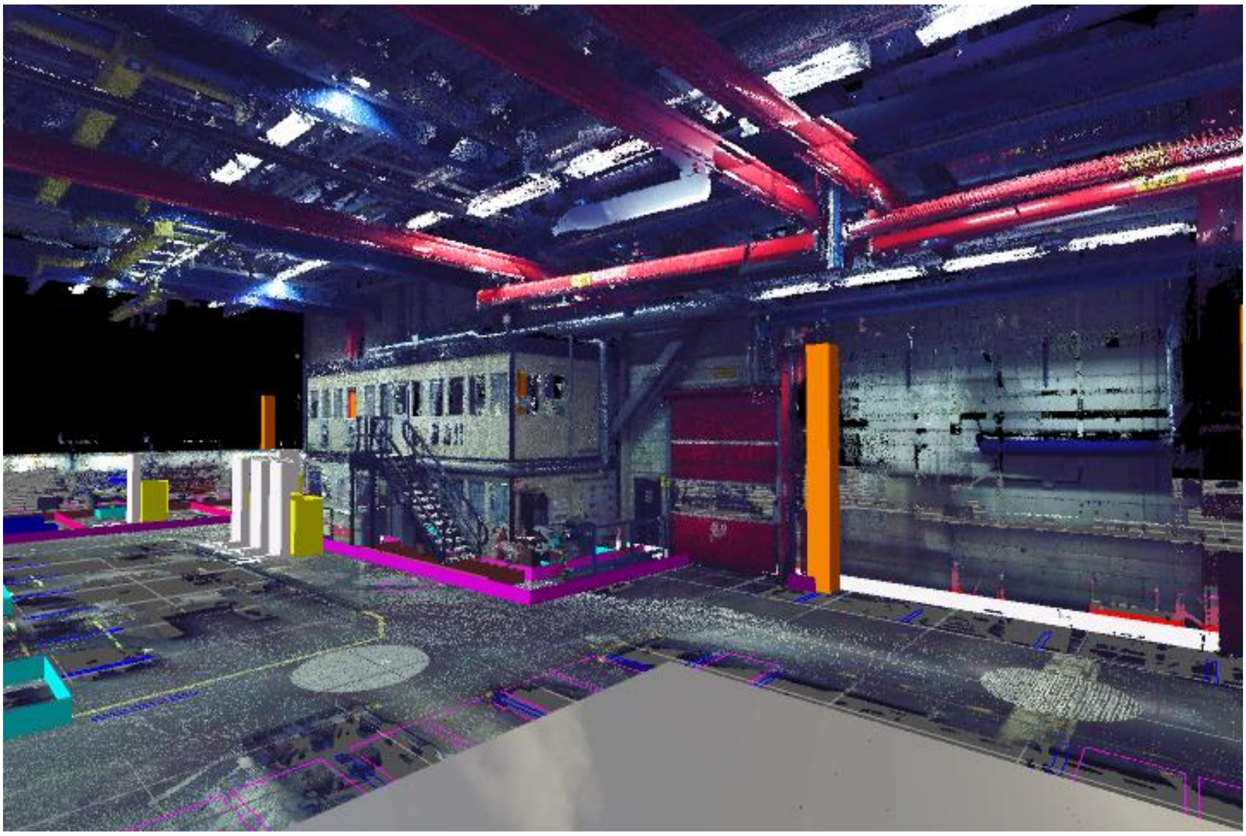
CHALMERS
UNIVERSITY OF TECHNOLOGY



Applications of 3D Laser Scanning in a Production Environment

Master's thesis in Production Engineering

DAVID REX
SIMON STOLI

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2014

Applications of 3D Laser Scanning in a Production Environment

DAVID REX
SIMON STOLI

Supervisor: Erik Lindskog

Examiner: Björn Johansson

Department of Product and Production Development

Division of Production Systems

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden, 2014

Applications of 3D Laser Scanning in a Production Environment

DAVID REX
SIMON STOLI

Department of Product and Production Development

Division of Productions Systems

Chalmers University of Technology

SE-412 96 Gothenburg, Sweden

Telephone +46 (0)31-772 1000

Cover:

Section of point cloud obtained by 3D laser scanning at UCMSWE combined with CAD-data.

Reproservice, Chalmers

Gothenburg, Sweden, 2014

Abstract

According to earlier research 3D laser scanning technology has proven to be a very efficient method for gathering spatial data, which with additional pre-processing results in a point cloud. The point cloud represent reality as-is and the accuracy of the generated points are, depending on the scanning hardware used, usually within just a few millimeters. Generating a point cloud is a fast method for generating a digital representation of an object, opposed to taking manual measurements and modelling the object in a CAD-software, such as AutoCAD. This thesis investigates the possibilities with 3D laser scanning and makes a comparison between 2D layout models and point clouds.

The 2D layout documentation frequently used as a base for decision making at the case-company UniCarriers Manufacturing Sweden AB (UCMSWE) is known to have inaccuracies. This thesis aim is therefore to provide a future work routine involving the use of 3D laser scanning at UCMSWE. Further, the study aims to identify issues regarding the 2D layout documentation and propose methods to eliminate them and to increase the efficiency of the layout documentation change process.

Additionally, the study has included researching potential areas of application for point clouds, which could be used at a future stage for UCMSWE. Important to note is that the potential applications will not be studied in detail, instead the applications will be briefly investigated in terms of functionality and benefits for UCMSWE. The potential applications investigated in this thesis are; visualization, clash detection, reverse engineering and discrete event simulation.

The methods used in this thesis to reach a conclusion include; interviews, observations and experimental studies. However, the project was initiated with a literature study to obtain the prior knowledge of layout documentations, point clouds and work routines. The interviews and observations assisted in understanding the general method of current work routine. The experimental studies served the purpose of providing software skills, in order to mediate point cloud handling.

The results of this thesis proved irregular inaccuracies throughout the currently used 2D layout documentation, with deviations of up to 80 cm in the worst scenario and this inaccuracy was found in one tenth of the whole facility. Cost calculations shows that utilizing 3D laser scanning as a mean to re-draft the complete 2D layout documentation is more costly than using the manual measuring method, however it will be a faster method, the quality of the result will be superior and additional applications are available for the created point cloud. After carefully analyzing the results, the recommendations for UCMSWE are to hire a consultancy firm to conduct a complete factory scan, to pre-process all scans and to hand over a complete point cloud. UCMSWE should immediately re-draft the entire 2D layout documentation by tracing the point cloud that has been obtained. For continuous use, recommendations are to utilize point clouds for visualization purposes and for measurement purposes. The work routine, regarding layout documentation changes should be altered in a way that it increases data-security and revision control. The defined work routines should be documented and displayed to increase the likelihood of personnel following it.

Keywords: 3D Laser scanning, point cloud, layout documentation, software investigation, virtual engineering

Acknowledgment

The authors of this thesis work would like to take the opportunity to thank all involved parties during this semester. By supporting us with knowledge, inspiration and honesty, you made this study possible.

We would like to thank the examiner, Björn Johansson, for clear inputs and instructions on how to initiate the study. Erik Lindskog, the supervisor provided by Chalmers supported us in the best possible way, thank you. We would also like to thank the supervisor from the UniCarriers Manufacturing Sweden AB, Carl Därnemyr for setting us up at the company and providing all necessary material.

Additionally, we also thank all the helpful personnel at UniCarriers Manufacturing Sweden AB. Many weeks have been spent at the company and several engineers and assembly personnel have been providing us with crucial information and material for this study. All support is gratefully acknowledged.

Kind regards

David Rex & Simon Stoli

Terminology

Point cloud – A dataset filled with millions of points where each point contains position data and color data. For more information on point clouds, see section 2.2.1.

Registration – The name of the process where two or more point clouds are aligned properly and merged together to build up a larger point cloud. For more information on registration, see section 2.2.1.

RGB – A color model consisting of red, green and blue and all the various combinations to reproduce a wide array of colors and this is used in electronic systems such as computer displays and televisions.

Virtual engineering – The definition of this is using engineering tools e.g. optimization, simulation or analysis with the aid of computer software to support decision making for the yet to come changes to the real production system.

Intensity – The brightness of a scanned point, dependent on the reflectivity of the scanned surface and environmental factors.

AutoCAD – A widely used software application for 2D and 3D CAD supplied by Autodesk. First launched in 1982.

Inventor – A 3D CAD software application mainly used for various mechanical CAD design, incorporates several other functions for plant layout among others. Available since 1999.

ReCap – A point cloud handling applications by Autodesk used for processing raw 3D scan files into creating point clouds.

Scene – A point cloud handling application by FARO, included with their 3D laser scanner series Faro Focus 3D. Used for processing raw 3D scan files into creating point clouds.

ReCap Unified Scan (RCS) – An Autodesk proprietary file format, mainly used in their point cloud software ReCap but is also supported in other Autodesk software.

AutoCAD drawing (DWG) – An Autodesk proprietary file format used for storing 2D and 3D drawings produced in Autodesk AutoCAD. DWG-files were introduced with AutoCAD version 1.2 in 1983 and have since become an industry wide recognized file format for CAD-drawings.

FLS – FARO proprietary file format. Raw 3D scan produced by a FARO 3D laser scanner are stored in FLS-file format.

STEP – A file format for exchanging CAD-data between applications and software, the file format is defined under ISO 10303 by the International Organization for Standardization.

E57 – A general purpose, open standard, file format for storing point clouds and associated meta-data. The file standard is maintained by ASTM.

Table of contents

1 Introduction

In this chapter a brief background to the project is given and the hosting company UniCarriers Manufacturing Sweden AB (UCMSWE, formerly known as Atlet) is presented. UniCarriers Manufacturing Sweden AB are experiencing layout documentation problems currently and trusting this master thesis might provide some answers. The problem definition and declaration of the aim will be specified in this chapter. Delimitations will be listed at the end of the chapter.

1.1 Background

UniCarriers Manufacturing Sweden AB is a forklift manufacturer situated in Mölnlycke nearby Gothenburg. Atlet has a long history, founded in 1958 by Knut Jacobsson in his home in Gothenburg. Atlet expanded rapidly and half a century later they were internationally represented in 45 countries. In 2007, Atlet was bought by Nissan Forklift. In 2012, UniCarriers bought Nissan Forklift and therefore Atlet is since a part of the UniCarriers group today. The factory has a yearly production volume of about 7000 forklifts and UCMSWE wishes to further increase the production per square meter in this factory. UCMSWE is currently using 2D CAD to document their plant layout, including current and future changes within the factory. The method of 2D CAD is well established within industry and is the default method for documenting factory layouts in many organizations even though it is very time consuming to achieve a satisfying level of detail and accuracy. UCMSWE 2D CAD layout documentation has been in use for a long time and several engineers has made modifications to it. This has led to inaccuracies in the model to a degree where it cannot be fully utilized for functional use. UCMSWE is aware of these issues and are pursuing suitable methods for obtaining a correct 2D CAD layout documentation.

Technological advancement has allowed new methods and technologies to rise. The method of 3D laser scanning has allegedly several advantages to traditional 2D CAD as a tool for layout documentation and communication including lower time consumption, higher accuracy and richer visual representation. In order to reach higher requirements of production, UCMSWE wishes to investigate how 3D laser scanning as a technology would fit in their organization and how it could contribute to improve their layout documentation.

1.2 Scope

The scope of this thesis is to investigate the benefits and drawbacks of using 3D laser scanning technology for layout documentation at UCMSWE. Additionally, to propose methods and routines for UCMSWE to continue working with 3D laser scanning and associated data, this includes an investigation of software compatibility and software capability.

1.3 Aim

The aim is to guide UCMSWE to increasingly efficient work procedures regarding development, documentation and visualization of production layouts by proposing new methods involving 3D laser scanning.

1.4 Research questions

1. What applications of 3D scanning are available for an organization within the manufacturing industry?
2. How does 3D scanning compare to the traditional 2D CAD method, what are the benefits and drawbacks compared to the traditional methods?
3. How can 3D scanning be implemented and used in an efficient way at UCMSWE Manufacturing Sweden AB?

1.5 Delimitations

During the project only a limited area, approximately one tenth of the entire workshop, will be scanned and used for researching the method and possible uses of the scanned data. Applications of the scanned data is only to be tested and evaluated briefly for exemplifying purposes, not to perform any full-scale actions for documenting the current layout or suggesting improvements of the manufacturing processes or layouts of the plant.

1.6 Project workflow

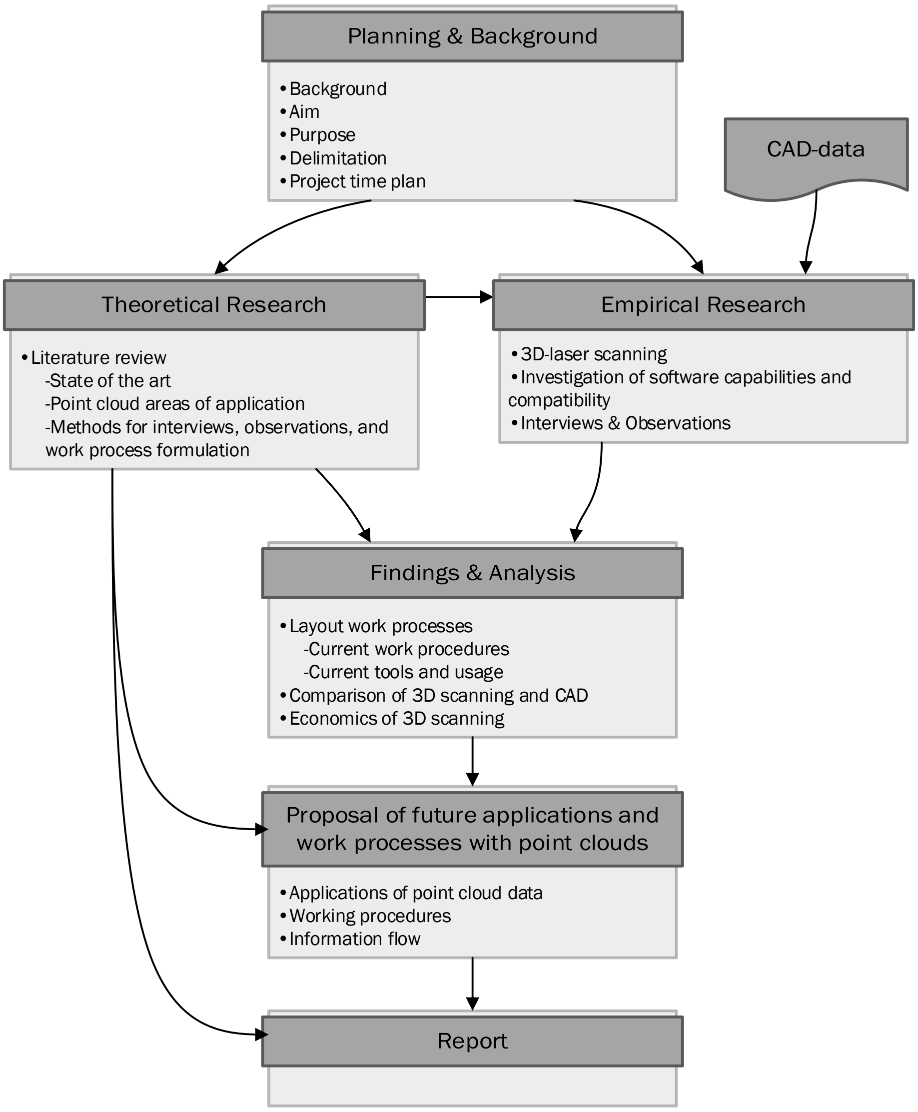


Figure 1: The project workflow with the six main activities presented.

The workflow depicted in figure 1 represents the general structure of the project. The initial processes of the project consisted mostly of defining the background, purpose, and aim of the project as well as outlining an overall time plan for the project. Using information from the company and the supervisor at Chalmers in combination with own assumptions and experiences, an introduction chapter and a feasible time plan for project execution was composed. Theoretical and empirical research has been conducted in parallel. The theoretical section consisted of a literature review which is further described in chapter 2. An empirical research was conducted where information was gathered through interviews, observations, and software experimentation.

With the results obtained in the research phases the possibilities and suitable applications of point cloud as a means for facility layout documentation and production development at UCMSWE was analyzed. The analysis sought to answer the questions *what are the differences and similarities of CAD and 3D scanning¸ what are the current problems with the layout documentation routines within UCMSWE*, and *how does 3D scanning compare to traditional CAD methods from an economic point of view*. The product of the analysis was furthermore condensed, in combination with the theoretical background and software investigation, into a proposal for UCMSWE on how 3D scanning and point clouds can be utilized. The results were followed up by a discussion around used methods and their accuracy.

1.7 Thesis outline

This thesis is structured with a brief background of the company being studied, the problem formulation and thesis aim in the first chapter. In the two following chapters, the underlying theory and methods used for this thesis are presented, including a work process on the software investigation. In chapter four all results of the software investigation will be given. After this chapter all empirical findings are presented. With the findings presented, chapter six analyzes the findings and research questions with presented theory to find a solution. Chapter seven is devoted to UCMSWE and their immediate, continuous and future use of 3D laser scanner technology. Chapter eight brings discussions of essential matters that have risen throughout the project. Lastly, in chapter nine the conclusions are presented and recommendations for future work at UCMSWE are given.

2 Theory

In this chapter the theoretical background in areas of interest will be presented. The theory will provide understanding in the used methodology to come and the reasoning behind the findings and discussion. Moreover, this chapter connects to scientific articles to contribute further in the learning process for the curious.

2.1 CAD and layout documentation

Computer aided design, sometimes called computer aided drafting, (CAD), has since it emerged commercially in the 1970's and 1980's become a very extensive tool. The technology has evolved from just being used for drafting simple wireframe geometries to considerable more advanced modeling (Stroud & Nagy, 2011). The use of CAD is widespread and diverse, often with several different uses within one organization (Lindskog, et al., 2012). In order to handle the various tasks there are many different CAD-software applications, some application also utilize different user interfaces to accommodate different tasks.

For the task of visualization and documentation of manufacturing systems CAD has proven to be an effective tool, thus also the most commonly used tool for such tasks (Lindskog, et al., 2013). Although, the process of documenting a manufacturing system is highly time consuming as an extensive amount of measurement data is necessary. This causes two serious issues with using CAD for facilities mapping. Firstly, the CAD-representation will be a simplified depiction of the real life system as the level of detail in the data gathering must be defined at a reasonable level (Lindskog, et al., 2013). Secondly, any measurement error may cause inaccuracies in the CAD-documentation, the great amount of measurements involved in such a process increases the likelihood of erroneous documentation. The accuracy and precision of measurements are dependent on both tooling and human factors. Using suitable and calibrated measurement hardware and being meticulous when carrying out measurements reduces the occurrence and magnitude or measurement errors.

The simplified representation of a manufacturing system presented as a 2D CAD wireframe may prove difficult to understand, especially for people not used to interpret such 2D drawings or unfamiliar with the depicted environment (Lindskog, et al., 2013).

2.2 3D Laser scanning

The importance and use of digital inspection and survey methods has increased within manufacturing industry. The use of digital tools has yielded savings by improving planning and measuring and has hence reduced mistakes and errors that are discovered in late stages which in turn eliminate expensive corrective actions (Bi & Wang, 2010).

3D laser scanning is a suitable method for gathering spatial data for many applications and settings, manufacturing environments included. Using laser light as the medium there are different methods for measuring distances and hence acquiring spatial data. The two most common techniques are time of flight (TOF) and phase shift (PS). The former of the two emits a laser pulse, the distance to the surface is then calculated by measuring the time it takes for the pulse to reflect back to the detector. Phase-shift technology uses the reflected light as well. The phase of the reflected light is compared to the emitted light. The difference between the emitted and reflected light, the phase shift, is then used for calculating the distance to the surface from which the emitted pulse reflected. Phase-shift technology grants drastically higher scanning speeds than TOF, however the technology is constrained by a maximum measuring distance. The scanner used in this study is shown in figure 2, a Faro Focus 3D, a phase-shift scanner with a maximum measurement distance of 120 meters (FARO Technologies Inc., 2013).

Figure 2: Faro Focus 3D, picture courtesy of Faro.

The laser pulse is emitted via a mirror rotating 360° in increments, higher scan resolution requires smaller increments and thus more scan points per revolution. The base of the scanner rotates 180° during the scan, in similar increments, allowing the scanner to register a spherical panorama of its surroundings with the exception of a spherical cone with an angle of 55° directly below the scanner (FARO Technologies Inc., 2013). The scanner has an accuracy that usually lies within ±2 mm when measuring distances within the interval 10 to 25 meters, integrated sensors record the inclination, height and compass bearing. Using an integrated digital camera the scanner is capable to gather color data that is fused with the spatial data using software (FARO Technologies Inc., 2013).

2.2.1 Point cloud processing

A point cloud is a representation in three dimensions of an object or environment. Usually 3D laser scanners are used to generate point clouds of real-life objects. The cloud consists of a large amount of points, each containing either Cartesian or spherical coordinates relative to the origin, i.e. the scanner position (Becerik-Gerber, et al., 2011).

To achieve a full three dimensional scan of a room or object several scans are required in order to avoid incomplete point clouds due to restricted line of sight from the scanner. To obtain a satisfactory point cloud based on several scans the scans has to be registered. Registration is the process where two or more point clouds are aligned into one single cloud (Lindskog, et al., 2013). Registration of scans are either performed successively where one scan at a time is aligned and added to the registered point cloud or globally where all the scans are aligned and registered simultaneously (Bi & Wang, 2010).

For a successful alignment of the scans common features shared by multiple scans are required. Traditionally, software has been using dedicated reference targets placed in the scanned environment, two common target types are spheres and checkerboards, shown in figure 3. The spheres have a highly reflective surface, a known diameter and precise roundness. These features enable proper target acquisition and accurate localization of the sphere center point which is then used as reference point. The spherical shape allows the target to be scanned from any direction (Becerik-Gerber, et al., 2011; Lindskog, et al., 2013). The checkerboard target consists of two black squares in checkerboard formation printed on cardboard. The registration software uses the center intersection point as a reference point. Being a flat piece of cardboard the checkerboard target is not properly acquired when placed in a steep angle in reference to the scanner (Becerik-Gerber, et al., 2011). When used, the targets placement in the scanning environment requires careful planning in order to achieve good results. Not all registration software require specific reference targets, software utilizing a target-free registration process instead relies on surfaces and corners captured in multiple scans.

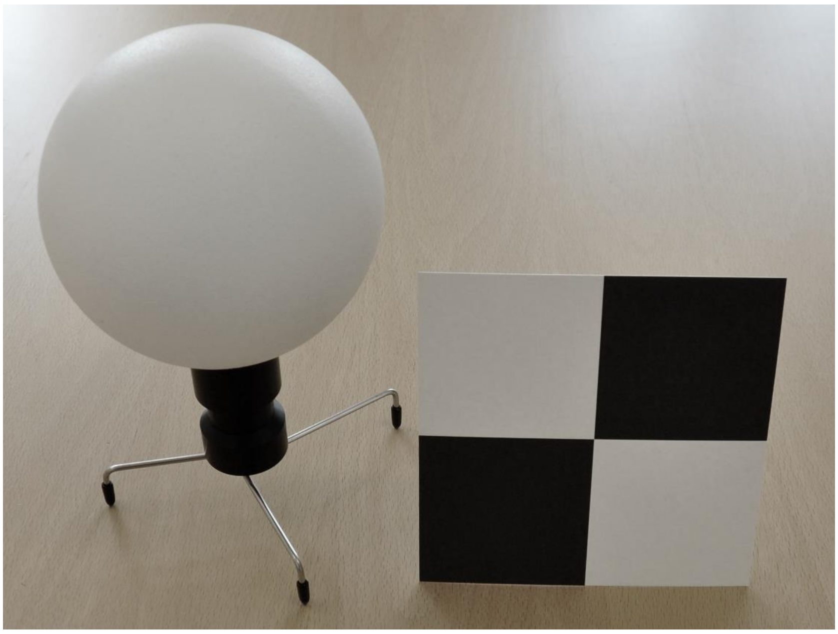


Figure 3: Sphere and checkerboard-style scan targets.

Invalid data points and artefacts are likely to be found in any point cloud generated by a 3D laser scanner. Errors will occur due to disturbances such as reflections or moving objects in the scanned area (Bi & Wang, 2010; Lindskog, et al., 2012). Further, incomplete spatial data from adjacent areas will also be included when windows or open doors are present in the scanned area. Erroneous points are eliminated by filtration on parameters such as intensity and distance, the filtration is later complemented by manual deletion of defective data points.

Point cloud handling can be extremely taxing for computer hardware, much dependent of the data set, that usually are vast which in turn requires large amounts of RAM, a powerful CPU and adequate GPU for a smooth handling process.

2.3 Potential point cloud applications

There are several practices for point cloud, already available in various software. The concept of utilizing point clouds for aiding in design purposes are quite new, thus the literature in this regard is relatively limited. The potential point cloud applications presented below has a various rate of previous research carried out in the topic and further search will likely yield additional applications. Moreover, these applications of point clouds will likely benefit UCMSWE if used correctly since wishes are to gain more details in the layout documentations.

2.3.1 Visualization

Point clouds are excellent for visualization purposes. The high level of detail in point cloud increases the likelihood of more people understanding the model (Lindskog, et al., 2013). Point clouds will help non-experts to gain the same mental model of reality, as point clouds are as-is representations of reality (Lindskog, et al., 2013). An increased level of detail can reveal flaws in the planning process earlier, which in turn saves time and money (Lindskog, et al., 2013). Point clouds can be combined with solid CAD models, such as 2D models or 3D models, called hybrid models (Lindskog, et al., 2013). Hybrid models can assist in layout planning, thus increasing the chance of successful layout proposals (Lindskog, et al., 2013). Visualization can be taken further, namely, creating a rendered movie of the point cloud and/or hybrid model where the camera view is moving through the environment for very powerful visuals. For an even greater immersive effect, stereoscopic 3D can be utilized. Presenting layout proposal before analyzers, investors and colleagues, a fly-through of the finalized virtual environment makes viewers feel closeness and recognition, and the chance of finding errors is increased (Lindskog, et al., 2013).

2.3.2 Clash detection

Collision detection is a feature that has been used in computer and especially computer games for a long time (Jiménez, et al., 2001). Since the last decade, when 3D laser scanning has become widely used, due to being affordable and the ability to get an as-is representation of reality, collision detection between point clouds has been investigated (Klein & Zachmann, 2004). Collision detection serves its purpose by calculating possible surface intersection of two or more geometries. There are generally four different approaches when calculating collision detection, utilizing different algorithms (Jiménez, et al., 2001). Clash detection, a software feature inside some 3D CAD programs such as Autodesk Navisworks, is utilizing automatic collision detection. Clash detection can detect collision between interior assets and walls, ceiling, pipes or other obstacle in the environment and give a report of detected clashes automatically (Genechten, 2008). Clash detection could also be utilized when doing offline programming to verify a clash-free operation inside the point cloud. Clash detection is a fast way of identifying collisions, however, precautions must be taken when utilizing this feature since a full scan coverage is nearly impossible to achieve (Genechten, 2008).

2.3.3 Reverse engineering

Reverse engineering, or Computer-aided Reverse Engineering (CARE) is, according to Raja and Fernandes (2008), the ability of generating a CAD model from a real-world object. The CARE process involves generating a point cloud of a real-world object, thus gaining near exact measurements. Next process in CARE is to detect features, where the CARE system identifies surfaces and crinkles from the point cloud. Lastly, the CARE system generates the complete CAD model description of the real-world object. In order to generate the CAD model, the CARE system utilizes the identified features in the earlier step and the entire point cloud (Raja & Fernandes, 2008). The benefits of being able to generate a complete CAD model of an existing object are many. Raja and Fernandes (2008) gives some examples; allowing for quick inspection and validation in real time, allowing for better collaboration between companies and aiding in recovering of lost or missing documentations of processed parts.

With help of either stand-alone software or plugins for existing software such as AutoCAD, users can generate meshes or detect features in the point cloud utilizing CARE. The mesh generating method analyzes the whole point cloud and creates a 3D mesh or NURBS-file that can be used in other applications. The feature detect method generates a solid 3D geometry representation from the specified point cloud object. These features are limited as of today to certain shapes, e.g. pipes and beams and capabilities depend on software and shape libraries. There are many different providers of reverse engineering software, e.g. Kubit's PointSense or Bentley's Pointools (Sandgren, et al., 2013).

2.3.4 Discrete Event Simulation

Simulation implies imitation of the processes and behavior of a system, either existing or conceptual (Banks, 1998). This definition applies to a wide range of purposes, one of them being simulation of production systems. To study a systems behavior over time a simulation model is developed. The model is designed based on observations and assumptions on the system, its processes and relations (Banks, 2010). The level of detail in the model should be decided in respect to the trade-off between quality, and time and cost: High level of detail implies long development time and hence high costs, however, without a sufficient level of detail it is not possible to achieve satisfactory results and answer all the questions intended (Banks, 1998).

To ensure that the simulation model is functioning properly there are two main quality assuring procedures during the development process; verification and validation. Verification serves to make sure that the model behaves as intended without failures and flaws (Banks, 2010; Banks, 1998). Validation is the process of comparing the model with the real-life system it is supposed to simulate and assuring that the model is indeed a well-performing replication of the system (Banks, 2010; Banks, 1998). Note that 100% accuracy of the system is not applicable as the model is merely a simplified representation of the real-life system, the level of accuracy is determined with respect to the quality/cost trade-off mentioned earlier.

Using 3D laser scanning and point clouds in junction with discrete event simulation may prove useful for several purposes (Lindskog, et al., 2012). Most prominent of these purposes are improved communication led on by the visualization support brought by point clouds and support in the verification and validation of the simulation model (Lindskog, et al., 2012).

2.4 Standardized work and work routines

A standardized way of working is an analysis tool, at least according to Toyota (Marksberry, et al., 2011). The concept of standardized work originates from scientific management during early 20th century, who P.W. Taylor introduced. It became widely known as *Taylorism* and the concept was a scientific way of working as effective as possible, in a standardized fashion (Spender & Kijne, 1996). Taylorism was not appreciated by everyone and some scientists believed that humans working under these conditions, almost as robots, may be affected mentally in a negative way and their productivity could suffer. The human relations movement started by E. Mayo, in a purpose to study human behavioral factors during the 1930s to find a balance in human physical abilities and psychical limitations (Bruce & Nyland, 2011). Standardized work is still thought of being an effective way of working even if the rules have loosened a bit the past hundred years. Now the concept is normally referred to as lean management and the goal is to increase productivity by reducing waste (non-value adding activities) wherever possible and working with continuous improvements, "kaizen" in Japanese. The concept is about learning “tacit” knowledge, the deeper type of knowledge that cannot be obtainable by reading (Liker & Meier, 2005).

Work routines are a building block in the lean production concept and a requirement for being able to continually improve as stated above. Work routines are a set of loose instructions to complete a given task (Liker & Meier, 2005). This thesis work endeavor to make a complete set of work routines for point cloud management at UCMSWE.

3 Method

In this chapter, the methods used for empirical research are presented and motivated. The investigation results for software compatibility and capability are gathered from Faro Scene, the software included with the 3D laser scanner used during this study and Autodesk's Factory Design Suite *2014*, which is the currently used CAD-suite used at UCMSWE. It is of high importance to note that the software experimental investigations are supposed to cover 3D laser scanning related abilities within and compatibility between, rather than comparing software abilities in any way. Moreover, interviews have been conducted and observations have been made, in order to acquire qualitative empirical data on the tasks and routines regarding layout documentation.

3.1 3D laser scanning of the workshop

Together with the company it was determined what section of the factory that would be most beneficial for performing scans. The assembly area for the U-series forklifts was chosen since a major overhaul for this area was planned to start approximately seven months from the start of the project. It was reckoned by both the production engineers and facility service department at the company that 3D laser scanning technology and point clouds could be of great significance in planning for said overhaul, it was agreed that this area held potential for many various uses of point clouds.

The selected area was scanned during an evening when the majority of the personnel in the area had finished their shift.

The scanning procedure was divided into three phases as shown in figure 4:

1. Walk through. Everybody involved in the scanning walked through the decided area to identify and discuss the features of the area important to capture with the scans. In this case permanent structures such as walls and beams were prioritized in junction with functional features mounted at ceiling level such as overhead cranes and ventilation ducts.
2. Planning of scanner locations and target locations. Next a more extensive planning was carried out: When walking through the decided area the locations of scan points and targets were planned in such way that sufficient data would be captured of the structures and features deemed as important during the initial planning. Decided scan locations were marked on a simplified map of the room as well as with a mark on the floor for quick identification during next stage. The scan target location was carefully planned in such way that each target would be visible from several scan locations, this is required for registration with scan targets in later processing.
3. Scanning. Using the map and marks from the previous planning, the scanner and targets were positioned. During the scans every person moved out of sight of the scanner to avoid erroneous scan points caused by moving persons.

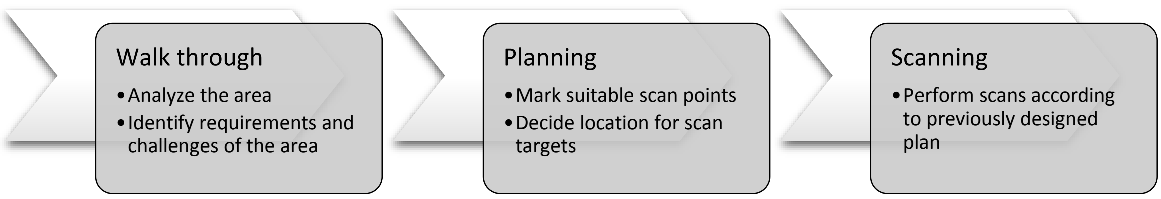


Figure 4: The scanning procedure was performed in three phases.

3.2 Investigation of software compatibility

For the sake of facilitating a smooth workflow during the layout documentation process it is of importance that the software used are compatible with each other to a satisfactory extent. The compatibility is researched by investigating matching file-formats and data types; file formats accepted for import are compared to the file formats outputted by other software to ensure proper transfer of data between software.

The investigation of compatibility between software was set to cover AutoCAD, Inventor, and ReCap; parts of the Autodesk software suite already available at UCMSWE. In addition to this, it was also decided to examine the software shipped with the 3D laser scanner equipment, Faro Scene, to find compatibility with other Autodesk applications. The compatibility concerns tasks and file formats that were assumed would be common in future work with point clouds at UCMSWE, three specific tasks with related data types were investigated. The investigation included reviewing software documentation and whenever applicable performing experimental testing using the various types of files available.

First out, the investigation covered the set of file formats supported by Faro Scene and Autodesk ReCap for importing 3D laser scan raw data and exporting registered point clouds respectively. The testing was carried out using the 3D laser scanning raw data from the scan carried out within this study, presented in Faro's FLS-file format.

Next, the support for combining point cloud with 2D CAD files was investigated. The experimentation was carried out using the point cloud from the scanning at UCMSWE using both a ReCap project file (RCP) and a ReCap unified scan (RCS). The point cloud was combined with the corresponding section of the current layout documentation presented in a standard AutoCAD DWG-file that was supplied by the company.

Further, the task of combining a point cloud with both 2D CAD and 3D CAD data simultaneously was looked into. A 3D CAD solid model of the yet to be implemented assembly line was used during this stage of the research. The 3D CAD model was supplied as a STEP-file from the consultancy firm designing the new assembly line.

3.3 Investigation of software capability

There is a wide range of software available for tasks related to the project such as handling and modification of point cloud, 2D CAD files, and 3D CAD files. Thus, it was decided to investigate a portion of the available software with the intention to determine the capability of the different software and the compatibility between them.

Software capability was tested over four different software products, as shown in table 1, two of which are dedicated point cloud handling software; Faro Scene and Autodesk ReCap, and two of which are multi-purpose CAD-software: Autodesk AutoCAD and Autodesk Inventor. The approach to the investigation consisted of studying the software documentation and empirical research through trial and error.

Table 1: Software products investigated

Type of software	Software name	Version
Point cloud processing	Faro Scene	5.2
Point cloud processing	Autodesk ReCap	2014
Multi-purpose CAD	Autodesk AutoCAD	2014
Multi-purpose CAD	Autodesk Inventor	2014

From observations of the current layout documentation processes at UCMSWE and assumptions of future tasks, a set of tasks and operations to be tested in the various software were defined, listed in table 2 below:

Table 2: Tasks investigated to determine software capabilities

Type of data	Task	Investigated software
Point cloud	Registration of point clouds	Scene, ReCap
Point cloud	Filtration of point cloud	Scene, ReCap
Point cloud	Modification of point cloud	Scene, ReCap
2D/3D CAD and point cloud	Combining 2D/3D CAD and point cloud	AutoCAD, Inventor
2D/3D CAD and point cloud	Measurements	AutoCAD, Inventor, ReCap

The processes of registration, filtration, and modification of point clouds are described in section 2.2.1, these can be regarded as tasks of pre-processing point clouds. The task of combining various kinds of data, which can be seen as operations of continuous use, implies juxtaposing and interaction of different data-types.

3.3.1 Pre-processing of point clouds

Prior any usage of a point cloud, the raw scan files must be processed. The pre-processing is generally performed with dedicated point cloud software and involves registration, filtration and modification of the point cloud.

Registration of point clouds

Registration of point clouds is a main feature of the dedicated point cloud software investigated. Hence, an investigation on the process of point cloud registration within the two varieties of dedicated point cloud software was carried out. The investigation of point cloud registration consisted of registering the raw scans of the forklift assembly section of the factory previously scanned.

Point cloud filtration and modification

As mentioned in section 2.2.1 on point clouds, there is a high prevalence of artefacts and other faulty points in any point cloud due to reflections or movements in the scanned environment or insufficient seclusion to adjacent areas not pertinent for the survey. The unwanted points are eliminated through filtering and modification of the point cloud.

For the investigation, data from the scans at conducted in this study was used. The various filtration option in each of the software was examined in terms of purpose and functionality. The capability of modifying was tested in the setting of removing unwanted points from adjacent areas and non-pertinent objects in the scanned environment. The various tools for selection, limiting, and grouping of points was tested in junction with the software capability of removing, hiding, moving, and adding points within the point cloud.

3.3.2 Continuous use of point clouds

There are many potential uses for point clouds in a production development process. Two of such operations that have been chosen for further investigation are combining point clouds with traditional CAD-geometries, and measurements within the point cloud.

Combining point clouds with CAD

Combining point clouds with CAD-data may prove to be a powerful tool for validation and visualization of existing or planned production system features. These functions were investigated in the two entities of multi-purpose CAD-software. The CAD-data used for testing these capabilities was a 2D CAD-drawing of the planned overhaul of the scanned area and a 3D CAD of the new assembly line that is being installed as a part of said overhaul.

Measurements

The tasks of performing measurements were divided into three sub-tasks as presented in table 3 below:

Table 3: Measurement capabilities sub-tasks and descriptions

Type of measurement	Description
Distance	Distance between two points or total distance of a route consisting of several stretches
Angle	The angle between two lines or planes, multiple methods may be available within each software
Area	The area of a section defined by the user.

It is expected for some of the software to have more than one method to perform some of the measurements, in such case investigation of each available tools will be done. If the software is capable of combining point clouds with 2D or 3D CAD the investigation will cover measurements not only within point clouds but also between point clouds and CAD-geometries.

To ensure a fair comparison of the software at hands the investigation will cover similar tasks in each software when possible.

There are several potential uses for measurements in point clouds, one may be validation of the 2D CAD layout of the workshop. Therefore, AutoCAD, Inventor and ReCap have been investigated to identify the tools available for this purpose. Where applicable, similar measurements has been carried out in all of the applications to facilitate a fair comparison.

3.4 Interviews and observations

Interviews and observation are two known methods for gathering qualitative data. Interviews can be performed in different ways, namely; unstructured, semi-structured and structured (Rowley, 2012). The different levels of structure define the degree of freedom when interviewing. The purpose of an interview is to get qualitative data such as opinions, personal interest and deeper knowledge to name a few (Rowley, 2012). The structured interview method is similar to using a questionnaire except that the interviewer is present and that increases the response rate compared to using a questionnaire (Rowley, 2012). The semi-structured interview is more adaptable and suits the more novice researcher. It consists of well-defined, open questions but the order of questions is flexible (Rowley, 2012). The unstructured interview method is based on defined topics of relevance and the idea that the interviewee can talk around these topics (Rowley, 2012). This method is generally tougher to conduct and interviewer skill is required in order to stay on the relevant topics. Interviewing is a complement to observations in that way it can strengthen criterion validity, meaning the accuracy of finding since two collecting technique can point to the same data.

Observations are a great alternative to interviews for collecting data in a working environment. The most important thing to achieve when conducting observations is to capture and understand people and their interest within their natural environment (Baker, 2006). Literature is speaking of different roles of the researcher, emphasizing the urgency to understand that the observer can fulfill an observation either as a nonparticipant, fully participant or something intermediate (Baker, 2006). In order for this research method to be ethically correct, reliable and valid, all precautions that Baker (2006) brings up in her scientific article on the subject will be followed.

Validity and reliability are important factors to consider. By using more than one observer, the chance of researcher bias is reduced (Johnson, 1997) and actively self-reflect to make sure the observed data is unbiased. Qualitative data gathering can be hard to generalize and therefore lack of reliability can be present. In order to avoid this pitfall, the observations should be of systematical nature and be done in varying conditions to get a wide range of data (Johnson, 1997).

In order to get a good understanding of the current workflow for layout planning and documentation at UCMSWE, it was decided to conduct interviews and make observations for collecting qualitative data from the production engineers working with these tasks. The semi-structured interviews were based on a questionnaire incorporating questions on both the current workflow and preferred future state to aid in the design of new work routines, the questionnaire can be found in appendix A.

Observations were utilized to get an unbiased view on the current work method, in the current work environment. The purpose of the observations is to complement the interview in a way that it is faster to collect and imitate work routine in present state. It also serves a purpose in aiding the design of future changes.

The first interview was carried out with two interviewees, both production engineers with experience in the layout documentation process at UCMSWE. One was responsible for updating the master layout models after changes has been done to the physical work shop. This task was earlier handled by the other interviewee from 2008 and up until last year (2013). The interviewees were also the only production engineers that daily works with AutoCAD and Inventor and were therefore crucial assets for the research regarding work routines and expertise level in the Autodesk program suite.

The second interview was performed with an engineer from the product design department as the interviewee. The personnel of the design department has established routines for making changes to a product in CAD software since they have more resources in common and utilizes a product data management system for tracking changes. This interview could prove useful for understanding work routines on design and an aid in planning future work routines in the department of layout planning.

3.5 Method motivation and validation

The reasoning behind the used methods was to be able to fulfill the aim in a solid way, thus do need a clarification and explanation. The interview and observation study was needed for gaining insight on the tacit knowledge of UCMSWE working routines. Utilizing semi-structured interviews were deemed most appropriate in order to get the information that was needed to fully understand the current work routine around layout documentation, using any other interview method crucial information could have been uncovered. The observations served to strengthen the validity of the gathered interview data by letting the interviewees demonstrate the work routine on a regular work day. There are alternative methods for obtaining the same results regarding qualitative data gathering, discussed in section 8.2.

The urge of a software investigation was determined early in the project. The motivation to study the Autodesk Factory Design Suite 2014 was mainly because of two reasons. Firstly, UCMSWE had this suite readily available, meaning no additional cost of purchasing additional software is required. Secondly, UCMSWE already have the competence in this suite and are working daily with Autodesk software environment, meaning that the learning curve of additional features within this environment will be less steep than learning a new software environment from scratch. The motivation to study Faro Scene to a degree judged sufficient, since it is currently not available at UCMSWE, was that this thesis work is based on a point cloud made by a Faro 3D laser scanner thus it was deemed appropriate to investigate the interaction of Scene and other Autodesk applications. The features decided to be investigated within the Autodesk Factory Design Suite 2014 was deemed to be essential for point cloud management in combination with 2D CAD- and 3D CAD objects. The features investigated in Faro Scene were limited to the pre-processing stage, even though there exists much more features within. This was a decision made early since the scope was to enhance UCMSWE already available work routines and thus it was perceived that it would be easier to implement a solution based on existing software. Regarding validity of the software investigation, the investigation was an experimental research with a trial and error method. Moreover, limited prior knowledge in the software environment was a fact. Therefore, the software investigation methods can have flaws and may not entirely reflect reality. However, it should be noted that if unsatisfactory results were obtained when using Autodesk Factory Design Suite 2014 and selected features, other software and features would have been investigated. There are other methods for determine software compatibility and capabilities, discussed in section 8.2.

4 Software investigation results

The results of the investigations on software compatibility and capability are presented below. The results are structured after the tasks and operations investigated.

4.1 Software compatibility

Software compatibility was tested over three main tasks including different software and data types. The tasks and the outcome of the research are presented below.

4.1.1 Point cloud import and export

Both software investigated for this task (Scene and ReCap) supports several file formats for import. Scene supports proprietary file formats from both Faro and Leica (another vendor of laser scanning equipment) as well as the open file formats XYZ and e57. On top of the formats mentioned for Scene, ReCap supports additional formats, both scanner supplier proprietary formats and open formats.

As for export of point clouds both of the software, once again, supports several formats. Both software supports the open file format e57 and the Leica proprietary PTS-format. Further ReCap supports exporting into Autodesk's proprietary RCS-point cloud scan format. Scene supports several additional open file formats, such as VRML, XYZ, and IGES.

The investigation of support for both import and export file formats has been mainly carried out by studying the documentation and specifications of the software applications, hence not all of the file formats has been actually tested within this study.

4.1.2 Combining point cloud and CAD

AutoCAD and Inventor, both being CAD-software included in the same software suite, has slightly different application. AutoCAD is mainly used for creating wireframe-style drawings, natively handled as AutoCAD DWG-files. Inventor is primarily intended for solid-modelling, hence drawings and objects are created and handled differently compared to AutoCAD and saved in other file formats. Both AutoCAD and Inventor are able to import and display files created in the other software respectively. Although it should be noted that the Factory Design interface of Inventor should be used for operation of this kind to ensure compatibility.

The process of importing point clouds and combining them with CAD-data is similar in both software in terms of functionality and file format support. Point clouds attached must be of an Autodesk proprietary file format; RCP, RCS, PCG or ISD.

4.2 Software capability finding

The capabilities of the four studied software applications were investigated through empirical testing and studying the software documentation. The tasks investigated was mainly concerning point cloud handling although some of the operations involved CAD-data as well, the results of the investigation is presented below for each task respectively.

4.2.1 Point cloud registration

Even though the process within the two point cloud software programs (ReCap and Scene) has the same purpose with the same input and similar output, there are some differences on how the software operates.

In Autodesk ReCap the full registration process contains of three main processes: Import, registration, and indexation. The middle step involves the user in five procedures: Selecting base scan, identifying common reference features, rough estimation, registration, and validation of registration result, as shown in figure 5.

The user is guided throughout the process by the user interface, the software is built on the idea of allowing the user to continue working while the software is processing data in the background. Hence, the user is able to begin the actual registration as soon as the first scan file is loaded which effectively reduces the passive waiting time for the user.

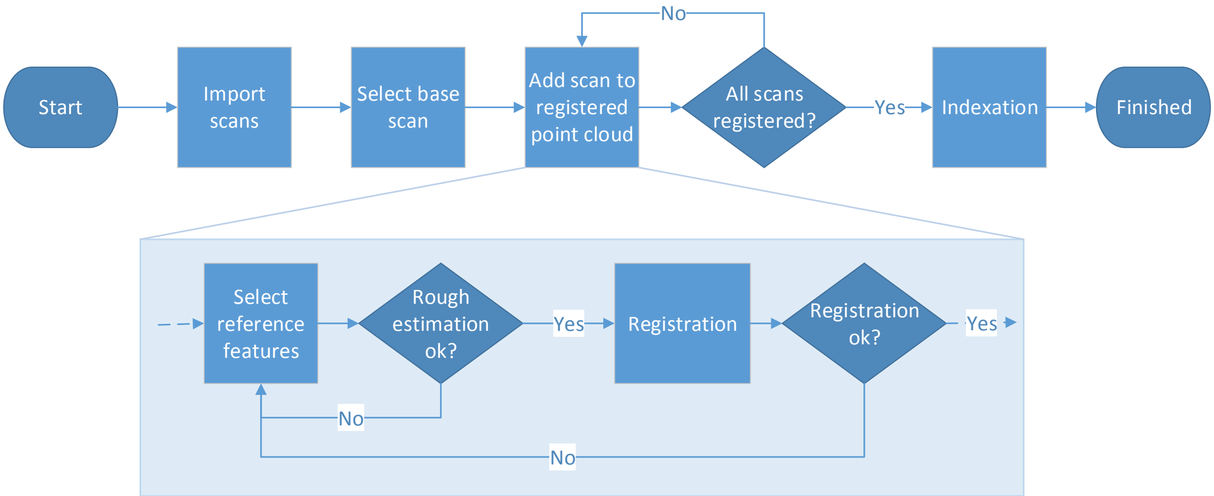


Figure 5: The general workflow of the registration process in Autodesk ReCap.

Autodesk ReCap utilizes a successive, target-free, registration process which means that the user is continuously adding scans to be aligned, one by one. The target-free method eliminates the need for placing special-purpose scan targets in the environment prior scanning, instead the user manually selects features common for two scans, either in the form of limited flat surfaces or distinct corners depending on the viewing mode used.

The quality of the registration is assured in two steps; first the user is presented with a rough estimate of the alignment prior the registrations in which the alignment of the scans is shown as well as an estimated grade of the registration quality. If the estimate shows a satisfactory result the user proceeds by launching the actual registration, adding the scan to the aligned point cloud. After the registration a detailed report of the quality is shown, parts of it is depicted in figure 6.

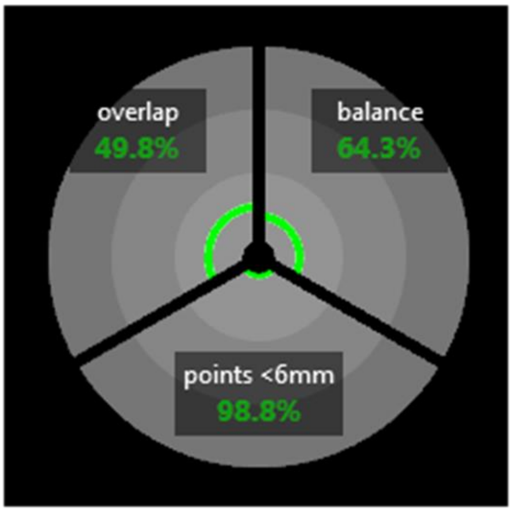


Figure 6: Registration quality visualization in Autodesk ReCap.

The quality is assessed in three criteria: overlap, balance, and points within 6 millimeter. The overlap criteria signifies by which percentage the newly added scan is overlapped by the base scan and other already registered scans, more overlap implicates better registration. The balance indicates the distribution of the overlapping surfaces over the x, y, and z-plane, high balance indicates a sufficient amount of surfaces in all three planes, which yields better registration result. Points within 6 millimeters indicates the portion of points that lies within a range of 6 millimeters on overlapping surfaces, for a good registration result this criteria should be as close to 100% as possible. Given the three criteria the user is presented with a summary grade of the registration quality, color graded in a traffic light style.

When all the imported scans have been registered successfully the indexation process begins. During the indexation ReCap processes the scan files and converts them into Autodesk's proprietary point cloud file format (*.RCS).

Faro Scene employs an automated global registration process that relies on special-purpose scan targets placed in the scanned environment. The registration process in Faro Scene, depicted in figure 7, consists of two main phases; target acquisition and automatic registration. The identification of scan referencing targets such as spheres or checkerboards is an automatic process, however, it is advised that the user examines the result of the process to make sure there are not any false target identifications or targets missed by the process. Such errors must be adjusted by the user prior the registration process is initiated. Since the registration process is automated it does not require any additional user input during the registration, instead it relies on the identified scan targets for the alignment of the scans. Being a global registration, all the scans are aligned simultaneously. Depending on the hardware used in junction with the size of the files being processed the registration process may become time consuming. As the registration is completed the user is presented with a report including a statistic evaluation of the registration result as a means for assessing the registration quality. If the quality of the registration would prove to be sub-par the user should return to the manual identification of scan targets to achieve a better alignment.

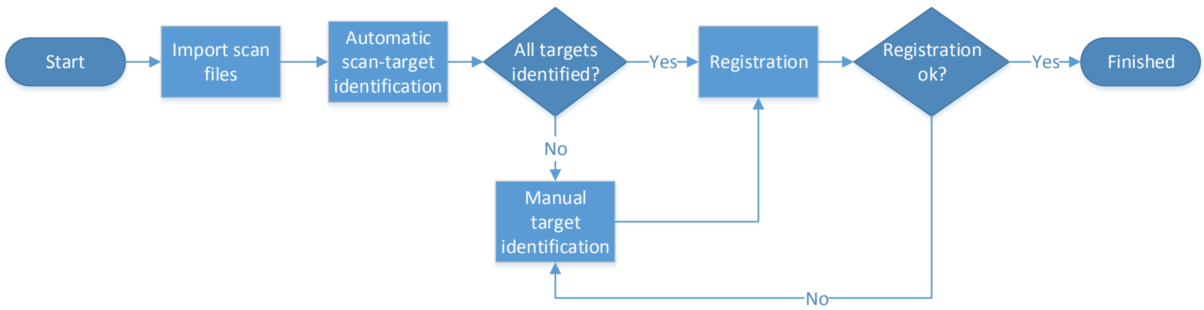


Figure 7: The general workflow of the registration process in Faro Scene.

4.2.2 Point cloud filtration and modification

Filtration
Both Autodesk ReCap and Faro Scene employ an array of filters to be used on point clouds.

ReCap has three filters available, first a noise cancelation filter and secondly two filters that sifts on fundamental properties of the points; distance and intensity. For both of these filters the minimum and maximum thresholds are displayed and set by sliders. When filtering on distance in ReCap the software processes the points distance from the scanner and eliminates those points that does not lie within the defined filter interval. The intensity filter functions in a similar fashion; an interval of accepted values is determined by the user and those points in the point cloud that has a higher or lower intensity is eliminated.

The noise cancelation filter does not allow for user input of parameters, instead there are three levels of filter aggressiveness; *none*, *standard*, and *aggressive*. As the name implies, the level called *none* does not apply any changes to the point cloud. The *standard* setting preserves most points and removes only those isolated points that do not seem to be part of any actual object or surface. The third level, *aggressive*, preserves only those points that clearly belong to an object or surface.

The filters in ReCap are applied during the registration process, prior the indexation of the scans.

Faro Scene has an arsenal of four filters with various functions: *stray*, *distance*, *dark scan points*, and *smoothing*. The *stray* filter could be likened to the noise cancelation filter of ReCap, the purpose of the filter is mainly to eliminate faulty points such as from the scanner laser beam only partially hitting an edge. The *distance* filter works in similar fashion as the corresponding filter with the same name in ReCap, points that does not lie within the defined distance interval from the scanner are removed. Also the *dark scan points*-filter is similar to its ReCap counterpart called intensity filter. Although in Scene, the filter only eliminates those points that falls beneath the minimum threshold. The last filter, *smoothing*, has no counterpart in ReCap. This filter suitable for remedying noise on surfaces by replacing measured points with an average position based on surrounding points. The user sets the size of the sample area and the threshold which within points will be altered. While the smoothing filter may be useful for surfaces Faro advice directly against using it on edges or fine detailed geometries as the geometries may become corrupted by the filter.

Modification
As for modification of the point cloud both instances of investigated software has at least some capability to make changes to an existing point cloud via various tools. Examples of using the point selection tools of each of the software applications are shown in figure 8.

Figure 8: Examples of point selection in ReCap (left) and Scene (right), selected points are white and yellow respectively.

In ReCap the user is able to limit, select, hide, and delete sections of the point cloud using the arsenal of tool supplied by Autodesk. If the user wishes to work with only a partial sector of the point cloud the limit box will come handy. The limit box is, just as the name implies, a three dimensional box which dimensions, rotation, and skew can be altered by the user to contain only the section of interest at the moment. The points within the limit box are shown as usual while the points being outside of it are temporarily hidden.

For selecting points in the cloud there are three selection tools: *window*¸ *fence*, and *plane*. *Window* is used for creating a rectangular selection, *fence* functions similarly although the shape of the selection is a polygon defined by the user. Both these selection tools select all the points behind the selection surface in an extrusion-like manner. The last selection tool, *plane* is rather different. The user defines a plane in which all points are selected by identifying at least three points in the plane. A slider allows the user to define the depth of the plane selection, ranging from 1 to 100 millimeters

Selected points can be grouped together using *scan regions*, this function lets the user define specific sections of the point cloud. Using the scan regions functions a section can be hidden from and/or locked from further selection and modification. In a fashion similar to the hiding of scan regions it is possible to hide or isolate individual scans within the point cloud.

In addition to using scan regions for hiding points there are two other functions for hiding or eliminating points within the point cloud: *clipping* and *deleting*. *Clipping* can be used for lossless erasure of points, clipped points appears to be deleted but can be reverted by the function *unclip all*. *Delete*, on the other hand does exactly what its name implies, points that are removed with the *delete*-command cannot be reverted after the file has been saved.

Faro Scene has multiple tools for selection, limitation, and modification of point clouds. The clipping box resembles the limiting box of ReCap; it is a box which dimensions and rotation is set by the user, the box is used to hide points either inside or outside the box. In Scene, multiple boxes can be used simultaneously and boxes can be enabled and disabled individually or collectively. Besides using clipping boxes to toggle visibility for certain points it is possible to hide or isolate single scans within the point cloud.

Further there are two main categories of selection tools; 2D selection tools and 3D selection tools. The 2D tools are used in the panoramic planar view where the point cloud is viewed from the viewpoint of the scanner in one of the included scans. The 3D tools can be used in the free roaming 3D view. In planar view the 2D selection can be made in many shapes; rectangular, circular, elliptical, polygonal, and linear selections are available. For 3D selection there are two tools available; polygon selection and brush selection. The polygon selection functions similarly to the fence selection of ReCap, the brush function allows the user to “paint” the points that are to be included in the selection in a fashion similar to a brush in a regular 2D painting software.

Using the selection tools the user is able to perform various actions to the selected points such as applying filters locally, export the selected points, or delete the selected points.

The multi-purpose CAD-software holds some capability to modify point clouds as well. In AutoCAD the user may define a limiting box to the point cloud, this box is used to temporarily hide points that are either within or outside the box similarly to the behavior of the clipping box in Faro Scene. By inserting a plane at desired position in the point cloud it is possible for the user to extract a cross section image of the point cloud in the direction and position of the plane.

4.2.3 Combining point cloud with 2D or 3D CAD findings

Adding a point cloud overlay to an existing CAD-model is well supported in the investigated Autodesk software (i.e. AutoCAD and Inventor): While the CAD-model is loaded into the software the user uses the *Attach*-function to insert a point cloud. The user is able to adjust settings such as the position, rotation, and scaling upon insertion of the point cloud. These parameters could either be numerically entered to the dialog or defined on-screen, in which case the point cloud is simply placed on top of the CAD-model and fixated to the point where the user finds suitable. The latter option is appropriate when the user is not aware of the offset between the coordinate systems of the CAD-model and the point cloud if the coordinate systems of the two are not previously aligned.

After the point cloud has been attached to the CAD-model it might be necessary to adjust the position to improve the alignment. Using the measurement tool the present offset to the CAD-model can be identified and the point cloud placement can be adjusted accordingly to eliminate offset. It was the matter of aligning point cloud and 2D layout satisfactory that requires most attention. The coordinate system of the point cloud and the 2D layout in this case did was not aligned and the solution used was to manually measure some corresponding points in the two models and document the results, which could be used in the aligning process to obtain a correct orientation. An exempt from the 2D CAD-layout with the point cloud juxtaposed beneath is shown in figure 9.

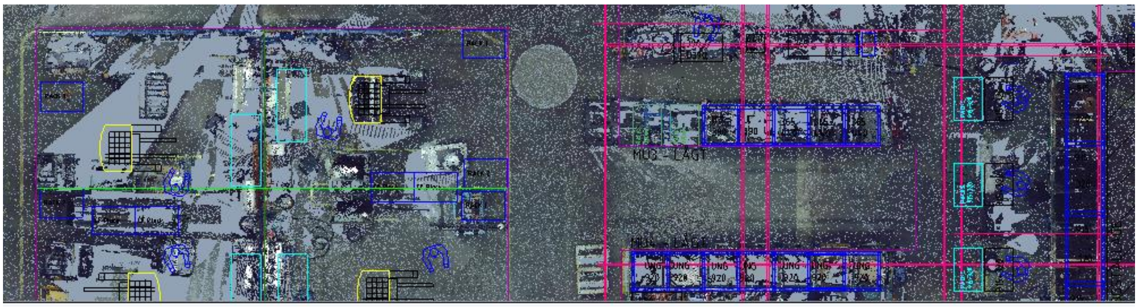


Figure 9: Example of 2D-CAD layout with juxtaposed point cloud.

4.2.4 Measurement findings

The measurement findings are given for ReCap and Scene respectively. One common feature for all applications is the ability to view in either perspective or orthographic mode. It was found that when making measurements in a point cloud environment, orthographical view yielded generally better maneuverability of the point cloud which in turn simplified the measuring.

It was found that ReCap has three measurement tools for different purposes. Distance between two points, angle between two faces and angle by selecting three points. The tools are intuitive and the user interface informs the procedure. Measuring between two points, as shown in figure 10, gives the total distance between as a vector with no additional information. Measuring an angle with help of faces gives the user an ellipsoid that attaches to surfaces, with two surfaces picked the resulting angle between these is given. The last option, defining an angle with three points is simply done by picking two point on separate lines and an intersection point for these, the angle at the intersection of the two lines is measured.

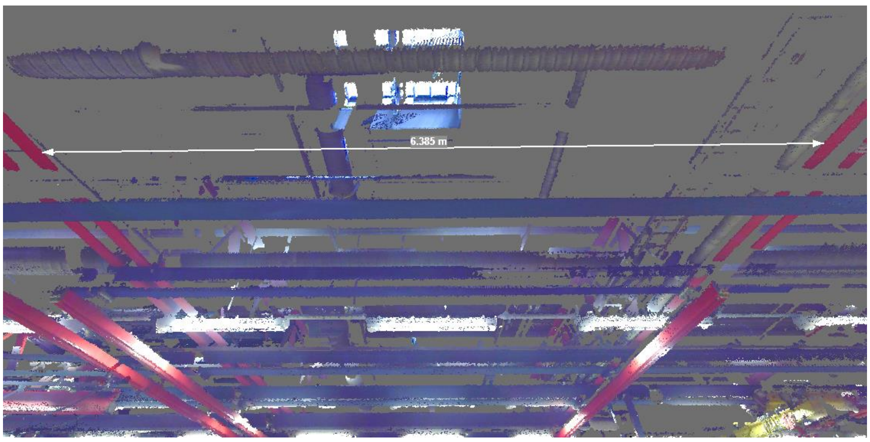


Figure 10: Measuring the distance between two ceiling level beams using ReCap.

In AutoCAD, similar tools as in ReCap were found with the addition of a function for measuring areas. When measuring distance between two points, more detailed information is shown to the user. Each point is presented in Cartesian coordinates and the differentiate of the two points is shown as dx, dy and dz with the addition of an resulting angle between the selected points relative to the Cartesian coordinate system. The area tool lets the user create a polygonal closed region with as many points as needed and display the resulting area.

Inventor incorporates measurement tools as well. The distance tool can either show total distance of a picked, defined line in a sketch or by selecting two different points where the resulting distance as well as dx, dy and dz between the two points. The angle tool returns the angle between two joined lines in a sketch. The loop tool calculates the total distance in a closed loop in a sketch and the area tool computes total area inside a closed loop.

5 Empirical findings

In this chapter the findings and gathered data are presented. From interviews and observations, a presentation of the perceived current workflow for layouts and documentations at UCMSWE will be given.

5.1 Layout documentation workflow

The factory at UCMSWE is divided into areas with groups of operations residing in specific zones. The production engineers has defined areas of responsibility, each group of operations is covered by one or two production engineers. Among the responsibilities of the engineers is the task to develop their area of the factory and to keep the layout documentation of their respective zones updated with implemented changes.

UCMSWE keep their manufacturing layout documentation stored on a shared network hard drive. One of the production engineers has been appointed with the main responsibility over the manufacturing layout documentation and is thus the only one supposed to make changes to the master layout file, which is a 2D CAD drawing of the entire factory layout. Each of the operations areas has designated folders where working copies of layouts are stored. Additionally, other specific documentation files based on the current layout, such as emergency evacuation plans are stored in designated shared folder. To facilitate company wide access to the current layout, the engineer responsible for the layout publishes copies on PDF-format.

The layout documentation is updated whenever any significant changes are made in a factory area. The interaction with the master-file layout documentation in connection with the production development is shown in figure 11 by a use case diagram. Each production development project is run by a production engineer having the main responsibility of the execution of the project. As this change driving engineer begins the planning of a new project he requests a partial copy of the latest version of the layout master-file covering the affected area from the engineer with the responsible for the layout documentation. The master-file is available to everyone in the production engineering staff but the layout-managing engineer has expressed his wishes to personally handle the area layout extraction to avoid inadvertent edits to the layout master-file.

During the project, the change driving engineer uses this local copy of the master-file. The use of these local copies of subchapters from the master-file is claimed to have substantial benefits according to both the current and the former layout-managing engineer: Working on local copies ensures that important files are not made unavailable by other personnel using the same file simultaneously. The local copies enable the change driving engineer to experiment with several alternative layouts during the project without affecting the actual master-file. Lastly, the layout-managing engineer appreciates the use of local files as this allows him to have exclusive control of the master-file, and hence reduce the risk of inadvertent editing by other users.

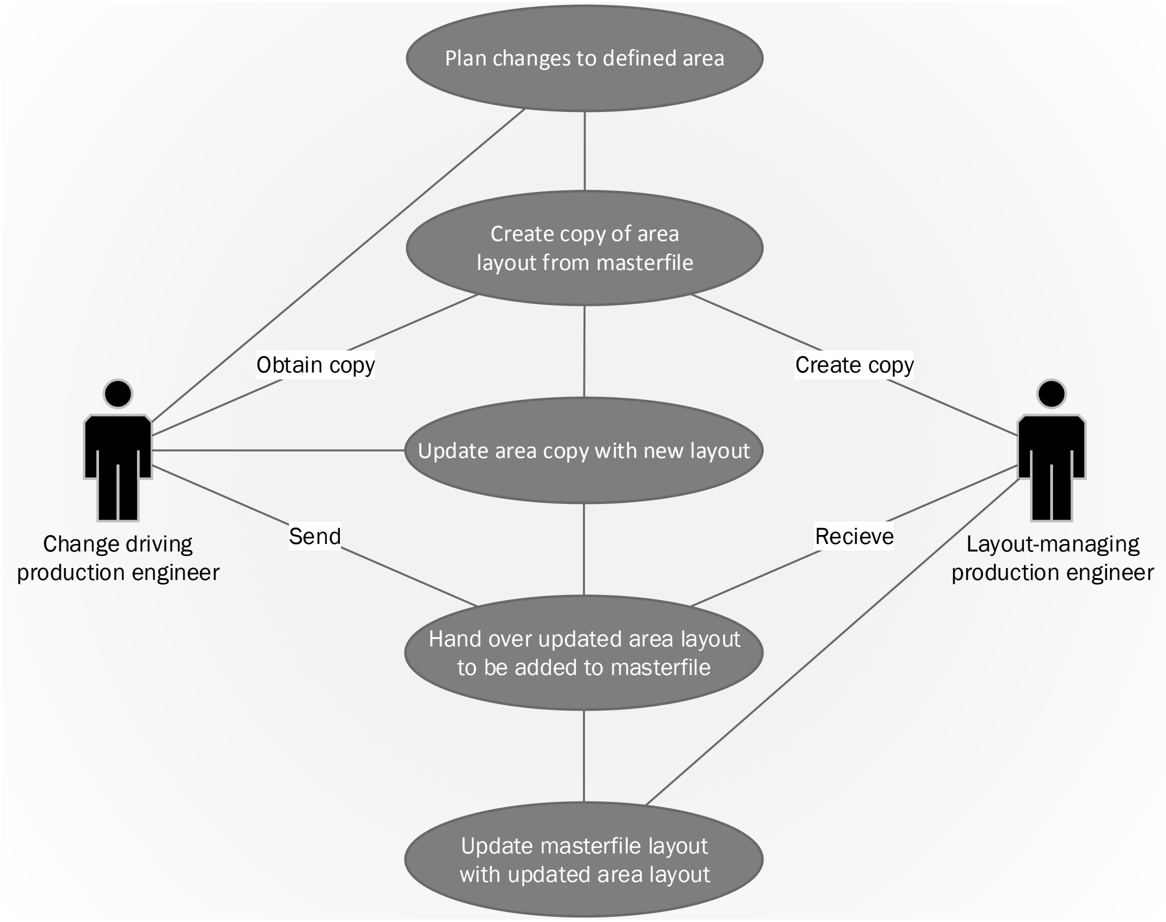


Figure 11: Use Case Diagram of the layout update process.

As a production development project is implemented the change driving engineer sends his local copy of the now realized layout to the layout-managing engineer who proceeds to transfer the new area layout to master-file, hence the layout documentation of the production development is completed. When the master file has been updated the date of change is appended to the filename. The date serves as way of keeping track of versions. This is currently the only version tracking feature in place for the layout master file; there is nor any documentation of what is changed when the layout is updated. Further, the layout-managing engineer says, the production engineers are not notified when the master layout has been updated. According to the layout engineer that is not an issue of concern as each change to an area of the master layout are designed by the engineer appointed to said area, hence the production engineers are aware of changes made to their areas.

To keep up with ongoing projects and changes to the layout of the factory the layout engineer hosts monthly layout meetings. Present at these meetings are all the parties involved with layout changes in the manufacturing area: the production engineers, the head of the production and quality department, the facilities manager, and the logistics engineer. The meeting follows an agenda set up by the layout-managing engineer where ongoing projects and other issues concerning the layout are presented and discussed.

5.2 Current tools

The tools used currently for layout planning are mainly computer aided design. The toolbox used at UniCarriers is the Autodesk Factory Design suite, which incorporates AutoCAD – the main tool for layout documentation at UCMSWE, all of the personnel involved in the layout documentation process has a sufficient level of proficiency in using the software. The nature of AutoCAD is to represent a reality in two dimensions with the ability to add assets, point clouds and synchronize into other tools for three dimensions representations and analysis. AutoCAD and its associated 2D layout file for layout planning has been in use for about two decades, it was originally made by one of the production engineers. The toolbox software suite includes several other programs with none or very limited amount of use.

Measurement data for the layout documentation is mainly retrieved by on-site measurements. Depending on situation and personal preferences the engineers uses either a handheld laser ranging device or a tape measure in this data gathering process.

5.3 Current usage of CAD-layout

The 2D layout is the foundation for all changes made to the workshop. The usage of the 2D layout is wide and not only limited for planning changes. It is an aid when designing safety routines and organizing areas of responsibilities. Personnel from the engineering staff of the company has expressed the importance for the current workflow that the 2D layout is present and that the 2D layout representation is accurate since many processes in the planning and development of the production utilizes it. Today, there are no detailed routines for how changes are made to the CAD-layout and there is no standardized way for measuring distances on-site. This has led to an inaccurate CAD-model, which is known, and has to be corrected in the future. To counter the faulty CAD-model, the engineers do not use it for measuring critical distances, more so for rough layout planning. Manual on-site measurements are utilized if distances are needed. Since there are no standard routine for making changes to the 2D layout, this process is time consuming and can easily results in more errors in the model. The way documenting changes today are as described in section 5.1 done by the engineer responsible for the master 2D layout model.

During one of the monthly layout meetings, described in section 5.1, it was observed how the CAD layout is currently used for visualization of future changes. It was clear that the 2D data is inadequate for successful communication of intended changes, the pictures were not able to successfully deliver the intended information but extensive explanations was required to transfer the information to the attendants of the meeting.

6 Analysis

This chapter brings all risen questions to the table for analysis. Empirical findings show issues in the layout documentation and the research questions need answers. Economic factors are estimated to further convince that 3D laser scanner technology is profitable for UCMSWE.

6.1 Comparison of 3D laser scanning and traditional CAD

3D laser scanning and point clouds is a completely different set of technology compared to traditional CAD, although some overlap exists in their areas of applications and uses in general. The extensive data gathering of 3D laser scanning makes it an excellent technology for as-is documentation of a manufacturing environment. The vast and speedy acquisition of spatial data with high accuracy could potentially substitute measurements by handheld devices as the scans contains information of which the thoroughness and accuracy is very difficult and time consuming to match by other means. Combining the spatial data with color information enables photorealistic 3D depictions of objects and facilities, which is useful for visualization purposes.

Even though 3D laser scanning is a very capable technology, there are still areas of application where CAD is unmatched. The main benefits of CAD technology are the discrete vector-based definitions of geometries and the ability to handle meta-data. These properties allows CAD to form parameterized geometries, useful for designing purposes, and simplified representations of existing or future objects and systems, useful for planning and mapping.

Point clouds handling is far more dependent on high levels of computational power and data storage capacity since point clouds easily becomes bulky in terms of file sizes. For example; the area scanned in this study the point cloud consisted of 110 million points stored in a 2 gigabyte sized file. In comparison; a CAD-model of the same area, which is not nearly as detailed as the point cloud, could be contained in a file only a few megabytes big. These requirements on computational hardware may very well act limiting on the usage; the availability of the point cloud and its gains must be valued against the potentially required investments in high-performance computers within any organization adopting the technology.

6.2 Problems and areas of improvement in UCMSWE's current processes

During observations and interviews a set of issues concerning the present situation and processes at UCMSWE regarding their layout documentation process were uncovered. The issues were unearthed in different ways, some matters were known and addressed by the interviewees, and others were illuminated during the interview and discussed further with the interviewees to gain more knowledge on the subjects.

6.2.1 Inaccurate layout documentation

The main problem illuminated by the engineers was the inaccuracy of the current 2D CAD used as documentation of the factory layout. Inaccuracies concerning the 2D layout model are affected by several different reasons. From interviews it was found that some measurement error originates from older layout models, which were not more exact than one tenth of a meter. Another influence for uncertainties is that the workshop has expanded in size during the years and that errors in the layout model can have propagated to new areas of the plant. It was also found that manual measuring of the workshop is done to get accurate values when making a change to the interior or when modifying the layout model. The problems of the inaccurate documentation and the need to solve this issue were incentive for UCMSWE to initiate the investigation of 3D laser scanning technology. Even though the issue of the inaccurate 2D CAD had been known for some time there had been no successful efforts in solving the problem, mainly due to the difficulty in identifying the faulty elements and the extensive measurements required to adjust the inaccuracy. A correct 2D layout will save measuring time and therefore also money and is another good incentive to initiate a process to achieve this. To confirm the inaccuracy by juxtaposing the current 2D layout of the scanned assembly area with the point cloud from the performed scans was effortless. Figure 12 shows a section of the scanned area, the position of the pillars along this wall were analyzed (shown as orange squares in 2D CAD), the pillar highlighted in green was used as origin for aligning the two files. Other identical pillars are highlighted in other colors, the current documentation is evidently severely inaccurate in this case and the position of the pillars was up to 80 centimeters off (red highlight). It was also noted that similar types of divergent elements were not necessarily offset in similar magnitude or direction, hence the faults were seemingly random throughout the 2D layout.

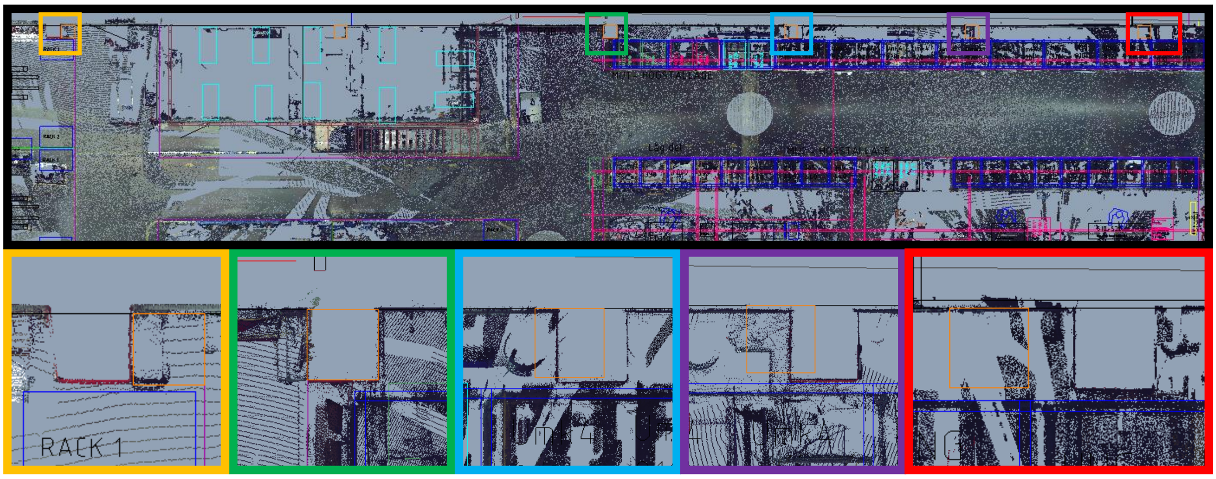


Figure 12: Juxtaposition of point cloud and current 2D layout, erroneous pillar placement highlighted.

6.2.2 Lacking documentation of revisions to the layout documentation

During the interview and observation session with the production engineers it was noted that the routines for version controls and documentation of changes were simple and primitive, or simply non-existing. A new version of the master layout file was denoted simply by adding the date of the latest change as a suffix to the filename. In terms of documenting changes there were no change-log describing the changes implemented, in consequence there were no records of previous versions or what was changed in each of the versions. Thus the handling of the master layout file stands in great contrast to how other important files are managed within the organization: In the product design department, collectively used files and information is stored in a PDM-database (Product Data Management), accessed by a special-purpose software. The database serves several useful purposes: Important data is stored centrally, accessible to anybody concerned. Additional information (meta-data) about the files is stored to keep track of version history and change-logs, and relations to other files. Workflows can be used to ensure that necessary administrative tasks are fulfilled upon changes. Files are stored in a virtual vault where users must first “check out” a file to edit it, eliminating any accidental or clashing changes to the files.

Regarding current work routines for making changes to the 2D layout documentation, it was deemed best to keep most of the work routine unchanged, since it is already a working concept and can be standardized. However, the urge of actually write a quick reference guide that explains the steps in how to change the documentation in a standardized fashion would be to recommend. That would speed up the learning process, increase the ability to improve the routine and increase flexibility among the engineers. In figure 13 is an example of how such a standard work routine could look like.

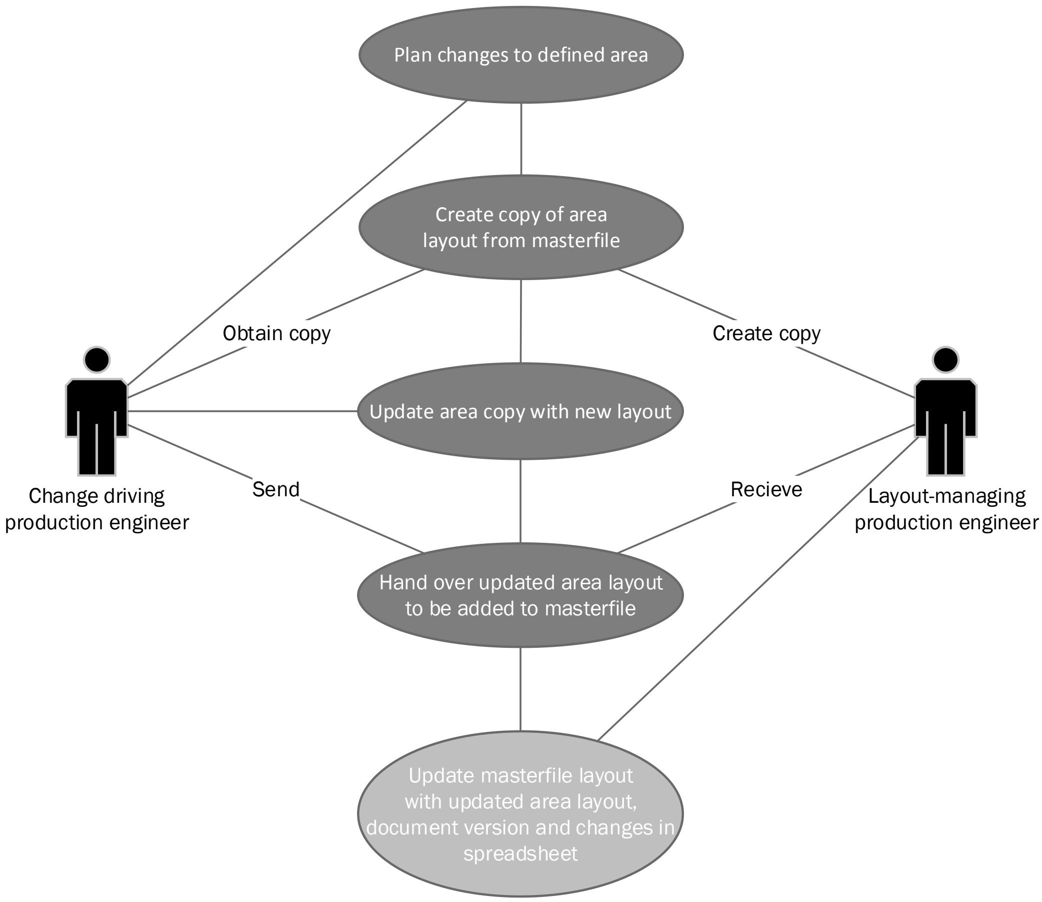


Figure 13: Use case diagram of proposed routines for layout documentation, tasks has been added to the final, highlighted bubble.

Additionally, version management is lacking currently, as stated above, and it is imperative to increase the safety level of the documentation. As a first step in increasing safety, the master layout file should be put on “read-only” and only be written to when a physical change is imminent. Secondly, the layout department is not ready for a full-scale PDM-database, based on interviews. Instead, creating an excel spreadsheet to keep track of; date of change, what did change and who was responsible for the change, would allow to keep track of changes in an easy and efficient way. This is based on the rare occasion of change and seems reasonable for what is gained in return.

Based on the findings at UCMSWE, both their needs and wants and by investigating different usage of point clouds applications, the most efficient way of using point cloud and 3D laser scanning technology are to get an accurate representation of the workshop for both measuring purposes and for visualization purposes. The way to implement it would be to make use of Autodesk’s software suite and correct the existing 2D layout made in AutoCAD and thereafter combine usage of 2D layout and 3D layout depending on situation and purpose for the layout planning task at hand.

6.3 Economic factors of 3D laser scanning

UCMSWE has stated their intentions to update their currently inaccurate 2D CAD layout. As previously mentioned, the current method for gathering factory layout data is measurements by handheld laser ranging devices or physical tape measures. The process of measuring the size and position of objects in the factory is time consuming and accuracy cannot be guaranteed. Recently a portion of the factory layout has been updated; an area approximately the size of a quarter of the total factory area was re-measured and drafted. According to the engineer performing the update it took roughly two weeks to finish the task, approximately half of the time was spent on measuring, the other half on drafting and validating measurements. Assuming that the time consumption for this process is consistent for the whole factory it would occupy an engineer for about 8 weeks. During this process the engineer would cost the company approximately 144 000 SEK according to the hourly cost of white collars at UCMSWE as defined in their internal accounting.

According to a consultancy firm performing 3D laser scans in the Gothenburg area, a full factory scan of a plant the size of UCMSWE's (about 14 000 m^2) could amount to roughly 200 000 SEK. In this price the required pre-processing such as filtering, registration, and cleaning of the point cloud is included. The authors has estimated that the full factory scan requires about 150-200 individual scans which in total would amount to 40-60 on-site hours using similar scanning hardware as in this study. When adding the time for the pre-processing of the point cloud, the total time consumed by the consultancy firm would amount to about two weeks.

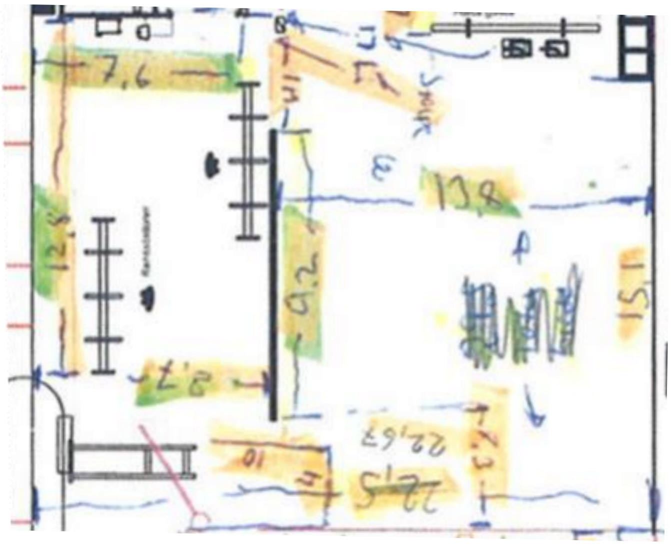


Figure 14: Example of manual measurements noted on layout sketch.

There are currently no drafting procedures at UCMSWE. But the latest example involves converting manual measurements noted on a rough pen and paper sketch, as shown in figure 14, to a 2D layout. To ensure that the layout is being depicted correctly the user must continuously compare the drafted CAD with the physical measurements as to make sure that objects has the intended dimensions and position. By juxtaposing the 2D CAD with the point cloud it is possible to draft the layout by tracing the geometries from the point cloud to the CAD and thus having an immediate visual verification of the drafted geometries in comparison to the underlying point cloud. It is estimated that such procedure may consume roughly half the time traditional drafting requires.

Table 4: Economic evaluation of 3D laser scanning based on estimations

	Traditional method	3D laser scanning and point cloud
Measuring	4 weeks = 72 000 SEK	2 weeks consulting = 200 000 SEK
Drafting	4 weeks = 72 000 SEK	2 weeks = 36 000 SEK
Total	**8 weeks = 144 000 SEK**	**4 weeks = 236 000 SEK**

As shown in table 4, re-drafting the current 2D layout at UCMSWE with the assistance from 3D laser scanner technology instead of the currently used manual measurement method would cut the total required time by more than 50% but costs would increase by over 60%. By just considering at the costs of the two compared options 3D laser scanning seems to be the less suitable of the two. However, a fair comparison must incorporate other factors, such as validity of collected data and drafted layout, additional uses of the data, and the distribution of consumed time. For instance, as shown in table 4, the required time involving a production engineer is cut to only 25% of the equivalent time using the traditional methods. In the case of reduced availability of production engineering resources it is extra favorable with a solution that decreases the consumption of such valuable time.

In general, accuracy and validity of measurements depends on the technical specification of the measurement hardware used the rigidity of the measurement method. The technical specs of and 3D laser scanner and a handheld laser rangefinder are similar in terms of accuracy and effective range as they are both based on similar technology. The difference is in the measurement method: Handheld measurement validity is highly dependent on the skill of the operator, unless being very meticulous there is a high likelihood of errors in the measurements. Depending on the method, these errors may propagate throughout the measurements. The rigid method needed for counteracting such errors requires a vast increase in measurements and thus an increase in time consumption. A 3D laser scanner is able to collect a massive amount of measurements in short time, the scanner used in this study is able to collect up to 976 000 points per second (FARO Technologies Inc., 2013). The automated comprehensive measurements provided by 3D laser scanning presented as a point cloud is to be valued as a considerably more valid data set compared to traditional measurement methods: Automated measurements eliminates erroneous data caused by human factors and the comprehensive and visual nature of the point cloud allows for easy identification of key data.

Using data acquired from 3D laser scanned data when drafting a new 2D layout at UCMSWE will certainly result in a considerably higher accuracy in the documentation. The lost time and thereby induced costs at UCMSWE due to the inaccurate layout documentation is difficult to assess, however, during the interviews it has surfaced that extra work such as on-site measurements is currently necessary to make up for the lacking accuracy of the documentation. A new, accurate layout documentation will hence aid in creating a smoother workflow as interrupting extra work will be eliminated. It should be noted that the circumstances may differ from one case to another.

3D laser scanning hardware pricing varies significantly depending on factors such as range, resolution, scanning speed, technology, additional sensors, and brand. Scanning hardware suitable for applications topical at UCMSWE generally starts at roughly 300 000 SEK.

7 Application of 3D laser scanning technology

This chapter is devoted to UCMSWE with the ambition to hand over solutions of today's most urgent problems. The solution's foundation originates from company employee wishes, the analysis of the spatial data and economic factors.

7.1 3D laser scanning

There is an imminent use for 3D laser scanning at UCMSWE in order to tackle the current problems with inaccurate layout documentation. Future needs of 3D laser scanning are expected to occur in conjunction with significant changes to one or several areas of the factory. Thus the total need for 3D laser scanning at UCMSWE the coming 5 years would consist of one full factory scan later to be complemented by only a few partial scans of areas where significant changes has been implemented.

The steep cost for investing in 3D laser scanning equipment in combination with the relatively low scanning volume anticipated at UCMSWE, recommendations for UCMSWE are to obtain the scanning through external consultancies. Given the quotes UCMSWE has received and the assumptions above, the cost of hiring consultancies to carry out the expected scans should be significantly less than the cost of investing in scanning hardware and educating personnel to carry out the scans.

The pre-processing procedures of the point cloud; registration, filtration, and cleaning may prove to be rather time consuming and requires certain software licenses currently unavailable at UCMSWE. Consultancy firms offering 3D laser scanning services in the area of UCMSWE normally includes the basic processing of the scans in their quote, thus the pre-processing should not be of any concerns for the employees of UCMSWE.

7.2 Immediate use of point clouds

When a point cloud has been acquired there are one-off tasks that should be handled promptly in order to relieve existing problems.

The most immediate application of 3D laser scanning and point cloud technology at UCMSWE is re-drafting their current 2D layout to remedy the present inaccuracies. The suggestion is that the re-drafting is to be performed by one single engineer familiar with the current software used for 2D layout drafting; AutoCAD. The point of allocating one single engineer to re-draft the whole factory at once is to avoid the issues of inconsistencies in the use of colors, symbols, and drawing-layers that is an existent problem with the current documentation. The point cloud should be used as a juxtaposed overlay to aid the engineer in the drafting process. The overlay will assist in matters such as determining the dimensions and location of any included object and additionally identifying objects currently not included in the layout documentation.

In the matter of availability of the point cloud within the organization in relative to computational resources required it should be considered what personnel gains the most from having access to the point cloud. As the use of point clouds increases within the organization with additional fields of application, it may very well be necessary to increase the user base and hence invest further in computer hardware.

7.3 Continuous use of point clouds and improvements to the layout documentation

As the immediate tasks has been carried out a day to day use of the point cloud begins. Presented here are tasks utilizing the point cloud that could be implemented at UCMSWE without delay that will aid and improve planning and development of the manufacturing layout. Further, a new, altered routine on documentation of the layout documentation in junction with changes to the production system is proposed.

7.3.1 Measurements

Given the fact that the point cloud of a properly performed scan should encompass the overall majority of the whole factory with high accuracy, the point cloud could be used for measurements and thus substitute physical on-site measurements. Using the point cloud for measurements is a more time efficient method, in addition it enables effortless measurement of features that may be hard to reach for on-site measurements, such as objects in ceiling level.

7.3.2 Visualization

The rich visual data of a point cloud could prove useful for visualization purposes; exporting a rendered image of short video of the point cloud in combination with 3D CAD geometries is a powerful visualization tool of intended changes. The purpose of having rich visual data at hand is to easier motivate an investment for decision makers that are not familiar with the low visual quality of the old 2D CAD layout drawing.

7.3.3 Work routines for layout documentation

The absence of written work routines around layout changes and layout documentations are a problem, theory have stated the importance of routines for continuous improvement and especially with the introduction of new technology. The study has shown that there are a commonly used routine that should be written down and modified slightly for increased safety against human-error and a better version history management. The analysis concluded that only small adjustments need to be carried out in order to have a good, improvable workflow regarding layout documentation. When changes are to be made in the 2D CAD layout, then and only then are the master layout file writable. Additionally, document the changes in a separate spreadsheet to keep track of changes and when they were finished and by whom. The assumptions are that in this stage of utilizing point cloud, all changes to the layout models will be in the 2D layout model. Therefore, routines for modifying the point cloud and routines for other point cloud applications are not given.

7.4 Potential future use of point cloud

3D laser scanning and point cloud-data has several additional uses that has not been deemed suitable or needed at UCMSWE at this current stage. However, in a longer time perspective UCMSWE may find these applications suitable and interesting as well. The applications examined during the study can very well be realized in the production environment at UCMSWE. However, in order to take advantage of these applications it is believed that some software skill support will be required for the practitioners.

Clash detection could be utilized for ensuring collision free operation as new and bigger trucks are manufactured and moved throughout the facility. Clash detection could also be utilized when installing new equipment, such as assembly lines to make sure that the line fit correctly. This feature is already available at UCMSWE.

Discrete event simulation is a good way of obtaining quantitative data about the manufacturing system and by using the point cloud as an environment, thus increasing the visualization aid, the results of the simulation will be easier for UCMSWE to communicate to the board, investors or other important persons. The manufacturing system at UCMSWE is getting increasingly advanced, new equipment is being installed, which in turn complicates the production flow. A discrete event simulation model would help to identify bottlenecks, starvations and other potential unwanted properties in the production system.

Reverse engineering could be used for generating solid CAD models for object and features on ceiling level, as an example. There were complaints from UCMSWE that the 2D layout documentation only covered the floor level and that there were no credible mapping of overhead cranes, pipes or ventilation shacks available. For this purpose, reverse engineering is the obvious choice for generating accurate CAD models of wanted physical objects. However, reverse engineering from point clouds is a relatively new field, hence there are still limitations in the complexity of geometries to be processed.

8 Discussion

In this chapter there will be discussions around the results of this thesis, the validity of the used methods and a comparison to earlier research on the subject of 3D laser scanner technology. There will be a paragraph dedicated to the development of 3D laser scanner technology and where the gaps most likely can be found. To end this chapter, discussions about further research will be given as this technology is still immature and needs more attention.

8.1 Results

The result obtained from the study is a highly applicable solution aimed towards UCMSWE. Therefore, both the analysis and the solution have been focused on the software already available at UCMSWE. The study has not aspired in being a full investigation or comparison of the range of available software with point cloud handling capabilities. In a case with a more general approach, more software able to manage point cloud and layout models equally well should have been investigated. However, it should be added that if a satisfactory solution would have been proven unattainable with the used software, other software would have been examined in order to provide an answer.

The solution has intentionally been designed to be an accessible and easily implemented solution for solving the problems identified and UCMSWE. Hence, functions included in the already used software has been sought to provide functioning solution and thus avoiding the need of acquiring additional software or implementing overly advanced state of the art applications.

This solution shows the benefits of 3D laser scanning mainly in the context of layout documentation issues. There should of course be known that many other applications can benefit from 3D laser scanning, depending what issues might be at hand.

8.2 Method

The method is considered being general and applicable on many cases. The software investigation can be carried out for other software suites to investigate compatibility and capability. The validity of the software investigation is highly dependent on the available documentation for the investigated software and the skills and experience of the investigator. For the software researched in this study the documentation has been thorough and the investigation has been methodically performed. Interviews and observations is a commonly used method for gathering qualitative data to gain insight in situations, otherwise hard to attain. However, interviews and observations can be biased or subjective even if precautions were made for this not to happen. This can lead to inaccurate findings which in turn may affect the final results. The utilization of semi-structured interviews, which require less interview skill, and having both researchers participating in each interviewing occasion were measures used to counteract bias and gain accurate results.

8.2.1 Alternative methods

There is however other methods for achieving the same results. Regarding the used method of having semi-structured interviews can be questioned. By having an unstructured interview and just a few topics known beforehand to discuss around, more insight might have been achieved. More insight might have led to a more detailed current work routine, ultimately resulted in a better proposed work routine solution for UCMSWE. But the skills needed to conduct that type of interview was lacking and the preparation work for the semi-structured interview required more time opposed to an unstructured.

The investigation of software could have been done in an altered way. Autodesk Factory Design Suite 2014 could have been evaluated by the engineers at UCMSWE by instructions that were made during this project. That should even out the learning curve more and the solution ought to have been easier to implement. This proposal was investigated but unfortunately not an option. More possible solutions in regard of software investigation could have included a quick course to quickly get many unknown questions answered by professionals. Attempts were made to contact a consultancy firm to arrange a meeting, although such an occasion could not be arranged for in the time frame of the study.

The method used in this thesis work did reach successful results, in that sense that the goal was reached. However, the results could have been obtained using entire different methods. The software investigations were not part of the primary goal of this thesis, but as a secondary goal. The secondary goal, to deliver a work routine for correcting the existing 2D CAD layout model, investigation of the software was considered necessary since this knowledge was lacking at the start of the project. Common Autodesk environment knowledge was also desired and therefore decided to investigate. If Autodesk familiarity would have been the case, the method of this master thesis would have been altered and more emphasis should have been put on deliver a more detailed work routine.

8.3 Previous research

Previous research within the field of 3D laser scanning has mainly gravitated towards state of the art technology and further development of the technology. Research has been carried out for all potential point cloud applications that are mentioned in this thesis. However, the benefits and implementation of 3D laser scanning, point clouds and utilizing additional applications of point clouds within small and medium sized manufacturing companies have not been explored in the existing research, when searched for on the topic, with the exception of a master thesis published in 2013. Therefore, this highly applicable solution is rather unique in that aspect.

8.4 The future in 3D laser scanning technology

Commercial use of 3D laser scanning of full environments such as manufacturing systems and use of associated point cloud has developed dramatically during the last half decade. The increase can be seen in the field of both hardware and software as new and improved scanners has been introduced to the market and the software support of point clouds has grown. Given this trend of increased supply of actors and products in the 3D laser scanning market in combination with the natural increase in accessible computational power as stated by Moore's law it is rather safe to conclude that the use of 3D laser scanning and point cloud handling will become more widespread and more advanced in the next decade.

8.5 Further research

The expected increase in 3D laser scanning availability over the next decade calls for the research within this field to expand. As the technology will become more widespread an increase of suitable applications may be expected. Research should continue to evolve the state of the art in order to further develop new areas of application and perfect the already existing.

Since the accessibility of the technology is likely to increase, more research, like this study, should focus on how 3D laser scanning is best utilized within a manufacturing organization. The set of organizations investigated should incorporate significant variance in factors such as organization size, level of technological maturity and level of automation. These factors most likely will have a heavy influence on the incentives of implementing 3D laser scanning and the applications for which the technology is suitable to utilize.

9 Conclusions

While still being an emerging technology there are several potential applications of 3D laser scanning and point clouds for manufacturing organizations. The vast and accurate combination of a spatial and photographic rendition of an environment could be used for facilitating production development and documentation. Visualizations of proposed future states can easily be crafted using point clouds which facilitates communication to personnel and decision makers when evaluating future investment. The spatial data from a 3D laser scan enables advanced analysis methods such as clash detection or discrete event simulation, allowing future states to be analyzed in depth early on in the development phase. Thus errors can be detected and avoided early. Using the 3D laser scanning in junction with traditional CAD provides a fast and accurate method for documenting the layout of production facilities. Using reverse engineering software, certain geometries could be extracted from the point cloud into a traditional CAD-setting for further processing. More research is desired, to recognize more features out of the point could data set automatically.

Compared to traditional CAD-methods for layout documentation 3D laser scanning provide an accurate and highly detailed depiction of an environment in short time. Although, it lacks the native distinction of discrete geometries available in CAD. Hence it may be concluded that 3D laser scanning and point clouds may not be suitable as a substitute for traditional CAD-methods but rather a powerful complement.

The organization in which this study has taken place could be regarded as being in the lower spectrum on a subjective technology scale. Hence the study has been aiming for a solution with an acceptable level of complexity to suit the organizations need rather than a state of the art solution.

A comparison of the resulting point cloud created in this study and a part of UCMSWE 2D layout documentation showed the current documentation dimension mismatch, which has been shown to require an extensive re-drafting of the current layout documentation. Given their current problems with inaccurate documentation of their facility layout, UCMSWE is recommended to use 3D laser scanning primarily as a measurement tool. Using 3D laser scanning in combination with CAD-drawings the company would be able to update their documentation to accurately depict their current state faster and more accurately than with their current methods. Further use of the point cloud generated by 3D laser scanning will be useful for measurements and visualizations, thus facilitating data gathering and communication within the organization regarding production development tasks.

This thesis shows how 3D laser scanning technology should be implemented and utilized at UCMSWE for improving recurring processes and tasks such as documentation and visualization of their manufacturing layout and proposed changes to it. In addition the study has presented additional uses of the point cloud data derived from 3D laser scanning that may become highly useful for the organization within a foreseeable future. The company has shown their interest in the technology and the solutions presented by this study.

Further research in the light of 3D laser scanning should involve case studies in a wide range of organizations in order to identify the ideal use and benefits of 3D laser scanning and point clouds in different environments and organizations. Such extended research concurs with the beliefs that the use of 3D laser scanning within the manufacturing industry will drastically increase over the next decade.

References

Baker, L. (2006) Observation: A complex research method. Library Trends, 55(1), pp. 171-189.

Banks, J. (1998) Handbook of Simulation - Principles, Methodology, Advances, Applications, and Practice. New York: John Wiley & Sons.

Banks, J. (2010) Discrete-event system simulation. Upper Saddle River: Prentice Hall.

Becerik-Gerber, B., Jazizadeh, F., Kavulya, G. and Calis, G. (2011) Assessment of target types and layouts in 3D laser scanning for registration accuracy. Automation in Construction, 20(5), pp. 649-658.

Bi, Z. and Wang, L. (2010) Advances in 3D data acquisition and processing for industrial applications. Robotics and Computer-Integrated Manufacturing, 26(5), pp. 403-413.

Bruce, K. and Nyland, C. (2011) Elton Mayo and the deification of human relations. Organization Studies, 32(3), pp. 383-405.

FARO Technologies Inc. (2013) FARO Focus 3D: Features, Benefits & Technical Specifications. [Online] Available at: http://www2.faro.com/site/resources/share/944
[Accessed 05 05 2014].

Genechten, v. B. (2008) Theory and practice on Terrestrial Laser Scanning: Training material based on practical applications. 4 ed. Valencia: Universidad Politecnica de Valencia Editorial.

Jiménez, P., Thomas, F. and Torras, C. (2001) 3D collision detection: a survey. Computers & Graphics, 25(2), pp. 269-285.

Johnson, R. B. (1997) Examining the validity structure of qualitive research. Education, 118(2), pp. 282-292.

Klein, J. and Zachmann, G. (2004) Point Cloud Collision Detection. Computer Graphics Forum, 23(3), pp. 567-576.

Liker, J. K. and Meier, D. (2005) The Toyota Way Fieldbook: a practical guide for implementing Toyota's 4Ps. New York: McGraw-Hill.

Lindskog, E. et al. (2012) Combining point cloud technologies with discrete event simulation. In Proceedings of the 2012 Winter Simulation Conference; 9-12 December, 2012, Berlin, IEEE.

Lindskog, E., Berglund, J., Vallhagen, J. and Johansson, B. (2013) Visualization support for virtual redesign of manufacturing systems. In Procedia CIRP 7; 29-31 May, 2013, Sétubal, CIRP. pp 419-424.

Marksberry, P., Rammohan, R. and Vu, D. (2011). A systems study on standardised work: a Toyota perspective. International Journal of Productivity and Quality Management, 7(3), pp. 287-303.

Raja, V. and Fernandes, K. J. (2008) Reverse Engineering: An Industrial Perspective. 1 ed. London: Springer.

Rowley, J. (2012) Conducting research interviews. Management Research Review, 35(3/4), pp. 260-271.

Sandgren, M. et al. (2013) Användning av punktmolnsdata från laserskanning vid redigering, simulering och reverse engineering i en digital produktionsmiljö. Gothenburg: Chalmers University of Technology. (Bachelor thesis in production development at the department of product and production development).

Spender, J. and Kijne, H. (1996) Scientific Management: Frederick Winslow Taylor's Gift to the World?. 1st ed. Boston: Springer.

Stroud, I. and Nagy, H. (2011) Solid modelling and CAD systems: how to survive a CAD system. 1 ed. London: Springer.

Appendix A

Interview with production engineers:

- Are there any standard procedures for your layout documentation process?
- What are your opinions regarding the current structure of the layout documentation process?
- How would your current procedures be affected by a change to more or less standardization?
- Describe the current procedures for layout documentation.
- What are the greatest advantages of the current procedures?
- What improvements, do you see could be implemented to your current procedures?
- What are the hardest tasks when making changes to your current layout and its documentation?
- What advantages and disadvantages do you see in increasing the use of 3D in the layout documentation process by the use of 3D laser scanning?

Interview with design engineer:

- What recurring tasks within your department are carried out with CAD?
- What software are you using for tasks involving CAD?
- Explain the procedures at the design department for tasks involving:
    - Collectively used files
    - Changes and versioning
    - Communication regarding designs and changes
- What advantages and disadvantages are there with the currently employed procedures?
- To what extent would deem the procedures within the design department to be standardized?
- What routines and procedures do you see as eligible for being applied in other departments (such as production engineering)?