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Towards Realistic Visualisation of Production Systems

ERIK LINDSKOG

Department of Product and Production Development

CHALMERS UNIVERSITY OF TECHNOLOGY

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ERIK LINDSKOG

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Department of Product and Production Development
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

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Abstract

Redesigning a production system is a complex process for which numerous virtual tools are available to support the planning process. These virtual tools are used to forecast and analyse the production system prior to implementing the redesign, which makes it possible to identify and prevent costly problems during the planning process. However, such problems occur anyhow due to incorrect information in the virtual representation of the production system and misunderstandings between experts responsible for different areas of the production system. These problems can be avoided by supporting the planning process with realistic and accurate information regarding the existing and redesigned production system.

The aim of this thesis is to show that realistic visualisation can support the process of redesigning production systems, in order to reduce the time required for planning and implementation. Three industrial studies were carried out to evaluate how realistic visualisation can be created to support the redesign process. These industrial studies focused mainly on discussing redesign considerations in groups of experts with different areas of responsibility. Additionally, two workshops were carried out to identify what information these experts found important to include in the realistic visualisations.

The results show the potential of using 3D laser scanning to create realistic visualisations of production systems with high accuracy. These visualisations can be used to present existing and redesigned production systems in a way that is easy for a wide range of people to understand. Redesigned systems can be visualised by combining 3D laser scan data with 3D CAD models to enable discussion and analysis of redesign alternatives. The support of realistic visualisation can reduce the time required for planning and implementing the redesigned production systems by enabling effective and accurate planning.

Keywords: *Realistic visualisation, Production systems, Manufacturing systems, 3D laser scanning, Point clouds*

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Gothenburg, Sweden, May 2014

Erik Lindskog

List of appended papers

Paper I **Visualization Support for Virtual Redesign of Manufacturing Systems**
Lindskog, E., Berglund, J., Vallhagen, J., and Johansson, B. 2013
CIRP Manufacturing Systems 2013

Paper II **Combining Point Cloud Technologies with Discrete Event Simulation**
Lindskog, E., Berglund, J., Vallhagen, J., Berlin, R., and Johansson, B. 2012
Proceedings of the 2012 Winter Simulation Conference

Paper III **Lean Based Problem Solving using 3D Laser Scanned Visualizations of Production Systems**
Lindskog, E., Berglund, J., Vallhagen, J., and Johansson, B. 2014
The Scientific World Journal (submitted)

List of additional papers

A Method for Determining the Environmental Footprint of Industrial Products Using Simulation
Lindskog, E., Lundh, L., Berglund, J., Lee, T., Skoogh, A., and Johansson, B. 2011
Proceedings of the 2011 Winter Simulation Conference

3D Movie Creation from Discrete Event Simulation Software Models of Manufacturing Industries
Faure, L., Koochakan, A., Berglund, J., Lindskog, E., and Johansson, B. 2012
International Conference of Modeling, Optimization and Simulation 2012

Evaluation and Calculation of Dynamics in Environmental Impact Assessment
Johansson, B., Andersson, J., Lindskog, E., Berglund, J., and Skoogh, A. 2012
Advances in Production Management Systems

Supply Chain Carbon Footprint Tradeoffs Using Simulation
Jain, S., Lindskog, E., and Johansson, B. 2012
Proceedings of the 2012 Winter Simulation Conference

A Hierarchical Approach for Evaluating Energy Trade-offs in Supply Chains
Sanjay, J., Lindskog, E., Andersson, J., and Johansson, B. 2013
International Journal of Production Economics

Multi-Resolution Modeling for Supply Chain Sustainability Analysis
Sanjay, J., Sigurðardóttir, S., Lindskog, E., Andersson, J., Skoogh, A., and Johansson, B. 2013
Proceedings of the 2013 Winter Simulation Conference

List of definitions

3D laser scanning: Technology used to gather spatial data of physical objects or environments by recording measurements of the distance from the scanner to the closest physical surface (Bi and Wang, 2010).

Measurement point: The resulting point from each measurement by the 3D laser scanner, which consists of information regarding each point's position in x, y, z coordinates and intensity (Staiger, 2003). This information can be complemented with colour of the point using the RGB colour model.

Point cloud: The combination of multiple measurement points (Staiger, 2003).

Realistic: Representations of objects that are presented in such a way that they are accurate and true to life (Oxford Dictionaries, 2013).

Shop floor: The section of a factory where the production is carried out, which is separated from administrative work (Oxford Dictionaries, 2014).

Spatial: Description of objects size, shape, and positions along with how they relate to other objects in space (Macmillan Publishers, 2014).

List of abbreviations

2D	Two-dimensional
3D	Three-dimensional
AR	Augmented Reality
CAD	Computer Aided Design
CAVE	Cave Automatic Virtual Environment
DES	Discrete Event Simulation
HMD	Head-Mounted Displays
GPS	Global Positioning System
R&D	Research and development
RGB	Red Green Blue
VR	Virtual Reality

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1 Introduction

This chapter includes an introduction to what the reader can expect from this thesis.

1.1 Background

Key factors to manufacturing companies' profitability are usually production systems with short lead-times and products with high quality (Schuh et al., 2011). This makes it important for companies to keep their production systems up to date, which is achieved by redesigning them when needed. In the planning of such redesign, it is important to ensure that no problems will occur after the implementation. As a rough estimation, the cost to fix a problem increases by a hundred times if the problem occurs after implementing the redesign compared with if the problem is found and solved during the planning (Johansson, 2008). An example of such a problem is when planning the location of a machine the machine operator and materials are not provided with the required physical space, which can result in the machine needing to be relocated again after the implementation. However, using virtual tools these problems can be identified and solved during the planning. The purpose with such tools is to forecast, analyse, and visualise redesigned production systems before making any implementation (Becker et al., 2005). A downside is that problems occur after the implementing anyhow.

That problems occurs anyhow when using virtual tools derives from a number of aspects, such as lack of accurate information and visualisations that are difficult to understand (Schuh et al., 2011). These aspects can create misunderstandings when communicating and discussing redesign alternatives between experts responsible for different areas of production systems, who have individual understandings based on their expertise, knowledge, and background. Such misunderstandings can result in problems that only manifest when the redesign is implemented and everyone has a good understanding of the overall redesigned production system (Wenzel and Jessen, 2001). To minimise possible misunderstandings, the experts involved in the planning should reach a common understanding that is very close to the planned redesigned production system (Vallhagen et al., 2011). The understanding is created as a model or imagination of the production system in the brain, which is described as the mental model (Schnotz and Kürschner, 2007). This mental model can be created using impressions and experiences from real or virtual representations of production systems, as presented in Figure 1-1 (Vallhagen et al., 2011).

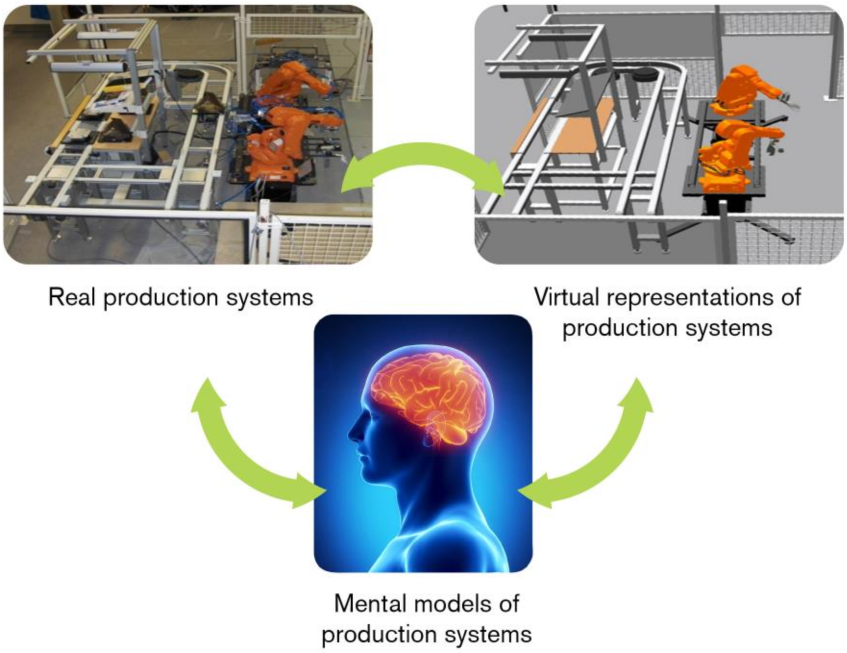

Figure 1-1: The relation between the mental model, virtual representation, and real production system

The virtual representations of production systems created with traditionally used virtual tools usually have problems such as lack of details, unrealistic depiction, and inaccuracies. These problems result in decisions being made using incorrect information that is difficult to understand, which can create additional problems during the implementation. This most often derives from difficulties in modelling virtual representations and to solve these difficulties there is a need for capturing accurate information of existing production systems and factory buildings (Gregor et al., 2009). With this information, it should be possible to create virtual representations of existing and redesigned production systems that are realistic and accurate compared with the real production system. In this thesis, these virtual representations are referred to as a realistic visualisation. The term realistic is defined by Oxford Dictionaries (2013), as follows:

> *"Representing things in a way that is accurate and true to life."* (Oxford Dictionaries, 2013)

By this definition, realistic visualisation is used in this thesis to describe close to life virtual representations that are easy to understand for a wide range of people regardless of their backgrounds.

1.2 Aim

The aim of this thesis is to show that realistic visualisation can support the process of redesigning production systems, in order to reduce the time required for planning and implementation.

1.3 Research questions

The following research questions (RQ) have been formulated to reach the aim.

> ***RQ1:*** *How can realistic visualisations of production systems be created?*

In production systems, there are multiple static and dynamical aspects to consider. Such aspects should be included in the realistic visualisation to give an accurate and sufficient understanding of the existing and redesigned production systems. To create these realistic visualisations there are a number of technologies and applications available. This question will focus on how these technologies and applications can be applied to create realistic visualisations.

> ***RQ2:*** *How can the process of redesigning production systems be supported by realistic visualisation?*

Experts involved in redesigning production systems are continuously facing a number of redesign considerations during the planning process. The focus in this question is on how realistic visualisations can support such considerations.

1.4 Scope and delimitations

The realistic visualisations used in this research have been created in industrial studies using of-the-shelf technologies and applications. These studies were carried out covering the redesign process of production systems by visualising the existing and redesigned systems. The realistic visualisations have been evaluated in groups of experts working with planning the redesign of production systems. These experts are assumed to have different responsibility areas in the area of production such as layout planning, workplace design, and materials handling. However, there has been no research in this thesis towards evaluating the human perception of the visualisations and the group structure.

The term production system is used to describe discrete systems that are producing some type of product and includes functions such as machines, workplaces, material handling, and manual work. Such systems can also be referred to as a manufacturing systems as used in some of the appended papers due to the scope of the publication forum, but should be considered as a synonym to production systems in this thesis.

1.5 Research activities

The research towards this thesis has followed the list of activities presented in Figure 1-2. These activities were initialised with the problem identification, followed by a literature study to establish a theoretical and technology framework in the research area. This literature study resulted in *Industrial study A* that evaluated how to create realistic visualisations of existing production facilities. During *Industrial study A* a need to gather the industrial needs was identified, which led to *Workshop A* and *B* that were carried out to establish an understanding of what type of information experts found important to visualise when planning the redesign of production systems. The result of

Industrial study A and *Workshop A* initialised *Industrial study B*, which evaluated how realistic visualisation can support a group of experts discussing the redesign of a production system. *Industrial study B* and *Workshop B* resulted in *Industrial study C*, where dynamical aspects were included in the realistic visualisation. The industrial studies and workshops are the main contributions to the result of this thesis.

The appended papers cover the following areas:

- **Paper I:** The possibility of creating and using realistic visualisation to support the redesign process of production systems is evaluated using *Industrial study A* and *B*.
- **Paper II:** A concept of creating realistic visualisation that includes dynamical aspects using simulation of production systems is presented and theoretically discussed.
- **Paper III:** The concept presented in *Paper II* is applied in *Industrial study C*, which is used to propose a Lean based problem solving approach.

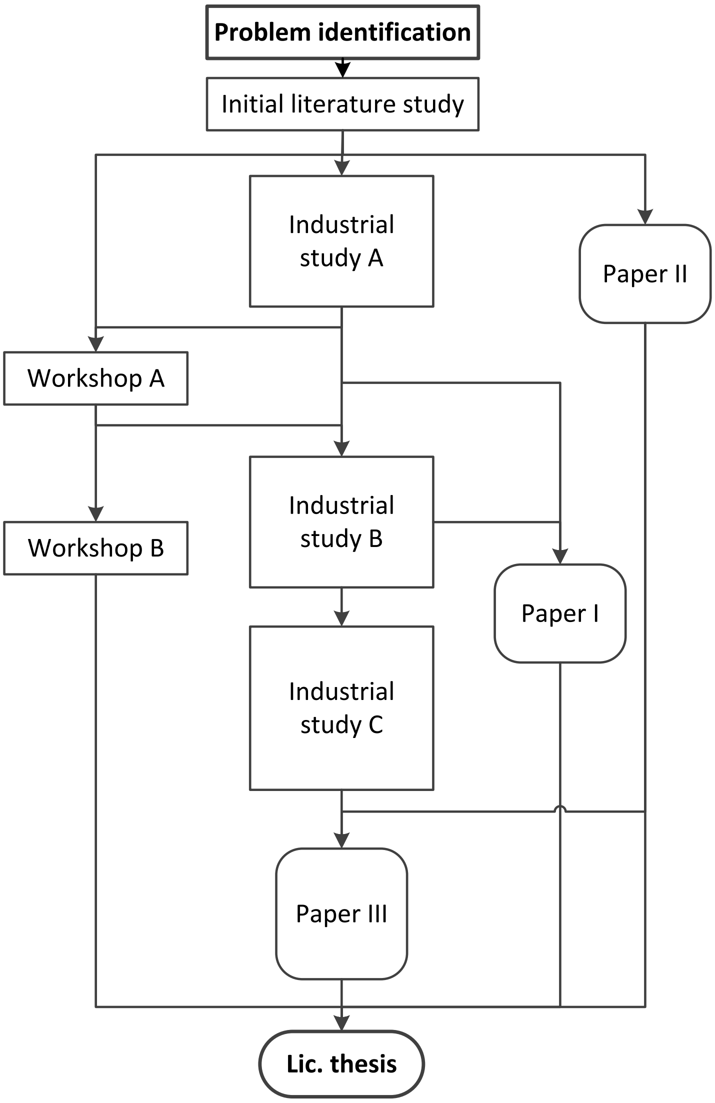

Figure 1-2: The chronological order of activities resulting in this thesis

1.6 Research context

This thesis was a part of the research project *Visual production* that was initialised in 2011 together with GKN Aerospace Engine Systems (former Volvo Aero Corporation and referred to as the company in this thesis). The aim of the research project was to increase efficiency and effectiveness during development of production systems using realistic visualisation. The conceptual idea was that a group of experts should be able to transform themselves into the future production system and make right decisions together using the realistic visualisation.

The company is producing high-end engine components for the aerospace industry, which requires their production systems to deal with extreme quality requirements and long product life cycles. This causes unique conditions with mixed product programs handling components for old and new engines. Production process technologies may change over time but need to be adapted for the old engine components. This is not always the case, which results in a large variety of production methods for different components. In combination with varying demands and volumes rather complex situations are created that need to be handled in production planning and development. The result over time is production systems that are mainly organised as functional layouts, but the company future vision is to change towards more product-oriented layouts.

1.7 Thesis structure

The remaining part of this thesis is structured in six additional chapters. In Chapter 2, the frame of reference of the research area is presented. This followed by the research approach and methods, which are presented in Chapter 3. The results from the workshops are presented Chapter 4 and a summary of the appended papers is presented in Chapter 5. The results, research approach, and future work are discussed in Chapter 6. Finally, Chapter 7 concludes by answering the research questions.

2 Frame of reference

This chapter includes the frame of reference used in this thesis to give the reader a better understanding of previous and existing work in the research area.

2.1 Visualisations to support planning processes

A well-known expression when discussing visualisation is "*A picture is worth a thousand words*" that derives from the fact that the human brain processes pictures and models easier than text and numbers (Ebert, 2005). Visualising pictures and models has been shown to increase peoples' understanding, which can for example improve training and learning (Gropper, 1963; Pinsky and Wipf, 2000). Using virtual tools makes it possible to visualise large amounts of data in one virtual representation (Ware, 2004). When creating such visualisations there are several factors to consider to increase understanding, such as light, colours, and textures (Ware, 2004). The visualisations can be used to create an understanding of the virtual representation in a group of people (Wenzel and Jessen, 2001). However, there is always a risk that different people will understand the same visualisation differently due to previous experiences that can interfere with the imagination (Dahl et al., 2001).

Visualisations have been shown to be an important tool for supporting decisions, which is applied in the area of planning production systems in a number of ways (Zhu and Chen, 2008). Using visualisations for collaborative planning of production systems enables for example better teamwork (Pehlivanis et al., 2004). This collaborative planning makes it possible to include personnel from different areas of companies in the decision-making, which enables the possibility to use their experience when visually evaluating a complex set of sub-solutions (Okulicz, 2004). How visualisations are presented is important to understanding, for example, when visually evaluating layout alternatives users obtain better perspectives if 3D models are used compared with traditional 2D models (Iqbal and Hashmi, 2001). When using visualisations during planning meetings it is important to collect information from the discussion right away, otherwise such information will be lost (Saadoun and Sandoval, 1999). This collecting can be made by making changes in the model during the meetings, for example by using a quick modelling process, which has been shown to enable effective decisions (Pehlivanis et al., 2004).

The use of visualisations has shown to be important in also other areas than planning of production systems. Such an example area is city planning where visualisations of future cities are important to make the right decisions (Abdul Ghani, 2012; Halatsch et al., 2009). Virtual representations of cities are created to visualise the planned situation to project groups or wider audiences, for example the citizens (Abdul Ghani, 2012; Halatsch et al., 2009). Another area where visualisations are used for decision support is the constructing of new buildings. In this area Building Information Modelling (BIM) is used to plan the building (Azhar, 2011). The main benefit with BIM is presented as accurate geometrical visualisations, time-effective processes, better design along several others (Azhar, 2011). The average return of investment for BIM in projects is stated as 634%, which is due to the cost saving that is a result of such models (Azhar, 2011).

2.2 Systems for visualising virtual representations

There are a number of technical systems identified in the literature of how to present visualisation of virtual representations to single users or a group of users. The two main concepts identified are Virtual Reality (VR) and Augmented Reality (AR). The main differences between these concepts are that VR is based on only virtual representations, compared with AR that uses virtual representations in combination with the real environment. Within these concepts, several systems are available that could be used for visualising the virtual representations. These systems and a main description of the concepts are presented briefly in this section.

2.2.1 Virtual reality

VR is defined as a 3D virtual environment that is rendered in real time and controlled by the users (Loeffler and Anderson, 1994). The aim is to give users a feeling of being inside the virtual environment, using some sort of display to visualise the 3D virtual environment (Korves and Loftus, 1999). The motivation to start using VR was the insufficient information presented by traditional 2D models (Smith and Heim, 1999). VR makes it possible to make accurate and rapid decisions based on the virtual representations presented in the VR environment (Smith and Heim, 1999).

There are four main traditional types of technical systems used in the area of VR: Computer display, Head-Mounted Display (HMD), Power wall, and Cave Automatic Virtual Environment (CAVE) (Menck et al., 2012). Computer display is the simplest and most cost effective VR system, which is mostly suitable in single-user scenarios (Menck et al., 2012). The virtual representation is presented on the display and the user interacts with the model using moving aids such as a computer mouse (Menck et al., 2012). To increase the feel of being inside the virtual representation, HMD can be used (Duarte Filho et al., 2010; Menck et al., 2012). Such displays are worn like glasses and the user interacts with the model with for example VR-gloves (Duarte Filho et al., 2010; Korves and Loftus, 2000). For collaborative teamwork, large-scale displays such as Power walls can be used to visualise virtual representations (Waurzyniak, 2002). Power walls make it possible to work in the same way as engineers would have done around a drafting table, but with virtual representations (Waurzyniak, 2002). Another system for collaboration with full interaction is using the CAVE system, which is a multi-projector system where the users have displays presenting the virtual environment on all sides as presented in Figure 2-1 (Duarte Filho et al., 2010). In such a system, the user gets the true feeling of being inside the virtual environment. Such a system could be used for modelling, reduction and conversion, visualisation, interactive and collaboration (Duarte Filho et al., 2010).

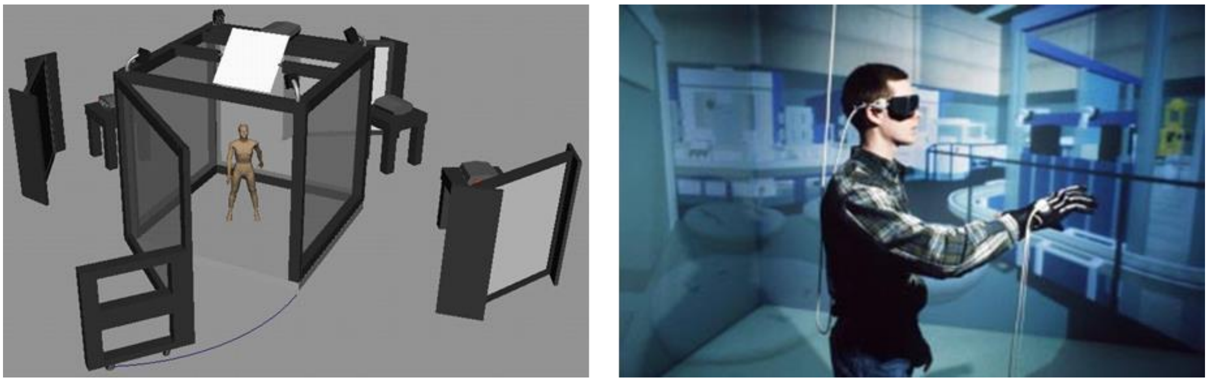

Figure 2-1: To the left a schematic illustration of the CAVE system and to the right a person using a CAVE system with AR-gloves (Cabral et al., 2005; Kelsick et al., 2003)

In the last couple of years, multi-touch tabletop displays have been an alternative for presenting, controlling, and modifying virtual representations (Zöllner et al., 2008). Such displays will enable people to collaborating and interacting intuitively with the virtual representations (Halatsch et al., 2009). However, the number of people that can be collaborating will be limited to the available space around the display. An example of a system that uses such displays is the visTABLE, which provides an 2D layout on the display and in the meantime presents a 3D CAD model of the production system on a projector (Neugebauer et al., 2011).

The use of VR for when redesigning production systems is rather wide, such an example is to present the result to decision-makers (Dangelmaier et al., 2005). VR can also be used when planning the operation of production systems and training of shop floor personnel (Schenk et al., 2005). Another similar use of VR is when carrying out workshops on continuous improvement process (Aurich et al., 2009). The workshop can be made parallel to the real production process, where changes are made virtually and later translated to the real production system (Aurich et al., 2009). However, even if the VR technology has good potential in visualising virtual representations of production systems there is still the problem of how to gather the data for the virtual representations.

2.2.2 Augmented reality

AR combines real environments and virtual representations in real time, by augmenting virtual representations onto the real environment when the AR application identifies some sort of target (Doil et al., 2003; van Krevelen and Poelman, 2010). There are a number of targets that can be used, for example pictures, frame markers, or GPS coordinates (van Krevelen and Poelman, 2010; Ong et al., 2008). In Figure 2-2, this is exemplified using the camera of a smartphone to identify frame markers as the target and augmenting the virtual representations at the locations of the targets. A motivation for using such AR is to be able to validate virtual representations in real environments (Nee et al., 2012).

Figure 2-2: Example of AR using frame markers and a smartphone

A number of AR technical systems have been developed during the last decades, which are today most often mobile devices such as tablets or smartphones (van Krevelen and Poelman, 2010). Previous AR systems were most often built around HMD, projectors, and hand-held displays with limitations in performance and mobility (van Krevelen and Poelman, 2010). Studies have shown that users prefer to use hand-held displays when collaborating with other users the view area becomes wider and the possibility to see what other people are pointing towards (Billinghurst et al., 2003).

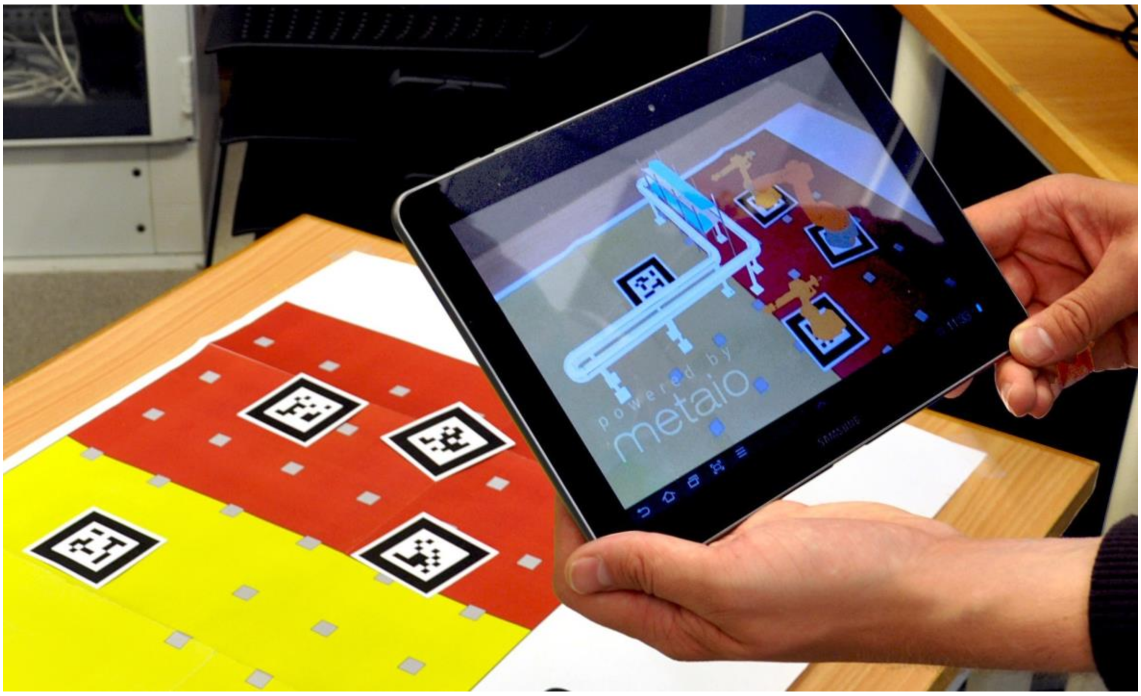

Figure 2-3: Example of layout planning using AR

In the production area, AR can be used for modelling and evaluating different redesign alternatives (Dangelmaier et al., 2005). Layout planning is a task that can be solved using AR, as demonstrated in Figure 2-3. Such an approach is for example addressed in the tool AR-plan, which is presented as a tool to be used for planning of different areas of a production system using AR technology (Doil et al., 2003). Other than layout planning, this tool can for example used to plan workplace environments and robot cells (Doil et al., 2003). Another industrial example comes from the AR company metaio that presented a case study from the robot manufacturer KUKA where AR is used for layout verification (metaio GmbH, 2014). This system is based on photographs of the real environment that are used in the AR application to augment 3D CAD models onto these photographs (metaio GmbH, 2014). AR seems promising for visualising virtual representations of production systems and compared with VR, it can provide a realistic and accurate view of the real production systems but may be mostly suitable for minor redesign changes.

2.3 Visualising production systems using simulation

Simulation is defined as an imitation of the operation of a process or system over time (Banks, 1999). The simulation models can be used as a problem solving approach for many problems in real-world or conceptual systems (Banks, 1999). In this thesis, the simulation of production systems is concerning Discrete Event Simulations (DES). DES is a simulation method used where events in the model are occurring at discrete points in time (Banks, 1999). For example, the process-times for machines are isolated events that occur along with the run time of the simulation.

DES models can be created to visualise the simulated systems, as exemplified in Figure 2-4 (Banks, 1999). The first visualisations were made in 2D, however, during the last decades visualisations in 3D have become frequently used (Jain, 1999; Rohrer, 2000). To create the visualisation, models are either imported as CAD models or through predefined model libraries (Jain, 1999). Visualisation of DES models are important for the verification and validation process, understanding and communication of results, getting buy-in from nonbelievers, and to achieving credibility for the DES model (Banks, 1999; Jain, 1999; Rohrer, 2000). These instances derive from the increased possibility to understand DES models, which could be related to interactivity, realism, performance, flexibility, and ease-of-use (Rohrer, 2000). As for the example with validation this process is typically done by presenting the DES model to a group of individuals with different expert knowledge (Robinson, 1997). The visualisation will in such process be important for the understanding in the group that then could make comments regarding the validity of the models (Rohrer, 2000). It will also become easier to sell to persons sceptical of simulation as well as help in achieving a higher credibility from those who already are believers (Rohrer, 2000).

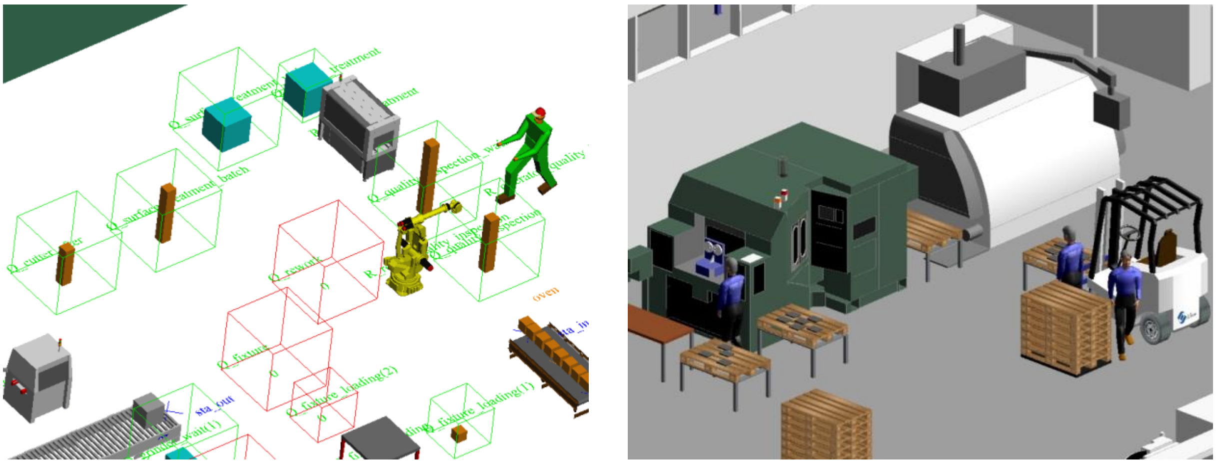

Figure 2-4: Example of visualisation from two different DES applications

There have been a number of efforts during the last decades to increase the understanding and user experience using visualisation of DES models. An example of how to improve the understanding of DES models is influences from the gaming industry, where textures are added to the parts in the models (Bijl and Boer, 2011). This has shown to be one of the most important features for marketing, validation, and analysis of DES models (Bijl and Boer 2011). To improve the user experience DES models could be presented in a VR environment. Such an example is the VRFactory project, where the users get the impression of being inside the DES model using an HMD and interacting with the model using VR-gloves (Kelsick et al., 2003). The purpose of this project was to enable for easy to understand visualisations and interactions with the DES models (Kelsick et al., 2003).

2.4 Realistic visualisations

Traditional methods for creating virtual representations of production systems are time consuming and result most often in representations with low accuracy (Gregor et al., 2009). To create virtual representations that are realistic and with high accuracy there is a need for capturing spatial data of existing production systems, which can be achieved using non-contact 3D imagining techniques (Gregor et al., 2009; Sansoni et al., 2009). Of the 3D imagining techniques presented in Table 2-1, Photogrammetry and Time of flight are promising for capturing building environments (Klein et al., 2012; Sansoni et al., 2009). The Photogrammetry technique uses photos of the physical environment to create virtual representations and the Time of flight technique creates virtual representations using laser to measure distances in the physical environment (Klein et al., 2012; Sansoni et al., 2009). Out of these two techniques, Time of flight is found most suitable for capturing production systems, mainly due to the higher accuracy (Sansoni et al., 2009). This technique is applied in a number of available 3D laser scanners, however these scanners are typically used for scanning scenes beyond hundred metres (Dassot et al., 2011). When capturing production systems, it is important to also be able to capture objects that are within a range of one or a few metres. Phase-shift is an alternative technique that can capture objects within a half metre, which is also applied in a number of available 3D laser scanners (Dassot et al., 2011). Gregor et al. (2009) describes 3D laser scanning in general to be promising for capturing large production facilities. The following sections will describe how 3D laser scanning can be used to create realistic visualisations of production systems.

Table 2-1: Classification of 3D imaging techniques (Sansoni et al., 2009)

	Triangulation	Time delay	Monocular images	Passive	Active	Direct	Indirect	Range	Surface orientation
Laser triangulators	X				X	X		X	
Structured light	X				X	X		X	
Stereo vision	X			X		X		X	
Photogrammetry	X			X		X		X	
Time of flight		X			X	X		X	
Interferometry		X			X	X		X	
Moiré fringe range contours			X		X		X	X	
Shape from focusing			X	X	X		X	X	
Shape from shadows			X		X		X	X	X
Texture gradients			X	X			X		X
Shape from shading			X		X		X		X
Shape from photometry			X		X		X		X

2.4.1 3D laser scanning

3D laser scanners operate by emitting laser beams and capturing their returned reflection to measure the travelled distance (Klein et al., 2012). Each captured reflection represents a sample of the surface of the closest object along the measurement direction, which is referred to as a measurement point (Klein et al., 2012). The measurement points store information about the position in x, y, z coordinates and intensity (Staiger, 2003). The 3D laser scanners have a typical field of view in the horizontal axis of 360 degrees and in the vertical axis of 300 to 320 degrees, which is shown in Figure 2-5 (Dassot et al., 2011). By systematically capturing measurement points in the field of view, the scanner generates a complete geometrical representation of the environment. This systematic capturing is referred to as a scan in which the 3D laser scanners have the capability to gather tens of millions of measurement points during a few minutes (FARO Technologies, 2013; Klein et al., 2012). For enhanced visualisation each measurement point can be complemented with information about the colour based on the RGB colour model, which is generated from photos taken by a built-in camera during each scan (FARO Technologies, 2013).

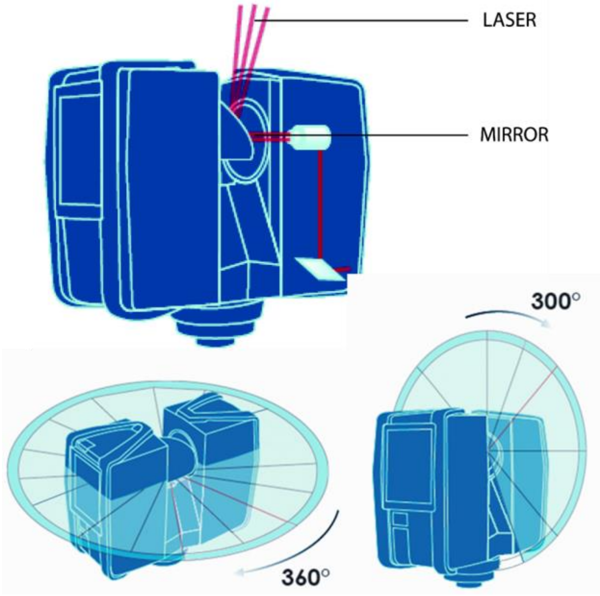

Figure 2-5: 3D laser scanning capturing (FARO Technologies, 2013)

The process of creating a representation of a complete environment, most often requires scans from a number of locations. To make it possible to combine two scans into one dataset, at least three corresponding reference objects need to be visible in both scans to combine them successfully (FARO Technologies, 2013). The reference objects can for example be white spheres or black and white checkerboards, as presented in Figure 2-6.

Figure 2-6: In the top left a close-up of the FARO Focus3D 120 phase shift laser scanner, bottom left the reference objects, and to the right the 3D laser scanner mounted on a tripod

The scanning process can be divided into three steps, as follow (FARO Technologies, 2013):

1. *Prepare scanning* - The locations of the scanner and reference objects are planned to ensure that all necessary data can be captured. It is important to consider the line of sight from the scanner to the objects of interest as well as the line of sight to the reference objects. To capture a production facility with its many interior objects such as machines and material facades it is necessary to scan from several locations.

2. *Perform scanning* - Locate the scanner at the planned locations and execute the data capture. For good results, it is important that the environment remains motionless throughout the scanning process. With the scanner used in this research, a typical setting for an indoor scan will result in 20-40 million measurement points in RGB colour in five to seven minutes.

3. *Process scan data* – The scans are aligned and combined into one dataset in a semi-automated registration process. This alignment is done using the reference objects or other specific building objects.

The above process results in a dataset representing the scanned environment. The size of the dataset depends on the resolution setting in the scanner and may vary between a few thousands to billons of individual measurement points (FARO Technologies, 2013). This dataset can be used to generate a point cloud, which consisting of all the individual measurement points. The resulting point cloud can be made sparser by filtering away a percentage of the points (FARO Technologies, 2013). This reduces data size and can be done to various degrees depending on the target application and processing performance. The point cloud can also be cleaned from any unwanted measurement points. Examples of unwanted measurement points are sensor noise and partially captured moving objects. Typical additional operations performed on point clouds are objected based selection and bounding of a subset of points. Such selection can for example be used to separate a robot from the overall point cloud and save it as a stand-alone point cloud, as exemplified in Figure 2-7.

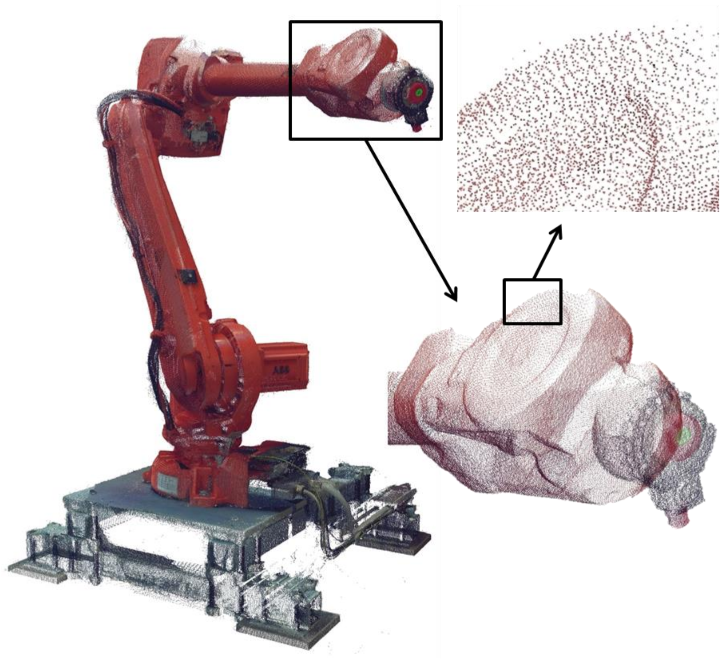

Figure 2-7: Point cloud representing a robot and a close-in of the surface

In the area of production some of the applications of 3D laser scanning are reverse engineering and rapid prototyping, part location and alignment, virtual assembly, flexible robot automation in assembly, welding, surface treatments, dimensional measurement, and quality control (Bi and Wang, 2010; Sansoni et al., 2009). A number of manufacturing companies have also applied 3D laser scanning in day-to-day work for production planning, such as the Volvo Cars Corporation who have used 3D laser scanning for the last 10 years (Alpman, 2013). By using the point clouds for the main layout of their factories they can ensure accurate planning when redesigning their production systems, such as when implementing new car models (Alpman, 2013). 3D laser scanning is also used across a number of other fields such as heritage documentation, forensics, and tunnel mapping (Bi and Wang, 2010; Sansoni et al., 2009).

2.4.2 Visualisation of 3D laser scan data

There are several approaches available of how to visualise 3D laser scan data. The two main approaches addressed in this thesis are to visualise individual scans as panoramic views or the entire datasets as point clouds. Visualising individual scans as panoramic views can be described as looking at spherical 360 degrees photos, which can be compared with how for example Google street view works. By virtually assuming actual scan locations it is possible to make measurements and study the scanned environment in detail. Panoramic views can be provided in standalone desktop applications or web-based applications. The web-based application FARO SCENE Webshare, presented in Figure 2-8, provides an overview map to visualise the layout of the scanned environment in 2D (FARO Technologies, 2014). There are also examples of web-based applications where 3D CAD models can be included in the panoramic views, such as Quantapoint Digital Facility (Quantapoint, 2014).

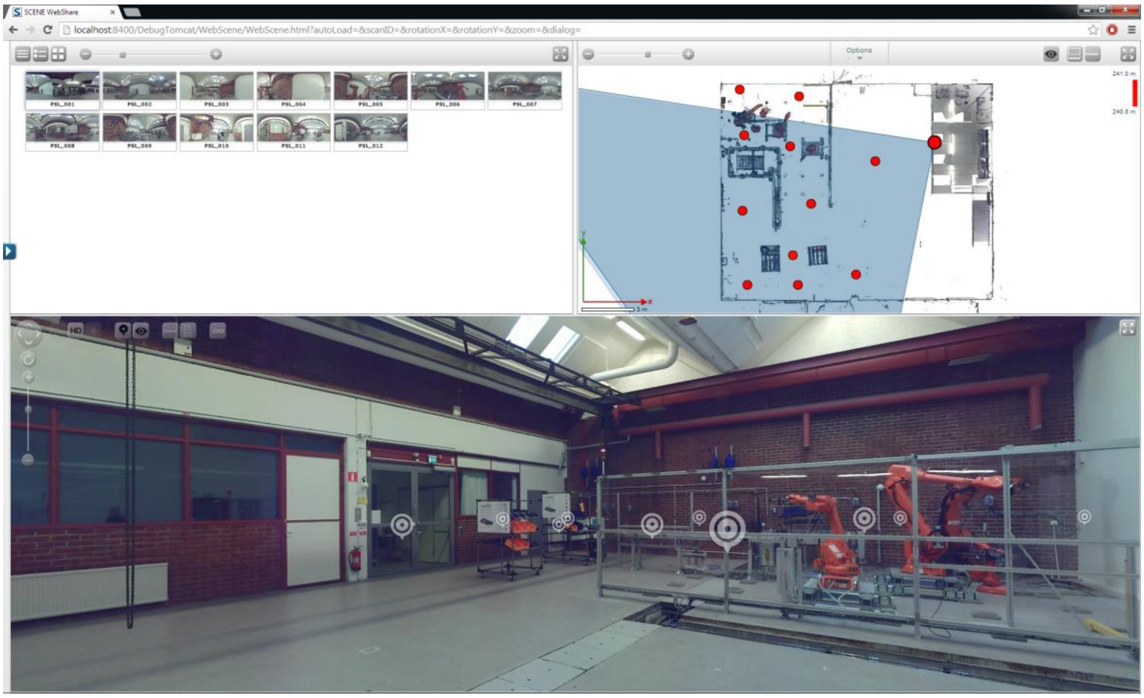

Figure 2-8: Panoramic view from one scan location in FARO SCENE WebShare

The approach of visualising 3D laser scan data as a point cloud enables the possibility to move freely through the scanned environment in 3D and analyse the scan data in close detail. An example of such desktop application is FARO SCENE, which is exemplified in Figure 2-9 (FARO Technologies, 2014). Using this approach makes it possible to visualise changes in the scanned environment by translating subsets of the point cloud or by adding 3D CAD models. There are also examples where point clouds are presented using a web-based application such as the Potree (Schütz, 2014).

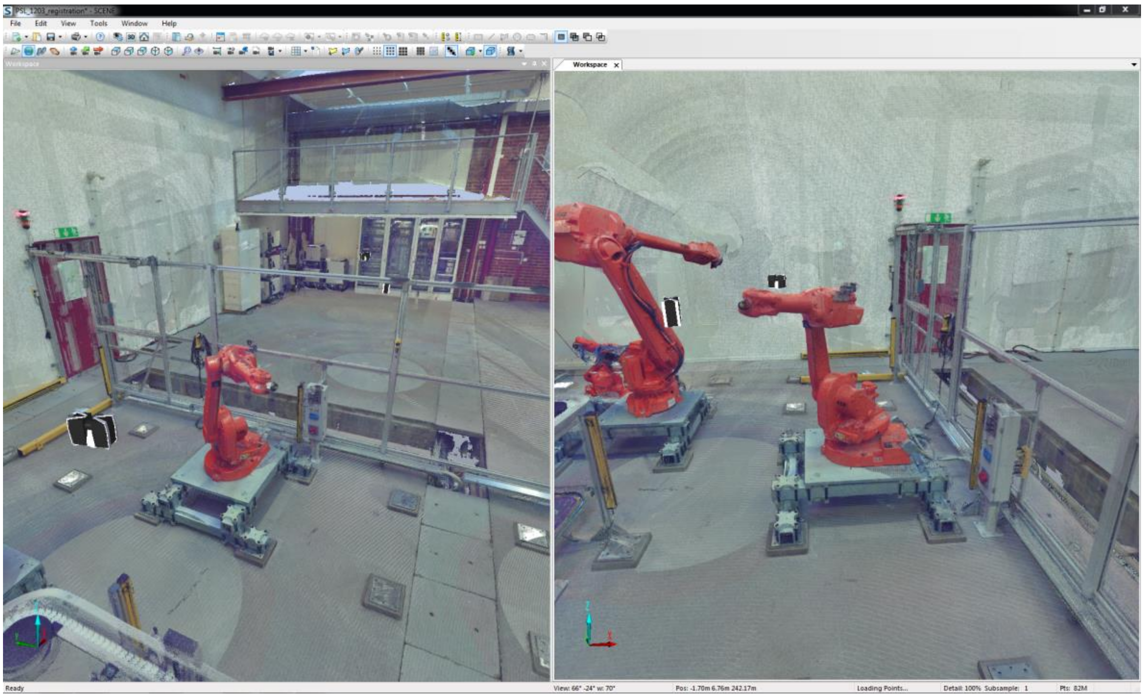

Figure 2-9: Point cloud in FARO SCENE

3 Research approach

This chapter includes the research approach for this thesis, which contains the process and methods applied to answer the research questions.

To understand the possible benefits of using realistic visualisation to support the redesign process of production systems, this thesis has required several activities as introduced in Section 1.5. These activities have mainly followed a qualitative research approach, which is described as one of the main approaches for data gathering along with the quantitate approach and the mixed methods approach (Creswell, 2014). The qualitative approach was chosen due to the possibility of gathering personal data from the employees at the company. Within this approach, a number of research designs can be applied (Creswell, 2014). For the industrial studies the research design applied in this thesis was *Action research*, which is presented as an overall description of the research (Crowther and Lencaster, 2008). This research design was chosen due to the possibility of building and analysing industrial scenarios in groups of individuals. *Action research* is typically described as a cycle where the process is iterated to reach the research aim, as presented in Figure 3-1 (Oosthuizen, 2002). This process could also be described as a spiral to represent the on-going iterative process (Hayes, 2011). By using such process, it was possible to carry out several industrial studies where the result from each study leads to the next study. In the industrial studies, *Action research* design made it possible for the researcher to be a part of the group that is studied and applying a variety of research methods to collect the data (Crowther and Lencaster, 2008; Oosthuizen, 2002).

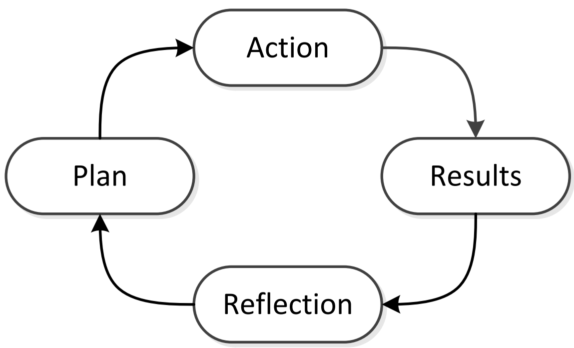

Figure 3-1: A typical Action research cycle, adapted from Oosthuizen (2002)

The purpose with the industrial studies was to evaluate how to create and apply realistic visualisation using 3D laser scanning one-step further in each study. The *Action research* design enables the result from each study to be used in the plan of the next study. To collect data from the studies different research methods were used, which are presented in the next coming sections. The literature study and the workshops were used as a theoretical and practical support to the industrial studies. All activities were carried out with the purpose to answer the research questions and reach the aim. As presented in Figure 3-2, the industrial studies are supporting one or two of the research questions.

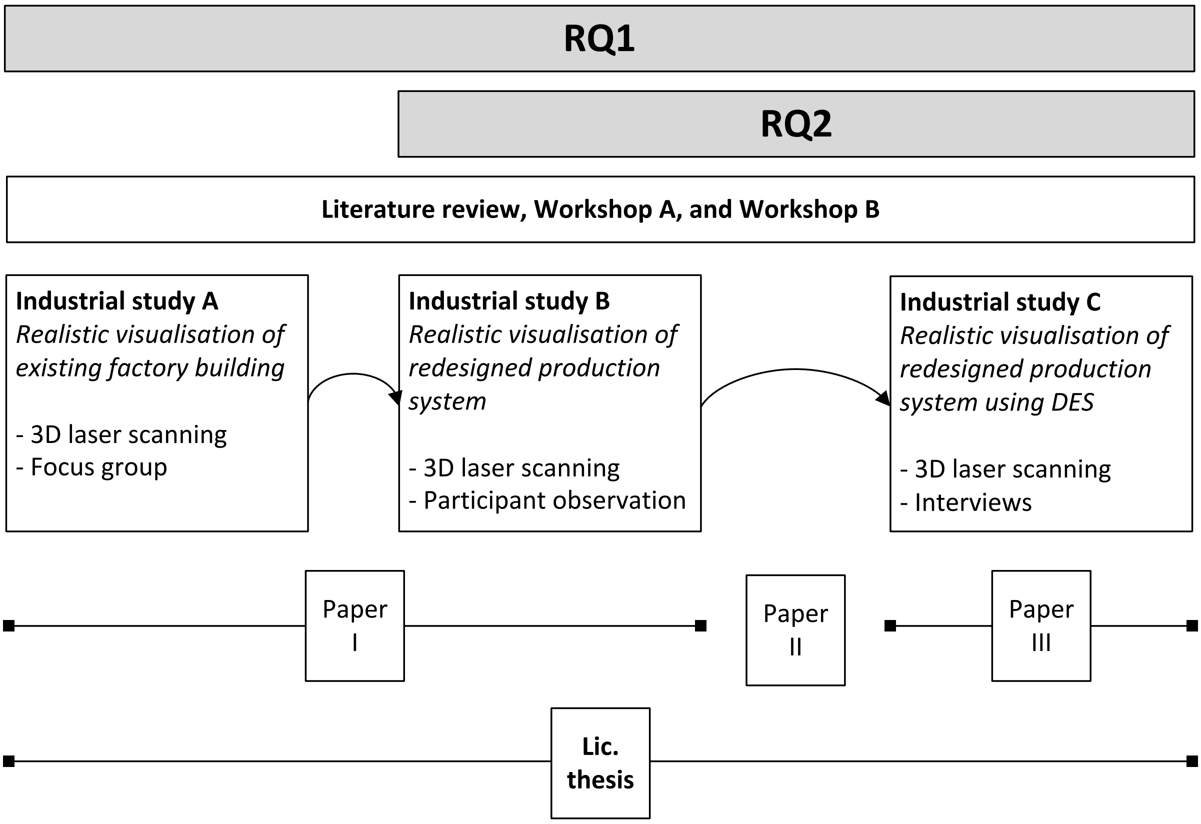

Figure 3-2: The relation between research questions, industrial studies, appended papers, and this thesis

3.1 Workshop A and B

The two workshops were carried out at the company with the aim to gather as much information as possible from employees working daily with redesigning production systems. The workshop method was used to make it possible to gather a significant amount of information in just a few hours. Compared with other data collection methods such as questionnaires, surveys, and interviews, this method was seen as a time-effective alternative.

Workshop A was carried out in May 2012 at the company's main factory in Sweden. The group of participants at *Workshop A* consisted of eleven employees. *Workshop B* was carried out in October 2012 at the company's factory in Norway with a group of five employees. At the workshops, the participants were answering the following questions (translated from Swedish):

1. *What type of information do you need to support your work tasks?*
2. *How should your information be communicated by visual aids?*

3.1.1 Keyword mingling method

The method used at the workshops was adapted from the *Keyword mingling method* (Berlin et al., 2012). This method was chosen due to the possibility to get a wide answer in a group of participants with different work responsibilities and backgrounds (Berlin et al., 2012). The method enables participants to present their own thoughts about the questions and discuss them in groups. Berlin et al. (2012) compares the method with the Delphi method that has the same aim to gather experts and consensus (Williamson, 2002). The main difference is that the Delphi method focuses on surveys and that the process should be held anonymous, but with the *Keyword mingling method* it is possible to track all data back to the participant (Berlin et al., 2012). The focus in the *Keyword mingling method* is on that participants are working together in real-time within a specific topic by presenting their individual thoughts as keywords on sticky notes (Berlin et al., 2012).

3.1.2 The workshop process

The workshops started with an introduction of the background to the workshops, a presentation of the participants, and some inspirational examples of how visualisations are used in other business areas. After the introduction, each participant was given a bunch of sticky notes. These sticky notes had different colours to make it possible to track the comments back to the participants when analysing the data. During *Workshop A*, the group was divided into smaller groups consisting of three to four participants with related work responsibilities. This was not possible during *Workshop B* due to the lower amount of participants. The workshop questions stated in the beginning of Section 3.1 were addressed in the workshops using the process presented in Table 3-1. This process was carried out twice at each workshop, one for each question. Step 3 and 4 were not possible during *Workshop B* due to only one small group of participants. The process presented resulted in a large number of sticky notes, which were documented at the end of each workshop. This documentation was made in spreadsheet documents linking individual keywords to the arranged category and responsible participant. The keywords were analysed by the categories, the participants work responsibility, and the most frequently used words.

Table 3-1: The seven steps of the workshop process

Step	Workshop activity
1	The participants wrote their individual answers to the workshop question as keywords on sticky notes.
2	In the small groups, the individual keywords were discussed.
3	The sticky notes from each group were organised on a whiteboard alongside the other groups. (Only *Workshop A*)
4	Representatives from the small groups were presenting their group's sticky notes, which were discussed with the other groups. (Only *Workshop A*)
5	In the large group, the participants were rearranging the sticky notes from the small groups in categories reflecting similar keywords. They were also writing a heading to each category.
6	The categories were adjusted according to a discussion in the large group.
7	Each participant was ranking the categories by giving out points; 3 points for the most interesting category, 2 points for the second most interesting category, and 1 point for the third most interesting category. The points were added up to make an overall ranking of the categories.

3.2 Industrial study A

Industrial study A was carried out during the second half of 2011 at the company's main factory in Sweden. The aim of was to evaluate the possibility of using 3D laser scanning to provide a realistic visualisation of an existing factory building. This evaluation was made by scanning a factory building where the company was currently running a redesign project with the aim to create a flow oriented production system. As for the time of the study, the project was in the phase of starting the installation of new machines and equipment in the factory building.

3.2.1 3D laser scanning

The aim with the scanning was to cover spatial data of the factory building, such as walls, ceiling, and pillars. This scanning was carried out during four hours with a FARO Focus3D 120 phase shift laser scanner according to the process described in Section 2.4.1. The scanner was set to a resolution of 1/5, quality of 3x, and speed of 244 000 points per second. During the scanning, 139 millimetres white spheres were used as reference objects. To attach the reference objects, 15 fastener plates were mounted at different locations in the building. The fastener plates ensure that the same coordinate system can be used in future scanning of the same building. The area of the scanned building was approximately 3500 m^2 and required 13 scan locations. The result and possible applications of using the 3D laser scan data to visualise existing production systems were discussed in the *Focus group*.

3.2.2 Focus group

The 3D laser scan data of the factory building was visualised in a *Focus group* consisting of eight employees at the company working with planning and implementing the redesigned production system. The *Focus group* method was chosen because of the possibility to time-effectively collect ideas and insights from the participants. *Focus* *groups* are described as a data collection method used to listen and gather information regarding a specific topic such as an issue, service, or product (Krueger and Casey, 2000; Morgan, 1996). This with the aim to gather as much experience as possible without pressuring the participants to reach consensus (Krueger and Casey, 2000). To make this possible, the moderator is described as having an important role of leading the discussion in the right direction (Krueger and Casey, 2000). During the *Focus group*, the moderator of the discussion was the leader of the research project and the co-moderator the author of this thesis. The co-moderator presented the two main approaches of how to visualise the 3D laser scan data of the factory building, as presented in Section 2.4.2. This presentation was carried out using a computer connected to a projector. The participants discussed the two a and suggested possible areas of application in their work of redesigning production systems. The result from this discussion was analysed, which lead to the planning of the next study.

3.3 Industrial study B

Industrial study B was carried out during the second half of 2012 at the company's factory in Norway. The aim was to evaluate how a redesigned production system could be visualised based on the 3D laser scan data. This evaluation was carried out by scanning a section of the existing production system that was planned to be redesigned. The plan was to move an old machine to an empty location in the factory and install a new machine in the previous location of the old machine. This was the first step in a large redesign project of the production system with the overall aim to create a better production flow. As for the time of the study, a layout alternative for the machines' locations did exist but was not validated.

3.3.1 3D laser scanning

The aim with the scanning was to gather as much spatial data as possible of the existing production system and the surrounding factory building to be able to create a realistic visualisation of the production system with high accuracy. This scanning was carried out during six hours with a FARO Focus3D 120 phase shift laser scanner according to the process described in Section 2.4.1. The scanner was set to a resolution of 1/5, quality of 3x, and speed of 244 000 points per second. During the scanning, 139 millimetres white spheres and 150 by 150 millimetres black and white checkerboards were used as reference objects. Tripods and other fastening equipment were used to mount the reference objects. The area of the scanned production system was approximately 1500 m^2 and required 22 scan locations. The resulting point cloud was modified according to the existing layout alternative created by the company. The visualisation of the new location for the old machine was created using two different approaches. First, a 3D CAD model of the machine was imported into the point cloud. Second, the section of the point cloud representing the old machine was translated to the new location in the point cloud. For the new machine and its surrounding equipment, these were imported into the point cloud as 3D CAD models and located in the previous location of the old machine. The redesigned realistic visualisation presented and discussed with a group of employees during the *Participant observation*.

3.3.2 Participant observation

The realistic visualisation of the redesigned production system was presented at a project meeting regarding the redesign using a projector connected to a computer. The participants at the meeting were a group of five employees with different relations to the production system, as presented in Table 3-2. During the meeting, the author of this thesis was acting as a *Participant as observer* which is described as an observer that interacts quite extensively with the participants (Bow, 2002). There are four levels of observations, *Complete observer*, *Observe as participant*, *Participant as observer*, and *Full participant* (Bow, 2002). To be a *Full participant* the researcher needs to be a member of the group being studied (Bow, 2002). Interaction with the visualisation was necessary in *Industrial study B* due to the technical difficulties of modifying the visualisation of the production system. After presenting the visualisation of the redesigned production system, the layout was discussed in the group. As the participants were discussing the layout, the author of this thesis made changes in the visualisation according to the discussion. The process was documented by the project leader of the research project, who was acting as a *Complete observer*. The observations from the project meeting was discussed and analysed, which resulted in the planning of *Industrial study C*.

Table 3-2: The participants' work responsibilities at the Participant observation

Participant	Work responsibility
1	Manager, Production development
2	Engineer, Production development
3	Engineer, R&D
4	Engineer, Production layouts
5	Machine operator

3.4 Industrial study C

Industrial study C was carried out during the first half of 2013 in a section of the same factory building as in *Industrial study A*. The aim was to further evaluate whether 3D laser scan data can support the redesigning process of production systems by including such data in a DES model of the system. Since the pervious study, a robotic cell for automated x-ray inspection of products had been installed. An identical cell was planned to be installed later the same year to meet the increased production volume. The industrial problem was to identify where to locate the new cell based on conditions such as available space, materials handling, work environment, and capacity specifications. This problem was addressed in the study, which was carried out in collaboration with Gustav Jansson and Sebastian Roos as part of their Master thesis work (Jansson and Roos, 2013).

3.4.1 3D laser scanning

The aim with the scanning was to gather as much spatial data of the existing cell as possible and of alternative locations for the new cell. This scanning was carried out during four hours with a FARO Focus3D 120 phase shift laser scanner according to the process described in Section 2.4.1. The scanner was set to a resolution of 1/5, quality of 4x, and speed of 122 000 points per second. During the scanning, 139 millimetres white spheres and 150 by 150 millimetres black and white checkerboards were used as reference objects. Three of the fastener plates mounted in *Industrial study A* were re-used in this scanning to align the data with that of the previous study. Tripods and other fastening equipment were used as well to mount the added reference objects. The scanned area of the building was approximately 1500 m^2 and required 13 scan locations. The 3D laser scan data of *Industrial study B* and 3D laser scan data from *Industrial study A* was combined to create a point cloud including a proposed location for the new robotic cell. This point cloud was imported in to a DES model where the dynamical aspect of the production system was included. The DES model was used to present a realistic visualisation of a possible redesigned production system. *Interviews* with employees at the company were carried out to evaluate the use of the realistic visualisation.

3.4.2 Interviews

The realistic visualisation was evaluated using two possible scenarios of how to use such visualisation to solve industrial problems. The first scenario handled layout and workflow planning of new equipment in different phases of the planning process. In the earliest phase, a point cloud of the empty factory building was used in combination with simplified 3D CAD models to roughly evaluate the location of the robotic cell. The level of details in the 3D CAD model was subsequently increased to mimic the planning process ending in the DES model of the production system. In the second scenario, the realistic visualisation was used to evaluate how new equipment could be installed in the existing production system by duplicating the first robotic cell. The two scenarios were discussed in four semi-structured interviews held by Jansson and Roos (2013). The interviews were based on the following questions:

1. *What virtual and visual tools are being used today in the development process?*
2. *What do you think about the presented scenarios?*
3. *How can the scenarios be related to the redesign process?*

The interviewees were working either directly with the studied production system or in the project group responsible for planning and installing the system, as presented in Table 3-3. Semi-structured interviews provide the possibility to create structured discussions regarding a specific question or topic with one interviewee or a group of interviewees (Dicicco-Bloom and Crabtree, 2006). This structure was selected due to the possibility to investigate a predefined hypothesis in groups consisting of interviewees with similar work responsibilities. At the interview sessions, the interviewers presented the two scenarios to the interviewees using a computer. During the ongoing presentation, possible benefits and drawbacks were discussed. This enabled collection of immediate reflections based on the different phases of the use scenarios. The reflections were sorted as problems with the existing layout planning tool along with benefits and drawbacks with using the realistic visualisation.

Table 3-3: Participants at the four semi-structured interviews

Interview	Participant	Work responsibility
1	1	Manager, Machine acquisition
	2	Project leader, Production development
	3	Engineer, Production facilities
	4	Engineer, Production facilities
2	1	Machine operator
	2	Production technician
3	1	Engineer, DES of production systems
4	1	Engineer, Production logistics
	2	Engineer, Production logistics

4 Results from workshops

This chapter includes the results from the workshops, which have supported the understanding of the need for realistic visualisation in the industrial studies.

The results from the workshops are based on the individual keywords presented in Appendix A from the workshop process described in Section 3.1.2. This chapter presents the points each participant gave the different categories and a summary of the three highest ranked categories for each question and workshop. In the first question, the results cover what type of information the participants find important to have available to complete their work tasks. In the second questions, the results describe how the participants want to communicate their information using visual aids.

4.1 Workshop question 1

Question: *What type of information do you need to support your work tasks?*

4.1.1 Workshop A

As presented in Table 4-1, the three highest ranked categories were *Layout and installation*, *Work environment*, and *Product information*. These categories obtained 71% of the total points allotted to *Workshop question 1* and can be related to the participants' work responsibilities. The category *Layout and installation* was the highest ranked, which can derive from that a major part of the participants being directly involved in the design of production systems. For example, participants working with machine acquisition and facilities find this category very interesting. The category *Work environment* was found interesting by a majority of the participant even though only the work responsibilities of participant 10 and 11 can be directly related to this category. Participants that had work responsibilities related to product development ranked the category *Product information* rather high.

Table 4-1: The relation between points, categories, and participants for Workshop question 1 at Workshop A (translated from Swedish)

Person	Work responsibility	Layout and installation	Work environment	Product information	Production flow	Quotation form	Hardware specifications	Production concepts	Directive
1	Project leader, Machine acquisition	3		2		1			
2	Project leader, Machine acquisition	3	2		1				
3	Project leader, Production facilities	3	2			1			
4	Project leader, Production facilities	3				2		1	
5	Project leader, Industrialisation projects	3			1			2	
6	Project leader, Manufacturing engineering			3	2			1	
7	Engineer, Automation	3		2	1				
8	Engineer, Manufacturing engineering		2	3	1				
9	Engineer, DES of production systems	3	2				1		
10	Head of safety delegates	3	2		1				
11	Engineer, Safety and health	1	2				3		
	Total number of points	**25**	**12**	**10**	**7**	**4**	**4**	**4**	**0**

Summary of the three highest ranked categories

Layout and installation: The focus in this category was on information regarding factory layouts and physical restriction in factories. Such information was described as important to have available for planning and decision-making when developing production systems. Examples of keywords are CAD models, building information, layouts, positioning of equipment, auxiliary media, and available space.

Work environment: In this category, the work environment for shop floor personnel was in focus. The discussion was mainly on how to ensure that the company provides a good work environment in factories. Examples of keywords are workplace design, noise level, lights, ventilations, ergonomics, training, and risks.

Product information: This category covers information that is required to adapt production systems to the product that should be produced. Such information needs to be communicated from the product development department. Examples of keywords are product data, processes, product flow, and function requirements.

4.1.2 Workshop B

As presented in Table 4-2, the three highest ranked categories were *Machine conditions*, *Decision support*, and *Production flow*. These categories obtained 77% of the total points allotted to *Workshop question 1*. Due to the low amount of participants, it is difficult to make any conclusions about the result more that it seems that the categories are related to the participants work responsibilities.

Table 4-2: The relation between points, categories, and participants for Workshop question 1 at Workshop B (translated from Norwegian)

Person	Work responsibility	Machine conditions	Decision support	Production flow	Building conditions	End-user confirmation	Project administration	System	Competence
1	Engineer, R&D	1	2	3					
2	Engineer, Production development	2	3	1					
3	Engineer, DES of production systems	2		1	3				
4	Engineer, Production layouts	2	3				1		
5	Manager, Production development	3			1	2			
	Total number of points	**10**	**8**	**5**	**4**	**2**	**1**	**0**	**0**

Summary of the three highest ranked categories

Machine conditions: In this category, access to information regarding machines and other equipment were found important when developing production systems. This information could for example be regarding conditions of existing or new machines. Examples of keywords are machine requirements, machine specifications, operation type, machine capacity, and geometric data.

Decision support: To make right decisions there is a need to have strategic information available to ensure that decisions are aligned within the company's overall plan. For example when making purchase decisions for new equipment a long time-plan needs to be considered. Examples of keywords are demand for new equipment, cost for new equipment, information on different suppliers, return of investments, future vision, and maintenance cost.

Production flow: The focus in this category was on having the right information available about the existing production flow when making developing production systems. This information could be presented in different formats, such as spreadsheet documents or simulation models. Examples of keywords are simulation of production flows, operation times, transport times, system capacities, and simulation of redesign changes.

4.2 Workshop question 2

Question: *How should your information be communicated by visual aids?*

4.2.1 Workshop A

As presented in Table 4-3, the three highest ranked categories were *Visualisation (what)*, *IT, document, and structure*, and *Application (how)*. These categories were accorded all of the total points related to *Workshop question 2*. The two categories with the highest points were also allotted the highest amounts of 3 points. It is difficult to draw a relation between the categories and participants' work responsibilities, due to an inconsistent pattern of points. Project leaders were in the majority in the group, which could be a reason why the category *IT, document, and structure* was found one of the most interesting.

Table 4-3: The relation between points, categories, and participants for Workshop question 2 at Workshop B (translated from Swedish)

Person	Work responsibility	Visualisation (what)	IT, document, and structure	Application (how)
1	Project leader, Machine acquisition	2	3	1
2	Project leader, Machine acquisition	3	2	1
3	Project leader, Production facilities	3	2	1
4	Project leader, Production facilities	3	2	1
5	Project leader, Industrialisation projects	1	3	2
6	Project leader, Manufacturing engineering	2	3	1
7	Engineer, Automation	3	1	2
8	Engineer, Manufacturing engineering	2	3	1
9	Engineer, DES of production systems	2	3	1
10	Head of safety delegates	3	2	1
	Total number of points	**24**	**24**	**12**

Summary of the three highest ranked categories

Visualisation (what): In this category, the participants sorted keywords covering different types of models used to visualise their information. A conclusion from the discussion was that such models should be easy to access and understand by others. Examples of keywords are 2D models, 3D models, animations, simulation, and flow analysis.

IT, document, and structure: The IT platform should be well structured and easy-to-use where information is shared between different users. The company use today a platform named Teamsite to share some of the information discussed at the workshop. However, the participants did not find the current platform to have the requiring functions and also several isolated information silos. Examples of keywords are were version history, clear directives, easy-to-use tool, shared platform, shard information, and Teamsite.

Software (how): The information should be easy to access within traditionally used applications such as Microsoft Excel and Power Point. Such information could for example be presented as diagrams, picture, and movies. Examples of keywords are Excel, diagram, text, Power Point, PDF, pictures, and movies.

4.2.2 Workshop B

As presented in Table 4-4, the three highest ranked categories were *System analysis*, *Presentation tools*, and *Virtual representations*. These categories obtained 71% of the total points allotted to *Workshop question 2*. The category *System analysis* was found as the most interesting, which may also reflect upon the participants' work responsibilities.

Table 4-4: The relation between points, categories, and participants for Workshop question 2 at Workshop B (translated from Norwegian)

Person	Work responsibility	System analysis	Presentation tools	Virtual representations	Physical objects	Presentation	Operation definition	Analyse tools
1	Engineer, R&D	3			1		2	
2	Engineer, Production development	2	3		1			
3	Engineer, DES of production systems	3				2		1
4	Engineer, Production layouts	2	1	3				
	Total number of points	**10**	**4**	**3**	**2**	**2**	**2**	**1**

Summary of the three highest ranked categories

System analysis: In this category, the keywords described tools used to analyse production systems and for project planning. To redesign production systems, the participants found it important to make proper analyses to find possible problems. Examples of keywords are flowcharts, Gantt diagrams, fishbone diagrams, and function deployment.

Presentation tools: The keywords described physical objects and computer tools used to present and visualise future state or changes to production systems. These presentations could be carried out either in the office environment or at the shop floor. Examples of keywords are tape on the floor, Excel, A3 sheets, Power Point, figures, and photos.

Virtual representations: It was found interesting to use virtual representations to visualise entire or sections of production systems. The virtual representations can for example be used to visualise proposed layouts during project meetings. Examples of keywords are 2D models, 3D models, and drawings.

4.3 Contribution to industrial studies and research questions

The results from the workshops show the interest to share information between experts working with redesigning production systems. The information to share has shown to vary depending on the experts' work responsibilities. However, a shared interest is found in tools used to visualise and analyse production systems. A majority of the participants found it important to have easy access to the information and that the information should be easy to present and understand. During the discussions, focus was towards factory and product information to be visualised. This contributes to the industrial studies as a motivation and framework of what type of information should be visualised. These results and the contribution to the industrial studies is an important step in addressing the research questions.

5 Summary of appended papers

This chapter includes a summary of the appended papers presented along with a description of how these papers contribute to the research questions.

5.1 Paper I

Title: *Visualization Support for Virtual Redesign of Manufacturing Systems*

The aim in *Paper I* is to evaluate how realistic visualisation can support groups of experts when making decisions when redesigning production systems. This evaluation was carried out in *Industrial study A* and *B*, where 3D laser scan data was used to create realistic visualisations of the production systems.

5.1.1 Results from Industrial study A

The 3D laser scanning in *Industrial study A* resulted in an 3D laser scan data of the factory building. As stated in Section 3.2.2, the scan data was visualised in the *Focus group* as panoramic views from each scan location and a point cloud as exemplified in Figure 5-1. When discussing the visualisations in the *Focus group*, participants working with layout planning and machine acquisition found them most interesting. The discussion included a number of problems usually occurring during the redesign of production systems, which could be possible to solve by support of a realistic visualisation. The main problem was described as not having accurate and sufficient information about existing factory buildings available when making decisions. Such information was for example found important when making decisions regarding new layouts, which was traditionally planned and discussed using 2D CAD models. These 2D CAD models were described as not including all necessary information about the factory building and production system. Such information could for example be the height between floor and ceiling or available space for a machine. The lack of information could result in that the participants were required to either go into the factory to see for themselves during planning meetings or postpone the issue to the next meeting. With the support of a realistic visualisation, it would have been possible to study the data and make measurements, in order to solve the issue during the meeting without leaving the room. The participants also found it important to have the two visualisation approaches available to direct different type of users. For example, the web-based application could be suitable for standard users and the point clouds for advanced users.

Figure 5-1: The point cloud representing the existing factory building

5.1.2 Results from Industrial study B

In *Industrial study B,* it was shown that point cloud in combination with 3D CAD models could be used to create a realistic visualisation of the redesigned production system as exemplified in Figure 5-2. The realistic visualisation was presented during the *Participant observation*, as described in Section 3.3.2. By analysing the realistic visualisation created using the proposed layout, the participants realised that the new machine and its surrounding equipment required more space than what was available. With this new information at hand, the group discussed alternative layouts. These layouts were evaluated in the realistic visualisation during the meeting by translating the 3D CAD models and sections of the point cloud to locations suggested by the group. This resulted ultimately in a new layout alternative.

Figure 5-2: The point cloud representing the production system

A known layout issue described during the *Participant observation* was to get new layouts accepted by the shop floor personnel, such as machine operators. When traditionally presenting new layouts using 2D CAD models to the shop floor personnel these most often received approval. However, when the new machine or workstation are installed and the shop floor personnel are fully aware of the new layout they did not always approve it, which resulted in costly redesign activities. This indicates the importance of including a variety of expert knowledge when planning the redesign, where for example shop floor personnel can contribute valuable insights.

The visualisation of the old machine at the new location showed some important differences between the 3D CAD model and point cloud of the same machine. Comparing the 3D CAD model presented in Figure 5-3 with the point cloud in Figure 5-4 some differences can be notified, such as the air flue on the top of the machine that is missing in the 3D CAD model.

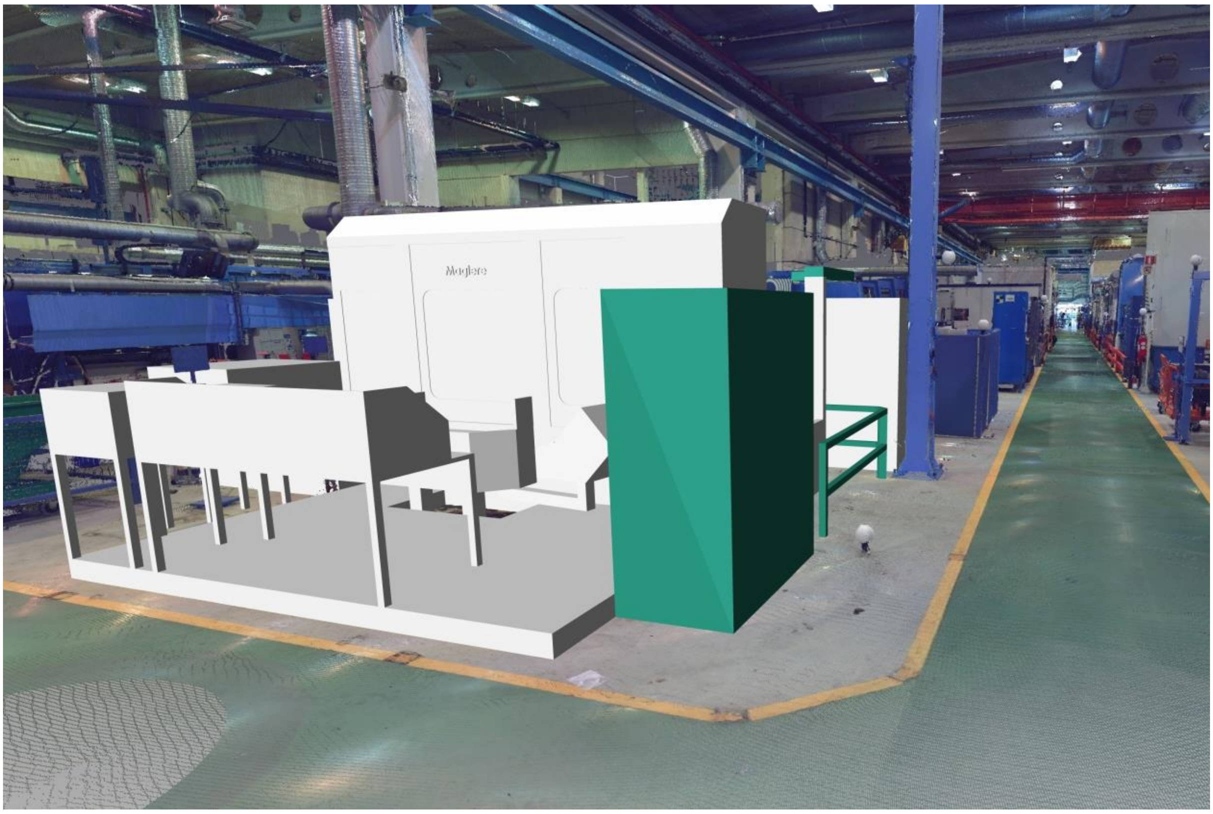

Figure 5-3: The point cloud representing the production system in combination with a 3D CAD model representing the machine

Figure 5-4: The point cloud representing the production system in combination with a section of the point cloud representing the machine (red circle marks the air flue that are missing in the 3D CAD model of Figure 5-3)

5.1.3 Contribution to research questions

The results of *Paper I* contribute to *RQ1* by showing that 3D laser scanning can be used to create realistic visualisations of production systems. These visualisations can enable people with different knowledge and interest to obtain a common understanding of production systems, which has shown to be important in discussions and modelling for decision-making. To support the discussion, point cloud combined with 3D CAD models have shown a possible way of evaluating layouts. Using such a realistic visualisation during project meetings has shown to solve possible problems before implementing redesign changes to the real production system, which contributes to *RQ2*.

5.2 Paper II

Title: *Combining Point Cloud Technologies with Discrete Event Simulation*

In *Paper II*, a theoretical concept is presented where point clouds are used to create DES models. The purpose with this concept is to create DES models that can be used as realistic visualisations of production systems. By implementing such a concept, can reduce the time consumed for creating DES models and make them easier to understand for non-simulation experts.

5.2.1 The concept of point cloud based DES models

As presented in Section 2.3, DES models of production systems are created with different levels of visualisations. The concept presented in *Paper II* uses point clouds to increase the level of visualisations. These point clouds are imported into DES applications as static parts representing sections of existing factory buildings and production systems. Combining the imported point clouds with 3D CAD models for new parts of the production systems have the potential to create realistic visualisations of such systems. This results in realistic DES models based on spatial data from existing factory buildings and production systems.

The main benefit identified with the concept is the possibility to communicate DES models to a wide audience. This possibility increase the common understanding of such models when presenting them for non-simulation experts, who will be able to contribute with their expert knowledge and views of specific problems when discussing and analysing the models. This can be important during the validation and verification process of DES models by finding possible problems earlier. It can also prevent doubts about whether the model is correct or not, which could have taken focus away from more important discussions.

5.2.2 Contribution to research questions

Paper II contributes to this research a conceptual paper and mainly to RQ1 as a concept to be further evaluated. The concept is supported by the theory presented in Section 2.3, which indicates the importance of visualising DES models to get a good understanding and adoption of the result in companies. Furthermore, *Paper II* provides a discussion to RQ2 of how realistic DES models can be used in groups of experts redesigning production systems.

5.3 Paper III

Title: *Lean Based Problem Solving using 3D Laser Scanned Visualizations of Production Systems*

The purpose of *Paper III* is to evaluate how realistic visualisation can be used to solve problems in early on in the redesigning process by supporting groups making required decisions. This evaluation derives from a theoretical framework on problem solving and the lessons learned from the industrial studies. *Paper II* includes the results from *Industrial study C* and a description of how the Lean product development approach LAMDA can be used to solve problems using realistic visualisation.

5.3.1 Results from Industrial study C

The 3D laser scanning presented in Section 3.4.1 resulted in a realistic visualisation of a point cloud based DES model, which is presented in Figure 5-5. This DES model was used in the two scenarios used during the four interviews as stated in Section 3.4.2. The result of these interviews are summarised below.

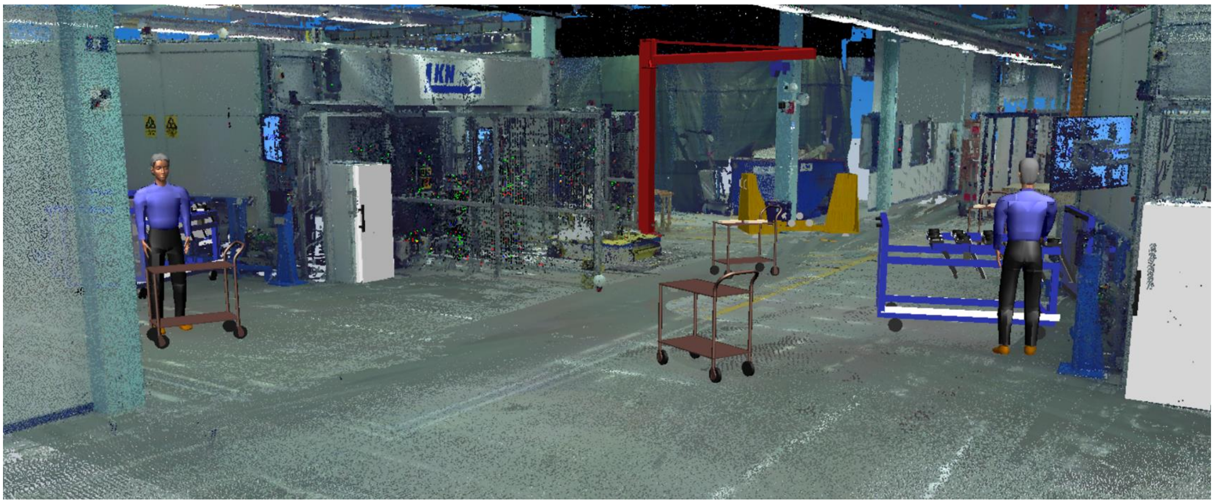

Figure 5-5: The DES model created from point clouds and 3D CAD models

Problems identified with existing layout planning tool

The existing tool used for layout planning at the company was described as 2D CAD models for evaluating and visualising different layout alternatives. In these models, objects such as power cables, pillars, and machine equipment are not always at the right location or even included at all. This causes potential problems during the implementation of the redesign. Another problem described with these 2D CAD models is for everyone included in the planning process to understand them correctly. This results in difficulties to communicate and discuss layout alternatives with other employees in the organisation or with machine suppliers. The solution to this problem was usually manual measurements in the real production system to provide machine suppliers with necessary information. It was seen as an excessively time consuming process to update the CAD models with accurate and sufficient information.

Perceived benefits from using 3D laser scan supported layout planning

The interviewees found that realistic visualisation would enable accurate layout planning when redesigning production systems. Using such visualisation would make it possible to compare layout alternatives with each other by thoroughly investigating each alternative before making any decisions. The realistic visualisation makes it more time-effective to evaluate if equipment fits in with a specified area of the factory compared to using the existing tool. Making this process more time-effective will reduce the risk of working too long with a layout alternative that cannot be realized. The realistic visualisation will also provide decision-makers with easy-to-understand presentations, enabling decisions based on accurate information. It will also support different functions in groups to align their understanding of how a layout alternative actually works, looks, and interacts with other parts of the factory. This will make it easier to involve and educate shop floor personnel the planning. Besides the shop floor personnel employees, it will be less time-consuming to include for example workers' union representatives and safety protection agents in discussions regarding work place design in the same phase of the planning process.

Perceived drawbacks from using 3D scan supported layout planning

The interviewees stated that working with realistic visualisation might increase the risk of spending too much time on creating the visualisation, which can create a risk of losing the potential time gained. For example it might be time-consuming to simulate the workflow for each project and not always necessary. The implementation of realistic visualisation was also deemed critical by the interviewees, due to the risk of it not being used. To obtain good interest and acceptance in the organisation, it is important to explain the benefits and make sure that the right people get to work with it. The interviewees foresee that it can be difficult to determine who should be the owner of the data and who should be authorized to edit the different models. It was also perceived that the 3D laser scan data has a slightly limited area of application compared with CAD models. This because point cloud cannot, at this point in time, be imported and exported between different applications as easily as CAD models.

5.3.2 LAMDA based problem solving approach

The result from *Industrial study C* indicates that realistic visualisations created from 3D laser scan data have the potential to support the layout planning when redesigning production systems, which verifies the lessons learned from *Industrial study A* and *B*. These studies showed that realistic visualisation would make it possible to create a common understanding of the redesigned production system in a group of experts. This common understanding is critical when identifying and solving possible layout planning problems during the redesign process. In the industrial studies, the problem identification and solving were made using the realistic visualisation without any well-defined work approach. To make the process more effective the problem solving approach LAMDA used in Lean product development was suggested. This approach is presented as an iterative process including five steps of how to solve a problem, as presented in Figure 5-6 (Ward, 2007). By applying this approach, it is possible to solve problems by evaluating and improve the realistic visualisations in a group of experts. The five steps of the approach are applied in the context of the industrial studies by reflecting on lessons learned in these studies, as presented in Table 5-1.

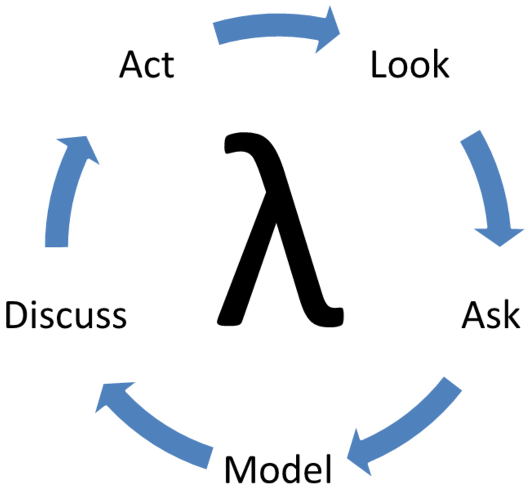

Figure 5-6: The LAMDA problem solving approach cycle, adapted from Ward (2007)

Table 5-1: A description of how the realistic visualisation can be utilized in the steps of the LAMDA cycle

Step	**Description of use in industrial settings**
Look	The realistic visualisation enables everyone in the group to get a common understanding of the redesigned production system.
Ask	Using the realistic visualisation will make it possible to make a qualified assessment of the situation, ask relevant questions, and identify problems or risks.
Model	Changes are made to the model based on identified problems or risks. These changes could be moving machines or other equipment by modifying the point cloud or adding CAD models.
Discuss	The updated model is used as basis for discussion to define and analyse the solutions and arrive at alternatives to improve.
Act	The defined solution is implemented in the final model, which is visualised in the group to verify the effectiveness. The process is then repeated until no future problems or risks are identified.

5.3.3 Contribution to research questions

Paper III contributes to both research questions to some extent. To *RQ1* is *Paper III* contributing by implementing and evaluating the concept of point cloud based DES models as presented in *Paper II*. By using this concept, an extra dimension adds to group discussions. *Paper II* also verifies the result from *Paper I* and especially *Industrial study B*, which contributes to *RQ2*.

6 Discussion

This chapter includes a discussion of how the results of this thesis relate to other research in the area, the research approach, and future work.

The research towards this thesis has followed the overall aim of using realistic visualisation to support the process of redesigning production systems, in order to reduce the required time for planning and implementation. In the three industrial studies, scenarios were identified where realistic visualisations can support the decision-making during the planning. This support has resulted in mainly effective problem solving and evaluation of layout alternatives, which have the potential to reduce the required time. The possibility to evaluate layout alternates was found most important by a strong majority of the participants at *Workshop A*. Such layout evaluation was for example applied in *Industrial study B*, where the realistic visualisation was used to find problems with the layout alternative created prior to the study. If the company had implemented the redesign according to the earlier layout alternative, problems would probably have occurred during the implementation. These problems would have resulted in extra time during the implementation, which were avoided by support of the realistic visualisation. Measuring the actual time reduction can be difficult due to the uniqueness of each redesign process and difficulties of ensuring that problems would not have been found as well in the use of traditional tools. However, for each redesign consideration supported by realistic visualisation there is a possibility of reducing the required time.

The 22 experts involved in the industrial studies showed a positive interest in using realistic visualisation to support different parts of their work. The main benefit identified with realistic visualisation was the possibility to gain access to virtual representations of entire production systems that are easy to understand. As stated by Dahl et al. (2001), the understanding of a visualisation is objective and each expert will create their own understanding based on a number of factors such as previous experience and knowledge. However, making the visualisations realistic can reduce the differences in how they are understood. With similar understandings of the redesigned production system, experts will have the opportunity to present their thoughts about redesign considerations to other experts. As stated by Ware (2009), there are several aspects to consider when creating such visualisations and making them easy to understand. These aspects are addressed along with the time consumption and the accuracy of the result, by using 3D laser scanning to capture spatial data of production systems. Nevertheless, the most important aspect may be how to make the best use of the realistic visualisations.

6.1 Realistic visualisations created by 3D laser scanning

RQ1 covers the problem of how to create realistic visualisations. This problem was addressed using 3D laser scanning, which was applied in the three industrial studies by creating realistic visualisations of the production systems. That 3D laser scanning is promising for capturing spatial data of production systems has been stated previously by for example Gregor et al. (2009). The difference between their approach and the realistic visualisations in this thesis is that they proposed an approach of using grey scale point clouds to create 3D CAD models of the production systems, as compared with using the point clouds as the realistic visualisations. This difference may relate to the possibility of using coloured point clouds, this being one of the latest technology changes within 3D laser scanning. This opportunity makes the point clouds and 3D laser scan data more suitable for visualisations in general. Alpman (2013) described a similar approach to the realistic visualisation used at Volvo Car Corporation, where their main factory layouts are based on point clouds.

The main benefit identified with 3D laser scanning is the possibility to capture an entire production system or factory building with an accuracy of a few millimetres within a couple of hours. For example, in the industrial studies, each production system was scanned during less than a workday. The required time for each scanning can be related to factors such as the size of the production system, number of scanner locations, and required scanning resolution. The time for processing the scan data is more difficult to estimate, and depends mainly on how well the scanning process was carried out and how the scan data should be used. For example, if the purpose is to create a realistic visualisation of the existing production system as in *Industrial study A*, this will be ready in a couple of hours. This time can be compared with for example, creating a DES model as in *Industrial study C*, which will require considerably more time due to required time for creating the simulation logic. The time for capturing and processing scan data can be compared with the traditional method of creating 2D or 3D CAD models of entire production systems. In the process of creating these models, measurements of existing production systems are required as well. If such measurements are made manually in the real systems, accuracy and time consumption can be questioned. An alternative to increasing the accuracy is to create CAD models from the point clouds, as described by Gregor et al. (2009). This alternative was applied in *Industrial study C,* where 3D CAD models were created to be used as parts with kinematics in the DES model. However, this process was found time consuming due to the manual work required.

Point clouds of existing production systems make it possible to create realistic visualisations of redesigned production systems, which can be made using different approaches. One approach applied in *Industrial study B* and *C* was to relocate sections of the point clouds that represented existing objects in the production systems. The main benefits identified with this approach were the maintained accuracy of the objects and the possibility to include for example equipment surrounding machines. However, moving or erasing sections will create holes in the point clouds. This is a result of the scanner only being able to capture visible area, which makes it difficult to capture for example sections of floors and walls covered by machines. Another view that can be difficult to capture is the top of a machine, due to the height position of the scanner. This view can be important when studying the top view of production systems, which may be useful for example in layout planning. In *Industrial study C*, this problem was addressed by locating the scanner on the roof of the robotic cell during one of the scans.

Visualising production systems using CAD models is well-implemented and supported by the results of the workshops that showed CAD models to be very necessary. In the industrial studies, 3D CAD models have most often been available for sections of the production systems, which were imported into the point clouds to create realistic visualisations of the redesigned production systems. The possibility to import 3D CAD models makes it possible to evaluate if and how new machines will fit into existing production systems. The main drawbacks identified with this approach are the accuracy and level of details of the 3D CAD models. Most often, the machine suppliers provided the 3D CAD models to the company, and these varied in quality and level of detail. An example is *Industrial study B*, where the 3D CAD model, presented in Section 3.3.2, of the existing machine, lacked information compared with the point cloud. This lack of information can result in machines being located in areas being too narrow in the real systems. A future alternative might be that machine suppliers provide point clouds of the machines.

Point cloud based DES models enable the possibility to create realistic visualisations that include dynamical aspects of production systems that vary over time. As stated by Rohrer (2000), visualisation is important for the understanding of DES models that most often represent entire production systems. Using these models as realistic visualisations enables better overall understanding of production systems. However, as stated by the interviewees in *Industrial study C*, it may not always be necessary to create a DES model, depending on the type of problem to be addressed. The main drawbacks are the limited amount of DES applications supporting point clouds and the increased data size of DES models. As described in Section 2.4.1, data size can be reduced by removing a percentage of the points by filtering. Such filtering was applied in *Industrial study C* to make it possible to import the point cloud, which can be observed as an increased space between each point when zooming in on the point cloud.

6.2 Realistic visualisation as support for redesign processes

The support of realistic visualisation when redesigning production systems is covered by *RQ2*. This question was mainly addressed in *Industrial study B* and *C*, where the experts used realistic visualisations to discuss redesign considerations. By providing accurate information of the production systems that are easy to understand the experts can gather support for daily work and meetings. In the daily work, individual experts can benefit from realistic visualisations when for example creating redesign alternatives within their specific areas. As presented in the results from *Workshop A* and *B*, a majority of the participants found it important to have access to virtual representations as a way to communicate their redesign alternatives.

In meetings such as described in *Industrial study B*, experts can use realistic visualisation to present and discuss redesign alternatives. The interviewees in *Industrial study C* described a number of problems with communicating and discussing redesign alternatives using traditional tools. As stated by Iqbal and Hashmi (2001), visualisations in 3D are important for example, to layout planning. The realistic visualisations will have the capability to provide redesign planning in 3D, which was exemplified in *Industrial study B* where the realistic visualisation was presented in 3D. As described in Section 3.3.2, this presentation was carried out using a computer connected to a projector. It would also have been possible to present the realistic visualisation using some of the VR systems presented in Section 2.2. With a suitable VR system, such as the CAVE system, it may have been possible to increase the experts' understanding of the realistic visualisation. However, it would not have been feasible because the required equipment was not available at the company. Other important aspects to discuss are how to control and modify the realistic visualisations. In the industrial studies, the researchers were controlling and modifying the realistic visualisations. From a research perspective, it may have been better to let the participants control and modify the realistic visualisations, but this was not possible due to difficulties with the applications. A multi-touch display system, as presented in Section 2.2.1, may have made it easier for the participants to be a part of the control and modifications. The importance of making changes to redesign alternatives right away during meetings to ensure that all necessary information from the discussion is gathered, is highlighted by Saadoun and Sandoval (1999). This was applied in *Industrial study B*, where the realistic visualisation was updated along with the discussion. Compared with creating updated redesign alternatives between meetings, instant updates can make the redesign process more effective, which is supported by Pehlivanis et al. (2004).

The industrial studies have addressed mixed groups of experts when presenting and discussing the realistic visualisations. For example in *Industrial study B*, a machine operator was involved in the meeting to present thoughts about the redesign from the shop floor. Another example is in *Industrial study C*, where one of the interviewee groups consisted of only shop floor personnel. *Industrial study B* and *C* showed that this knowledge was very important and might otherwise have been missed. The problem of shop floor personnel rejecting redesigns after implementation, described in Section 5.1.2, can be avoided by bringing them in at the planning of the redesign.

6.3 Quality of research approach and methods

As stated in Chapter 3, this thesis is based on a qualitative research approach, which has required objectivity in the process of gathering and analysing the empirical data. The qualitative approach and the use of an *Action research* design has required the researchers in the industrial studies to be very close to the study object, and it should be discussed how this may have affected the result.

In *Industrial study A*, the *Focus group* method was used to gather the participants' ideas and reflections. The method was time effective, but the way the method was used may have affected the result. During the *Focus group*, the researches were presenting possibilities for how to use the 3D laser scan data. The way of presenting and selecting possibilities may have had an effect on the result. An alternative would have been to give the participants the possibility to present a number of problems that they wanted solve, and try to solve these with the realistic visualisation. Another important factor was how the discussion was moderated, because this could have affected the participants' ideas and reflections. Similar problems also occurred in the *Interviews* used in *Industrial study C*. The way the scenarios were presented and the interviews were structured are important to be aware of when considering the result. Another type of problem was in *Industrial study B* and during the *Participant observation*, where the researcher was interacting with the point cloud according to the participants' discussions. In such a situation, it is difficult not to influence the discussion and result. To ensure the quality of the data one solution was to have a secondary observer that was not involved in the discussion.

The possibility of generalising in this research derives mostly from the number of studies and that only one company was involved. To make the result more generalised, it may have been possible to make a quantitative study involving several companies where understanding and usability of realistic visualisation where evaluated. However, such an overall study was not feasible due to each company's production system being unique and the time available.

6.4 Future research

The future vision is a concept where point clouds are the foundation in realistic visualisations that consist of information combined from different sources, as presented in Figure 6-1. To implement this concept as support for redesigning production systems, a standardised work method is required. In future research, the development of such a method should be in focus to establish the clear purpose of the implementation. An example of an approach that can be a part of the method is LAMDA, as introduced in Section 5.3.2. Further studies of the standardised work method are required to evaluate possible alternatives and outcomes. However, the method needs to be developed in combination with overall methods and models for redesigning production systems. To make the method transferable to other companies, the importance of the method needs both benefits and drawbacks to be provided in a general context. Besides the method, the interaction and level of understanding of the visualisation should also be further studied.

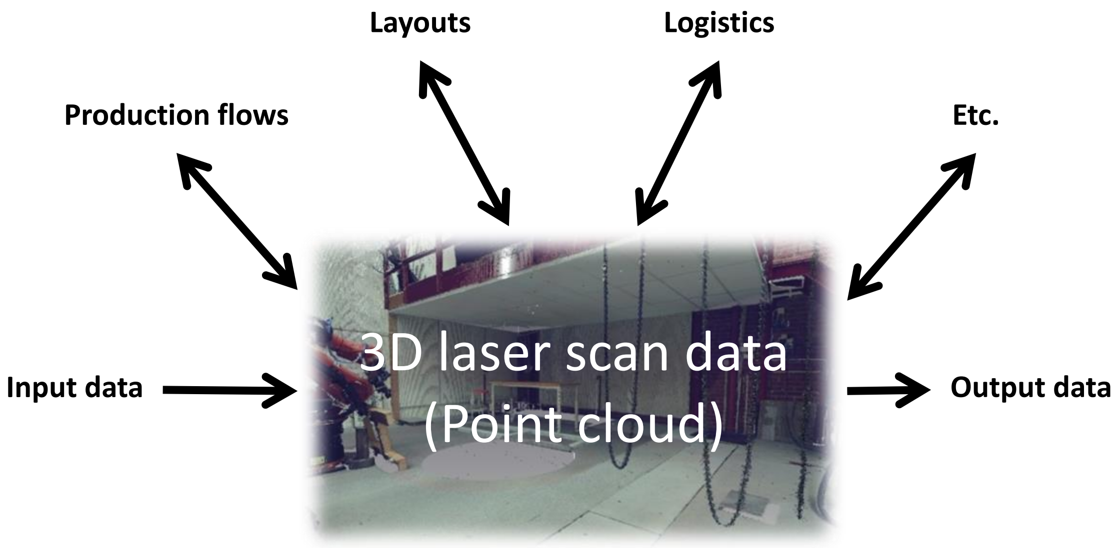

Figure 6-1: A possible future scenario of using 3D laser scan data as the main data source

7 Conclusion

This chapter includes the conclusion of this thesis related to the research questions and aim.

The 3D laser scanning applied in the three industrial studies has shown to be time-effective for capturing production systems with high accuracy. The resulting point clouds have been shown to be suitable for creating realistic visualisations of production systems, as addressed in *RQ1*. Modifying such point clouds, or combining them with additional 3D CAD models, will provide realistic visualisations of redesigned production systems. By using point clouds to represent sections of production systems in DES models, realistic visualisations can be created that include dynamical aspects.

The three industrial studies show that realistic visualisation can support the planning process of redesigning production systems, as addressed in *RQ2*. The support from realistic visualisation with high accuracy of existing production systems enable problem solving and decision making that traditionally have required physical visits to the production systems. *Industrial study B* and *C* showed that realistic visualisation of redesigned production systems enable effective evaluations of redesign alternatives. During such evaluations, realistic visualisation make it possible for experts to present their thoughts in groups, based on accurate and easy to understand information. The implementation of realistic visualisation will make it possible to eliminate misunderstandings and problems when planning the redesign, resulting in a reduced number of problems after and during the implementation.

The overall aim of the thesis has been to reduce the time required for redesigning production systems. The research towards this aim has shown strong indications that support from realistic visualisation can reduce the time required for planning and implementing redesigned production systems. During the planning, realistic visualisation can reduce the time for addressing considerations regarding existing production systems and evaluating redesign alternatives. The time for implementing the redesign can be reduced if problems are eliminated during the planning to prevent these occurring during or after implementation.

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Appendix A

Workshop question 1: Workshop A

Layout and installation

(Layout/installation)

- Layout 3D (takhöjd, pelare)
- Layout
- Placering
- Media
- Placering
- Låst layout
- CAD-modeller
- Layout (grovt)
- Förvaringsplatser (antal)
- Buffermöjligheter kring utrustning
- Lyft och media kring stationer
- Människans utrymmen kring utrustning
- Översiktsbilder som diskussionsunderlag
- CAD-underlag in
- Mediabehov för kostnadsuppskattning
- Teknisk indata vid projektavslut
- Lokal
- Placering

Work environment

(Arbetsmiljö)

- Ergonomikrav
- Fysiska risker
- Kemikalier
- Ventilationsbehov
- Buller
- Ergonomi
- Utbildningsbehov
- Ergonomi
- Buller
- Arbetsplatsutformning
- Utrymningsvägar
- Ljusintag
- Personalutbildning
- Omklädningsrum
- Utbildningsbehov
- Arbetsplatsutformning

Product information
(Detalj/product)
- Operationssekvens
- Produktdata (mått, vikt, material)
- Vad ska produceras
- Process
- Grundkrav (produkt)
- Vikt
- Mått
- Produktflödet -> maskingrupp
- UG-modeller
- Produktinfo (vikter, dimensioner, inklusive verktygsvikter, årsvolym)
- Produktens process krav (produktspecar)
- Dimensioner och vikt på detaljer
- Material
- Vilken funktion krävs?
- Vad ska utföras?

Production flow
(Tillverkningsflöde)
- Flödesanalys
- Tillverkningsvolymer
- Tillverkade produkter (takt)
- Styrprincip (FIFO, Kanban)
- Aktivitetsflöde (sekvens), tid
- Resursbehov (operatörer, fixtur, processmaterial, ingåendematerial)
- Operatörer (skift, kompitens/behörighet, tillgänglighet)
- Emballage
- Tillgänglig produktionstid/år

Quotation form
(Offertunderlag)
- Testförfarande
- Tekniska uppgifter
- Anslutningspunkt
- Indata dimensioner
- Indata för media behov
- Enkla kopplingar till våra nuvarande visualiseringsverktyg
- Vilket underlag finns?
- Vilka leverantörer finns?
- Bakgrundsinformation

Hardware specifications
(Förutsättningar hårdvara)
- Verktygsbehov
- Fixturer
- Interna specar
- Maskiner
- Automationsgrad
- Teknik/metodinformation (tidsåtgång, krav, hemlighet)
- Maxdimensioner som kan hanteras i nuvarande framtida utrustning

Production concepts
(Förutsättningar mjukvara)
- Produktplattform
- TRL nivå för nya metoder
- Produktionsplattform
- Tillverkningsmetoder
- Visualisering av logiska flöden
- Tekniska beskrivningar
- Materialhantering logistik
- Produktionsvolymer (prod/år)

Directive
(Direktiv)
- Budget
- Tidplan
- Resurser
- Budget
- Tidsram
- Vilket resultat förväntas?
- Budget/kalkyl
- Startdatum
- Färdigdatum
- Bättre kostnadsuppskattningar
- Resultatkrav

Workshop question 1: Workshop B

Machine conditions
(Maskinkrav)
- Maskinfunksjoner hvor på innstallasjon
- Spesifikasjoner for hoved alle komponenter
- Geometrisk data på installasjons objekter
- Tilkettinger: hva trengs hva finnes, hvor finnes
- Tiltenkte operasjoner/produktdata
- Hva kreves av ved likelvodd utstyr. Hvor på maskin? Tilgang
- Hva krever operasjonen av fiksturering og manuell tilpassning?
- Sporbarhet
- Maskin spesifikasjoner
- Maskin kapasitet & belastning
- Nødvendig lagringsplass
- Automatiseringsgrad
- Teknisk spec.
- HMS krav
- Vedlikeholdsbehov/vennlighet

Decision support
(Beslutnings støtte)
- Behov for nytt utsfyr
- Alternative leverandører
- Liosløpskostnader
- Lønnsomhet
- Tilleggsutsfyr f.eks. Fåksfar
- Kostnad for utstyr
- Hvor enkelt er det å vedlikeholde? Kost?
- Fremtidsvisjoner

Production flow
(Flyt)
- Hvur er kapasiteten til det ankringliggende produksjonssystemet
- Hvor lang er opr.tid. Transport tid.
- Hvor robust er tilhorande produksjonssytem?
- Trenger data fra flyt-simuleringer for å bestemme strategi for automatiseringsløsninger
- Simul8 new state (tider, gaming, till behøntilgang, I/O produkte
- Simul8 hava blir erstatet
- Operationsdata REELL nøyaldig
- Flyt info sannsynlige (VIA)(før/efter)
- Produksjonsflyt
- Produksjonsflyt

Building conditions
(Byggningskrav)
- Bryggningsrestriksjoner
- Geometrisk data fra verkstad (plassering)
- Hvilket areal er tilgjengelig…?
- Fundament behov
- Kjelker/takhøjde
- Hvordan fa dingsen inn… (gator, størreljer, svinger)
- Fundament
- Plassering i verkstad
- Bygningsfilpassinger
- Takl: kreves mer buffer plass?
- Sanering san installasjon?
- Installasjonstid (installasjons redskap, hva kan brukes)
- Det blir viktig å vite hvilke passmessige begrensinger en har
- Hvilke regler i forhold til vår produksjons HMS må vi overholde?

End-user confirmation
(Forankring/sikring)
- "Enigkit" om løsning. Imput fra operatorer, drift, teknisk, prg, prosess etc.
- Informasion fra operatører på hvordan dejtter, hvordan de vil jotte (for "konsept" er bestent og etter)
- Operatør krav/ønsker

Project administration
(Prosjekt adm)
- Prosjekt deltakere
- Tidsperspektiv på prosjekt
- Produksjons data for tidsberegning

System
(System)
- Kvalites hindteringsløsninger

Competence
(Opploving)
- Opploving vedlietiold
- Hva slags opplovings/kompetens kreves for å operere?

Workshop question 2: Workshop A

Visualisation (what)
(Visualisering (vad))
- 3D-modeller
- Ritningar
- Animeringar
- Simuleringar
- 3D
- 2D
- 3D Layout i "visualiseringsrum"
- 2D Layout i "PDF"-format lästbart för alla
- 3D Layout/modell i neutralt format (NX, AutoCad, Process Simulate, TeamCenter, Visualisation etc.)
- Volympåverkan
- DWG/DXF filer
- Modeller för åtkomstsimulering
- 3D virtuellt
- Flödessimulering
- Spagettidiagram
- Flödesscheman (processkarta)
- 5D CAD-modeller (3D + tid och pengar)
- Viewer för CAD-ritning m.m.
- Simuleringsprogram för CAD-modeller
- VR
- Simulering
- 3D simulering
- Plugin i Power Point av 3D-miljö

IT, document, and structure
(IT och Dokument/struktur)
- Uppdrag skall beskrivas i skrivna direktiv
- Med välkända programvaror ex Microsoft
- Via Teamsite
- Styrd mötesstruktur
- Tydligt och förklarande
- Sprida information mellan avdelningar/discipliner
- Datum och spårbarhet på dokument/visualisering
- Format som kan "öppnas" i fler verktyg
- Verktyg som "alla" kan använda utan arbetsstation och licens
- Visualisering av produktflödet, som stöd till beredning- och kapacitetsanalys
- Arkivering och sök system för (svets och kvalificeringar, teknologier, simuleringar)
- WEB-plattform
- Spårbar revisionshantering (TeamCenter?)
- Importera data från TeamCenter, SAP etc.

Application (how)
(Programvara (hur))
- Visuell Skärm
- Färgkoder (eller 1, 2, 3)
- Fakta
- Power Point
- Word (rapport, listor etc.)
- Excel
- Foto, Film
- Produktdata svenska
- Produktdata text
- Excel datatabeller
- Diagram
- Anläggningsarkiv R3
- Excel, Word, PDF

Workshop question 2: Workshop B

System analysis
(System analys)
- Function Deployment (QFD)
- Blockdiagram
- Flytdiagram (maskin, operator, system)
- Fiskebein
- Gantt diagram
- Flyt-diagram
- Tidsplan Gaml el. Pert
- Flyt diagram
- Fiskebeins stakeholders krav
- Bokser og Piler
- Swimlanes
- Grafer diagram

Presentation tools
(Verktoy)
- Tape på gulv
- Excel
- A3
- Qs-stat (SPC)
- Power Point
- Excel
- Teskst/Foto/Bilder dokument
- Whiteboard
- Dedikerte presentasjoner ved behov (PP)
- Power Point/Excel -> graf av tall

Virtual representations
("Verklig modell"/CAD)
- 3D-CAD
- 3D-modell
- 3D-modell
- 2D-tening
- Punktsky + CAD modell
- 3D-modell
- 2D-modell

Physical objects
(Fysisk)
- Tavler i produksjon
- "Sandbox" modell
- Omvsining med god forteller
- Konsept tegninger (håndslesse)
- Peke på det riktige svaret
- Modellering

Presentation
(Fortelle)
- Grafisk simuleringsverktoy
- Animasjon
- Story telling
- Tegneserie striper
- Real time 3D animasjon
- Spill-motor gå i modell
- Visuell CONOPS/aktivitets diagram
- Animert process 2D->Story board, 3D->sinalog
- Stnekmann
- VR

Analyse tools
(Definering teknikker)
- Stakeholder ananlyse
- Fysisk og funksjons -arkitektur
- USE CASE Diagram
- Flyt simulering
- "Krav modell"/tracing -> Enterprise Architur
- Flytsimulering
- USE CASES

Operation definition
(Operassonsdetinering)
- Processmaster
- Før etter tegning, Toleranser+geometri
- Operasjons "sammendrag"