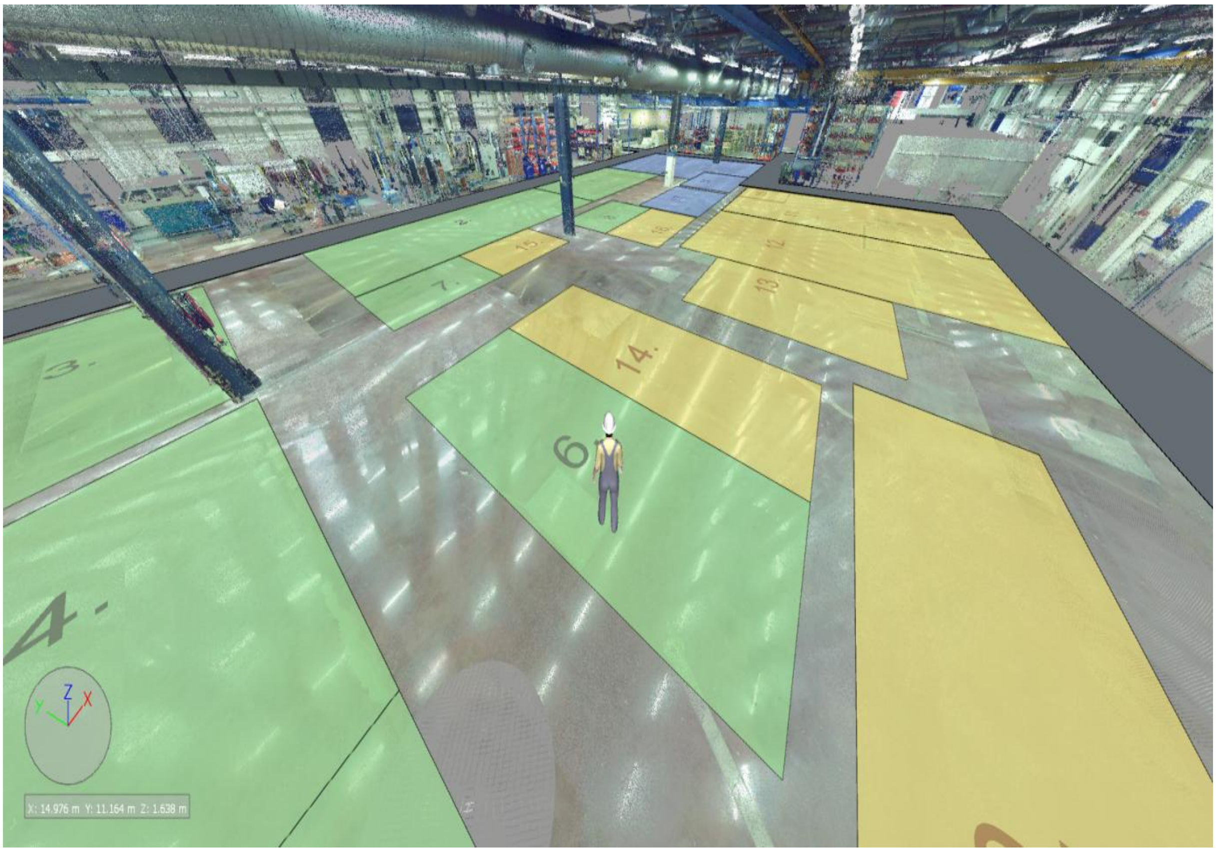

Visualisation of Production Development

Merging Point Cloud and Block Layout to Support Factory Layout Planning

Master's Thesis in Production Engineering

ROBIN NILSSON

Department of Product and Production Department
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Point cloud with merged block layout and operator.

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Abstract

Nowadays, there is an emphasis on gaining a competitive advantage through continuous improvements. However, no company is immune to radical production changes to stay competitive as production system ages, product portfolio develops and market demand varies. It is becoming increasingly important to conduct radical changes more efficiently with less installation errors. Thus, it is important to be able to handle cutting edge technology to decrease design lead time and increase understanding. 3D laser scanning is such a technology that has the potential to revolutionise production development. However, the methodology to facilitate 3D laser scanning is still underdeveloped. At Danfoss Heat Pumps while planning the future production layout, has an action research attempt been made to continue developing the methodology for 3D laser scanning by combining simplified systematic layout planning and workshops with 3D laser scanning. This was conducted to complement the existing 3D laser scanning method with an approach that considers the entire factory layout planning life cycle, as the general layout phase is considered the most important phase. Moreover, by planning the block layout and merging it with a point cloud of the factory it is possible to create a visual support that potentially increases understanding when evaluating and planning the factory layout. The research contributes with a recommended layout planning method which is based on the important aspects that was presented during the action research case and semi-structured interviews with the layout planning team.

Keywords: 3D laser scanning, block layout, facility layout planning, layout planning method, simplified systematic layout planning, workshops, point cloud, facility layout problem, realistic visualisation, production development.

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I would like to thank Danfoss Heat Pumps and the employees that have been involved and contributed to this thesis. A special thanks to the production engineering department that has made me feel like one in the team and for holding your heads high at the disappointment of Atlas project being terminated because the product design became too expensive.

Much love to family and friends for your unconditional support during this period of ups and downs. Big thanks to my father Jan-Inge for sacrificing his car to ensure I could smoothly travel between Karlstad and Arvika every day to conduct the thesis on-site. Special thanks to my girlfriend and bride to be Apinya and mom Lilian to always been there supporting and pushing me no matter what.

Robin Nilsson

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Nomenclature

2D	Two Dimensional
3D	Three Dimensional
3D-SSLP	The developed and recommended layout method
AR	Augmented Reality
CAD	Computer Aided Design
DMU	Digital Mock-Up
DPP	Danfoss Productivity Program
FLP	Facility Layout Problem
H+S assessment	Health and Safety Assessment
LAMDA	Look, Ask, Model, Discuss and Act
LASER	Light Amplification by Stimulated Emission of Radiation
LiDAR	Light Detection and Ranging
LoA	Level of Automation
MIFA	Material and Information Flow Analysis
PDCA	Plan, Do, Check and Act
PDP	Product Development Program
PFMEA	Process Failure Modes and Effects Analysis
SLP	Systematic Layout Planning
SOP	Standard Operating Procedures
SSLP	Simplified Systematic Layout Planning
VR	Virtual Reality
VSM	Value Stream Mapping
WIP	Work-In-Process

1 Introduction

This chapter will introduce the study conducted in this master thesis. The following sections are the background, problem definitions, purposes, objectives and delimitations of the project presented.

1.1 Background

This section will give a concise background of the subjects contested in this thesis, which are layout planning life cycle, the facility layout problem and visualisation with three-dimensional (3D) laser scanning. Subsequently, the hosting company and organisation are presented.

1.1.1 Visualisation and factory layout planning

Nowadays, production development has become a vital process for companies to learn and understand in order to gain competitive advantage. It is a comprehensive and complex area that concerns about setting up effective production processes and developing the production ability (Bellgren & Säftsen, 2010). According to Wiendahl & Hernández (2006) there is an increasing demand to have transformable factories to stay competitive on the global market. Transformable factors are characterised by either: rapid planning and implementation of results or ability to rapidly make modifications and adjustments (Wiendahl & Hernández, 2006). In Lean Production, is Kaizen (continuous improvement) referred as an important part to master to achieve effective and efficient production. According to Johansson (2008) continuous improvement mentality has become normality within companies. However, from experience it is known that Kaikaku (radical change) is not as emphasised as Kaizen in literature but arguably as important. Since production systems ages, product portfolio develops, and market demand varies, thus it is important for numerous reasons to adjust and redesign whole production systems to remain competitive. According to Johansson (2008) external factors are mainly the reason for radical changes and lately factory layouts have been the main focus in change projects.

The facility layout problem (FLP) is a combinatorial optimisation problem and is defined as determining the physical organisation of a production system (Meller & Gau, 1996; Singh & Sharma, 2006). Facility layout is the placement of everything that is required to produce the final product and the problem is to find the most efficient arrangement. The arrangement significantly affects lead time, production costs, work-in-process (WIP), and productivity. Well planned layouts can reduce the total operating expense by fifty percent (Drira et al., 2007). The original objective of FLP is to minimise internal material handling cost, however, research has shown that other objectives can also be focused and achieved, e.g. reduce material movement, lower WIP levels, overall congestion, and throughput times (Singh & Sharma, 2006). The result of FLP is a block layout, which is a two-dimensional (2D) representation that specifies the location of departments and work stations in a factory template. The block layout is then further developed into a detailed layout which specifies details in each block, e.g. input/output locations, aisle width, layout within departments and stations. Problems to be solved in the detailed layout are flow line problems, machine layout problems and cellular manufacturing design problems (Meller & Gau, 1996).

According to FLP literature reviews the research on FLP is strong, but diverging (Meller & Gau, 1996; Singh & Sharma, 2006; Drira et al., 2007). Moreover, the research has long been focused on developing different algorithms for layout planning. However, mathematical based algorithms are difficult to apply due to complexity and computational limitation. Thus, sub-optimal manual planning approaches like Systematic Layout Planning (SLP) are often applied. SLP was first developed and also simplified by Richard Muther in 1960 (Kusiak & Heragu, 1987). Johanssson (2008) mention the most used layout planning method is the simplified version of SLP. Moreover, some reviews point out the lack of concurrent engineering between layout planning and material handling system design or production system design. Thus, future research should be on breaking the sequential processing of layout and material handling system design or production system design (Meller & Gau, 1996; Singh & Sharma, 2006). Drira et al. (2007) stated that future research should focus on embedding layout procedure into software tools and combine it with graphical tools to make it more efficient and realistic.

3D laser scanning technology has been proven to be a powerful tool to utilise when planning and visualising production system and layouts (Lindskog, 2014; Olofsson & Sandgren, 2015). Some presented advantages with 3D laser scanning are that a high quality and accurate 3D factory model can be built in matter of hours, which eliminates time consuming tasks such as collect and insert measurement data into 2D or 3D CAD models. Moreover, it eliminates the risk of human mistakes when measuring the factory and inserting data into CAD models. Another advantage with scanned models is that they can still be merged with other CAD objects, e.g. machines, robots, layout planes, etc. Moreover, 3D visualisation is a very good way to verify layouts and systems (Olofsson & Sandgren, 2015).

Current methodology for using 3D laser scanning to plan layouts and design production systems is still developing. Lindskog (2014) presented *LAMDA-cycle* to be applied during design phase to increase teamwork quality. Olofsson & Sandberg (2015) expanded the approach by introducing *7 flows with cross-functional workshops* which should follow the LAMDA-cycle during sessions. The intention was to make design decisions during the workshops. However, according to Olofsson & Sandberg (2015) this was not accomplished due to unknown reason(s). The cross-functional workshops with 7 flows and LAMDA-cycle have been mostly focused on developing the detailed layout directly in 3D scan models. However, the life cycle of large factory layout planning consists of four common phases when planning layouts: location analysis; general layout; detailed layout; and implementation (Muther, 1974; Phillips, 1997; Zardin, 2001). Currently the 3D laser scanning methodology does not aim at the general layout phase, which produces the block layout that directly affects the efficiency of detailed layouts. So to ensure and increase efficiency of planned layouts this phase must be integrated. Moreover, block layouts are a visualisation technique that can benefit 3D scan models when combined to increase the visual understanding when planning the detailed layout during collaborative workshops with third parties. Moreover, it can give layout planners the option to start applying optimal FLP approaches, which can provide efficient block layouts based on quantitative measurements, instead of qualitative approaches which are commonly used today.

1.1.2 Danfoss Heat Pumps and Danfoss Group

In this study, Danfoss Heat Pumps (former Thermia but still also branded as Thermia) in Arvika, Sweden, has been selected to perform the study, which will be referred as the company here on. The company develops, produces and sales heat pump systems for heating, warming water and cooling. The company has approximately 190 employees with revenue of 700 million SEK. In 2005 did Thermia become a part of Danfoss Group and operates as an independent business unit within Danfoss Heating Division. The company is still branded as Thermia within the Nordic market while for the rest of the world it is branded as Danfoss. Danfoss Group made the company as the site for its global research and development of heat pumps. Today the company is a technology leader and has one of the leading development sites in Europe.

Danfoss Group is a private owned Danish company which produce a diverse range of energy solutions for four different divisions: Power Solutions, Cooling, Drives, and Heating. Danfoss has approximately 23 400 employees worldwide with revenue of 5.1 billion EUR. Danfoss Group operates on a global market with widely sales in 100 countries and 61 factories in 20 countries.

The company, an independent site, develops, produces and markets heat pumps for three different product segments: geothermal heat pumps (high volume), air-water heat pumps (medium volume) and large capacity heat pumps (low volume). Due to the nature of business, the sales of heat pumps are fluctuating according to seasonal changes. The sales sharply increase during September to November (high season) and sharply decrease during January to March (low season). The final product is produced from three sub-parts that are assembled and covered: frame with or without water tank, heat pump and control unit.

In the present production system, all product segments are being produced in parallel sharing some resources. Each sub-part is produced in separated sub-flows which later converge in the final assembly flow. Today, the production system has faced problems as the system has become outdated and lacks capability to change due to previous design solutions within the production system. The company recently initiated a new product development project called Atlas, where both the next generation of geothermal heat pump and new production system will be developed to modernise the product segment and production.

1.2 Problem definitions

The company's current production layout has work stations designed with pits under the ground with scissor hydraulic lifting tables to support ergonomic work. Thus, the system has experienced inefficient transport and obstructed to change for the old production layout and system. Moreover, the current production system does not have the capacity to introduce a new product family. Accordingly, the company has decided to develop a new production system to eliminate current inefficiencies and increase the flexibility for future remodelling. Moreover, the production engineering department lacks adequate knowledge of a structured method to plan the physical structure of a new production system. As a result, the production engineering department requires assistance from specialist to introduce a new practical and efficient planning method, which is aligned with current practices, to assist planning primarily larger layouts. Also, the specialist will conduct training to the production engineering department in order to maintain knowledge and skills within the production. Moreover, the design procedure to utilise 3D laser scanning still requires further development to consider all details and improve the robustness and quality of the end result. Currently, the results are very depended on the first impression of the empty point cloud model when conducting collaborative workshops with any third parties. Further, it can be difficult for third parties without previous layout planning knowledge to grasp the whole system and to estimate area requirements and placement of functions when viewing an empty point cloud model. To achieve the above statement, the following research questions have been raised:

RQ1: How can simplified systematic layout planning, 3D laser scanning and workshops be combined to create an efficient and practical layout planning method, which will be referred as 3D-SSLP here on, that can complement current 3D laser scanning methodology?

RQ2: How are simplified systematic layout planning, 3D laser scanning, workshops and 3D-SSLP, experienced?

Block layout, point cloud model and physical mock-up are three different ways to visualise during layout planning of production systems. Block layout is a conceptual 2D layout that gives an overview of the initial area requirements of each required function to produce the products. However, height requirement cannot be considered in this layout, also other small details are often difficult to plan since most schematics are inaccurate due to human error during the measurement. Whereas, physical mock-up, today commonly used by the production engineering department, is a realistic 3D representation that gives a realistic environment and feeling of the layout but the technique requires the production floor to be empty this can become more problematic as the size of the layout increases. However, a point cloud model provides a very detailed and accurate virtual 3D environment, which has proven very useful for visualising the available area when planning layout which possibly can enable developers to replace physical mock-ups with digital mock-ups (DMU). These problems lead to the following research questions:

RQ3: How are block layout, physical mock-up and 3D-Block (DMU of block layout and point cloud) experienced? When and in what context are these visualisation techniques preferred during the layout planning life cycle?

1.3 Purpose

The purpose of this thesis is to develop a practical and efficient layout planning method while training the production engineering department and planning the new production layout using simplified systematic layout planning, 3D laser scanning and workshops. Moreover, it is also aimed to integrate point cloud model and block layout to be able to facilitate a collaborative coalition between the facility layout problem and 3D laser scanning and lastly, to further contribute to the methodology of utilising 3D laser scanning during layout planning projects.

1.4 Objectives

The main objective of this thesis is to: develop a practical and efficient layout planning method using simplified systematic layout planning, 3D laser scanning and workshops; and to investigate how block layout and point cloud model can be integrated by:

- Mapping the current development practices and process flow of the new production system
- Training the department in the components of 3D-SSLP
- Planning the future block layout using the components of 3D-SSLP
- Conducting 3D laser scan of the factory facility and machines of interest
- Processing the raw scan data and build the point cloud models
- Investigating how the block layout and point cloud model can be integrated
- Evaluating the effect of applying simplified systematic layout planning, 3D laser scanning, workshops and 3D-SSLP
- Evaluating the effect of applying block layout, physical mock-up and 3D-Block

1.5 Delimitations

Firstly, this thesis is limited to the production functions and practices which are used in producing the geothermal heat pumps in Arvika, Sweden.

Concept and detailed layout planning phases will only be considered in this thesis due to the company's time plan for the Atlas project and time limitations as this thesis was conducted by only one author and was carried out on-site for 20 weeks.

The results will focus on the planning and visualisation methods but not on analysing the new layout, due to time limitation and not to risk disclosing confidential information to competitors in a sensitive market. Thus, the actual planning result will be briefly presented with relevant data for the planning method and also briefly illustrate an example with depersonalised data.

The 3D-SSLP has been developed to fit the current practices and responsibilities of the department as it is intended to be a method that is practical and serve the users.

2 Theoretical framework

This chapter will present fundamental theories are applied in this thesis to provide the reader with basic knowledge and understanding as well as create a foundation for discussion and conclusion.

2.1 Visualisation

In companies, communication occurs for different important reasons between different parties. It is important to communicate in an appropriate way to convey the right message and increase understanding. Communication can be both verbal and nonverbal, visual materials, e.g. pictures, graphics, etc. (Gropper, 1963). Today's visual materials are focused on using human-computer interfaces also known as visualisation to convey and handle information (Ebert, 2005). According to Gropper (1963) do visual materials serve two functions: as a *cue/reinforcement* function to create feedback; and as an *example* function to increase understanding. Moreover, the use of visual materials can aid communication to increase time-efficiency and communicate specific information which words simply cannot do (Gropper 1963). Rohrer (2000, pp. 1211) states that "*Visualisation is the foundation for human understanding*" and highlights that the first languages were visual that later evolved to verbal. Moreover, Rohrer (2000) argues that visualisation has become an important part to communicate results and better understand simulation models. According to Teyseyre & Campo (2009) visualisation has changed the scientific community as nowadays it is considered inappropriate to communicate research without the use of visualisation. With the use of graphical representations can complex solutions be communicated with high precision, clarity and efficiency as the human visual system has enormous bandwidth to communicate and process information with our brains (Ebert, 2005; Rohrer, 2000; Teyseyre & Campo, 2009). Teyseyre & Campo (2009) mention that visualisation can be used to enhance different cognitive processes: *Exploratory* to discover new data; *Analytical* to make decisions based on data; and *Descriptive* to explain and verify data. Rohrer (2000) mentioned that, in simulation, computer graphics can be used to assist communicating complex concepts to novices and it is important with good graphics. According to Rohrer (2000) good graphics consist of five key elements: interactivity, realism, performance, flexibility, and user-friendly, see Table 1.

Table 1: Summary of the key elements (Rohrer, 2000)

Elements	Summaries
Interactivity	It must be able to navigate, i.e. zooming, panning, etc., the graphics in real-time.
Realism	The graphics should be realistic so no explanation is needed and to increase credibility.
Performance	The navigation must be performed smoothly so viewers have no problem focusing.
Flexibility	The user should be able to select what information should be displayed so the focus can be directed to important aspect.
User-friendly	Adding graphics to the virtual model should be easy and it is better if the model is accurate and mimics the real system as it can improve decision making.

Visualisation can be presented in both 2D and 3D environments, and the purpose of 3D is to create representations that are closer to reality by adding an extra dimension.

Inside the 3D environment, e.g. Virtual reality (VR), the user is able to navigate and manipulate 3D objects without any problems (Smith & Heim, 1999; Teyseyre & Campo, 2009). Teyseyre & Campo (2009) presented a number of strengths and weaknesses of 3D visualisation to its counterpart 2D, see Table 2. Moreover, the authors argued that 3D can improve the development procedure if the weaknesses can be avoided while the strengths are utilised. Moreover, recent research has shown that 2D and 3D are best for different purposes and therefore it is recommended to combine both 2D and 3D, however, all visualisation techniques should be tested to ensure they serve the intended users in practice (Teyseyre & Campo, 2009).

Table 2: Strengths and weaknesses of 3D visualisation (Teyseyre & Campo, 2009, pp. 90)

Strengths	Weaknesses
• Greater information density • Integration of local and global view • Composition of multiples 2D views in a single 3D view • Facilities perception of the human visual system • Familiarity, realism and real world representations	• Intensive computation • More complex implementation • User adaptation of 3D metaphors and special devices • More difficult for users to understand 3D space and perform actions in it • Occlusion

Furthermore, the use of visual information and the development of software visualisation are increasing (Teyseyre & Campo, 2009). Today, visual information and software are broadly used to increase effectiveness and efficiency when developing and managing production systems, e.g. digital factory, VR, augmented reality (AR), Genchi Genbutsu, Andon, etc. Rohrer (2000) stated that visualisation is the best way to validate production systems that still do not physically exist. Wiendahl & Hernández (2006) mentioned that a success factor in factory planning is “visualisation of results” meaning that the planning results should always be visualised and it is very valuable to use as realistic 3D-images as possible.

The original factory planning tools used simple 2D representation of the production factory to arrange the layout with rectangular blocks which represented, e.g. workstations, machines, etc. (Smith & Heim, 1999). Over time the visual information has moved into visualisation software. In Lindskog et al. (2013) it is mentioned that production systems are now normally visualised in 2D CAD or simple 3D CAD representations. The 3D models have the advantage to give the user a better perspective. Nevertheless, these CAD representations often lack in level of details and precision in comparison to reality which can cause misunderstanding and to create realistic visualisation could eliminate this problem (Lindskog et al., 2013). The benefits of detailed virtual models have been widely reported and some of the benefits, e.g. better evaluation to avoid mistakes, co-operative planning, increased understanding, increased planning speed and quality, and decreased planning costs, have been presented in (Lindskog et al., 2013; Weindahl & Fiebig, 2003). Moreover, according to Zhou et al. (2016) photorealistic visualisation is important to accurately present all the important features embodied in manufacturing processes. Nowadays, there exist solutions to efficiently achieve photorealistic and accurate visualisation models by using 3D laser scanning technology (Lindskog et al., 2013; Lindskog, 2014) which will be presented in the following section.

Furthermore, the founding fathers of Lean also seemed to understand the importance of utilising the human visual system to convey information to knowledge. One of the Lean principles, Genchi Genbutsu is a visualisation technique and means *"Going to the place to see the actual situation for understanding"*. It is important to visit *"The actual place"* (Gemba) to deeply understand the situation in order to solve problems, develop the system or to evaluate the performance (Liker, 2004). However, no physical Gemba exists when developing a new production system. Instead an accurate and photorealistic model can be used as a virtual Gemba throughout the development procedure to visit the future production system. Moreover, when visualisation such a virtual model it is important to use cross-functional team to achieve the best result and also realistic visualisation can be extra useful when including operators (Lindskog et al., 2013). Moreover, Lindskog (2014) concluded that realistic visualisation can support decision-making and evaluation of different layout solutions.

2.2 3D laser scanning

Ever since LASER (Light Amplification by Stimulated Emission of Radiation) was invented in the 1960, it has been a steady development of laser ranging systems, ehich can be seen in Figure 1. However, the hardware development increased rapidly after the first commercial 3D laser scanning systems was introduced to the market. Since then the quality and customer value has increased rapidly while the scan time and cost has decreased rapidly (Randall & Philp, 2013). Bi & Wang (2010) concluded that today's 3D scanners are powerful and the areas of data gathering and processing techniques are developing quickly. An expert in the field estimated that today an investment package to efficiently utilise 3D laser scanning within a company would cost approximately 500 000 SEK. The package would include 3D laser scanning technology, software and training, but due to the growth of the area there are alternative services such as hiring a third party to perform the 3D scanning or renting a 3D scanner.

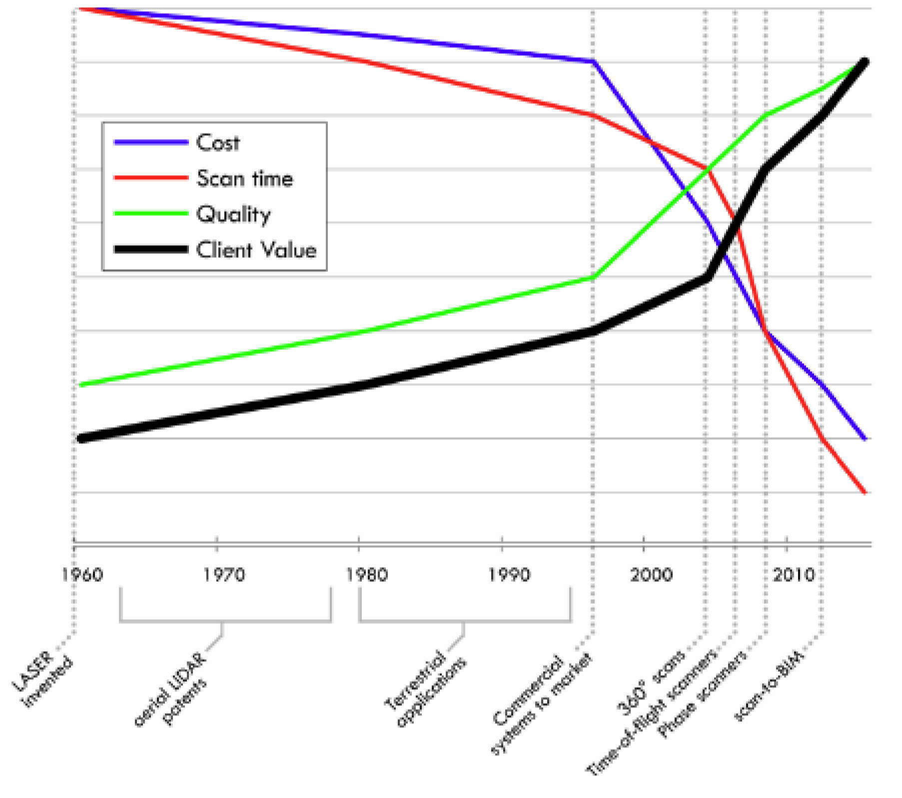


Figure 1: Development of hardware systems (Randall & Philp, 2013, pp. 3)

2.2.1 Scan technology and procedure

There exist different 3D laser scanner techniques and classes but this thesis will focus on terrestrial LiDAR (Light Detection and Ranging) phase-shift scanners. According to Dassot et al. (2011) are phase-shift scanners the most suitable to gather high precision and detailed measurements in environments up to 100 meters due to its wide fields of view, fast scanning speed and large point quantity gathering. This makes phase-shift scanners suitable for capturing existing production systems to create realistic visualisation (Lindskog, 2014). According to Gergor et al. (2009) 3D laser scanning is the digitalisation and reverse engineering tool to connect virtual reality and real virtuality for digital factory, as 3D scanning makes it possible to acquire accurate data to produce detailed 3D digital mock-ups (DMU) of large existing objects i.e. factory facility.

A phase-shift scanner continuously emits and deflects an infrared laser beam which is reflected back from objects and captured by the scanner and the distance is calculated by analysing the phase shift between emitted and captured beam (Dassot et al., 2011; FARO Technologies, 2011; Klein et al., 2012). The captured reflection also known as measurement point represents a point on the surface of the closest object (Klein et al., 2012) which stores data about the position in Cartesian coordinates (x, y and z coordinates) and the intensity (Staiger, 2003). Dassot et al. (2011) reviewed different terrestrial phase-shift tripod scanners and the typical *"Field of view"* is in the horizontal axis of 360 degrees and in the vertical axis 305 to 320 degrees, which can be seen in Figure 2.

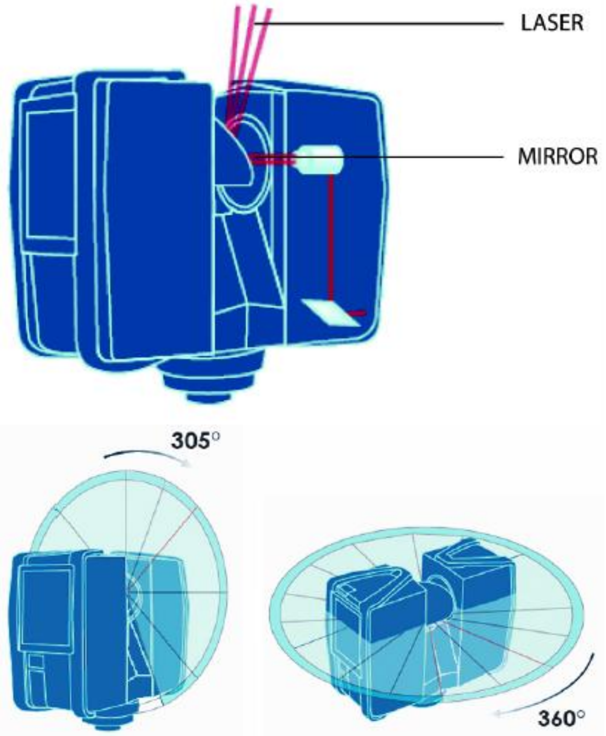


Figure 2: Data capturing with a tripod 3D laser scanner (FARO Technologies, 2011, pp. 3-4)

Moreover, the phase-shift tripod scanners can collect large amount of spatial data (Klein et al., 2012) and has a capture capacity up to approximately a million points per second (Dassot et al., 2011) and by systemically combining the points into a data set, a point cloud can be created (FARO Technologies, 2011). Point cloud is a 3D representation of the scanned environment (FARO Technologies, 2011; Olofsson & Sandgren, 2015). Moreover, to enhance visualisation of the point cloud has at least the 3D laser scanner manufacturer FARO integrated a digital camera to take photorealistic images of the scanned environment which can be layered on top of the data set to assign a RGB colour to each measurement point (FARO Technologies, 2011). Thus, it is possible to create virtual representations with realistic visualisation of production system which has been proven value to enhance production systems in research like Lindskog et al. (2013), Lindskog (2014) and Olofsson & Sandgren (2015).

It is common that a number of scans are required from different location in order to cover an entire object of interest. In order to combine two or multiple local scans, it is required that two scans at least share three different reference objects to be successfully combined. The reference objects can either be natural object from the scanned environment, e.g. walls, pillars, etc., or placed artificial reference object, e.g. white spheres and block checkerboards or white spheres (FARO Technologies, 2011). It is recommended to use the artificial reference objects as it normally results in more accurate registration process (FARO Technologies, 2011) but it can also requires additional planning before the scans as these artificial references has to be place according to certain requirements, e.g. sphere should be completely visible in both scans, laser beam should not hit the checkerboards with an angle less than 45 degrees, etc., and have to be systematically relocated during the scan procedure as there are limited amount of reference object (FARO Technologies, 2011) which can make the procedure more time consuming in comparison to the little extra achieved in accuracy. When scanning with a terrestrial tripod scanner, e.g. FARO Laser Scanner Focus^{3D}, the scanning procedure can be summarised into following three steps (Lindskog et al., 2013; Lindskog, 2014):

1. *Prepare scanning* – Decide what type of reference object is necessary for the situation and task. Plan the position of the scans and reference objects to capture the data of interest and ensure two scans that should be combined have three suitable reference objects visible. Moreover, ensure the lines of sight need to be clear from the 3D scanner to important features of the scanned object and reference objects to maximise the accuracy. Lastly, mount the scanner with the tripod and level the scanner using one of the existing inclinometers (FARO Technologies, 2011).
2. *Perform scanning* – Position the 3D scanner according to the pre-planned scan locations, ensure it is levelled and perform the data capturing. To improve results, it is important that there are no motions in the scanned environment. Thus, if the scanned location is not separated from the current production flows the scanning should be performed after working hours. A scan takes on average five to seven minutes depending on the quality and resolution settings (FARO Technologies, 2011).
3. *Pre-process scan data* – Pre-processing the scan data to increase quality by eliminating or correcting faulty points through filtering processes. Assign colour to the scan points if recorded (FARO Technologies, 2012). Register and combine different scans to create a unified data set using the reference objects (natural or artificial) in a manual, semi-automated or recently developed

automated process (Autodesk, 2016a; FARO Technologies, 2016b). Finished the procedure by with exporting the unified scan data for post-processing (FARO Technologies, 2012).

However, preparing and performing the scanning is different when using a handheld scanner, e.g. FARO Scanner Freestyle^{3D}, in comparison with a tripod scanner. With a tripod scanner, the data capturing is an iterative and static process, i.e. place scanner, start scanner, user move away and wait until completed, move scanner to next position, start scanner, etc., but with a handheld scanner the data capturing is a dynamic process,. The handheld 3D scanner is visualised in Figure 3. The user shall slowly and constantly move around with the handheld scanner to scan the object and move the scanner in front of the object in small circles and between the specified minimum and maximum range for the sensor.

Figure 3: Data capturing with a 3D laser scanner (FARO Technologies, 2016a, pp. 7)

Furthermore, the user can connect the handheld scanner to a tablet-computer which makes it possible to track the captured data in real-time. In Figure 4 are real-time data capturing app presented. The right software interface visualises how appropriate the data capturing is in the environment, green colour represent areas which are suitable to capture good data and yellow colour are not suitable so the scanner needs to be moved to capture good data in these areas. Moreover, in the left interface visualise the capture points in real-time (FARO Technologies, 2016a).

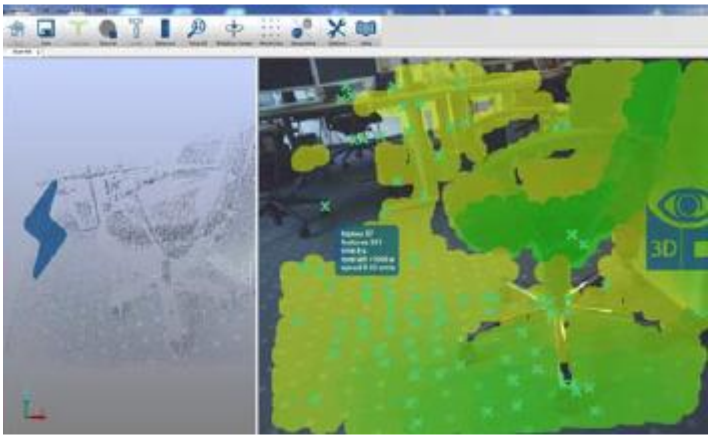


Figure 4: Tablet-computer interface (FARO Technologies, 2016a, pp. 38)

Furthermore, before the scanning is performed a calibration plate is scanned in 90 degrees in two tests. The calibration plate can be seen in Figure 5. First, the handheld scanner is calibrated for accurate measurements and secondly it is a *"Device White Balanced"* calibration performed to adjust the digital colour camera (FARO Technologies, 2016a).

Figure 5: Calibration plate (FARO Technologies, 2016, pp. 89)

Independent from type of 3D laser scanner, the result from the pre-processing is a data set which represents the entire scanned environment in x, y and z coordinates, intensity and RBG colour (FARO Technologies, 2011). This data set can then be exported into different formats and software tools for further inspection, analysis and modelling of the environment, e.g. production systems (FARO Technologies, 2012).

2.2.2 Scan software tools

Today, there exist an extensive range of commercial software tools associated with 3D laser scanning, to handle everything from registration to 3D modelling (Bi & Wang, 2010; Klein et al, 2012). Bi & Wang (2010) presented that the software market for handling scan data is growing which will probably consolidate stand-alone developers, e.g. Kubit GmbH, and push large CAD and 3D modelling companies, e.g. Autodesk, to update their software. Simonsson & Johansson (2015) presented different cases from Siemens PLM, Autodesk and Dassault Systèmes which indicate that this development currently is happening. Furthermore, the stand-alone developer Kubit GmbH was acquired by FARO (FARO, 2015). The current software can be generalised and categorised into the following four categories (Simonsson & Johansson, 2015):

- *Pre-processors* – FARO SCENE (SCENE) and Autodesk ReCap360 (ReCap360) are examples of pre-processors. All 3D laser scanner manufacturers provide their own pre-processer (Bi & Wang, 2010; Olofsson & Sandgren, 2015). The software is dedicated to pre-process and register data from the scan locations to consolidate an entire data set, as described in above scanning procedure.
- *Web-based viewers* – FARO SCENE WebShare 2Go (WebShare) is an example of a web-based viewer. The software is dedicated to visualise the scan data in panoramic photorealistic view and overview map in a web browser which can be used and shared either online or offline. WebShare have both simple features to explore and review the scan data which can be seen in Figure 6. The panoramic

viewer operates very much like Google street view with where it is possible to move between scan positions and zooming. Moreover, it has point-to-point measurement feature to review distances (yellow/black dashed line) and in the overview map it is also possible to review measure areas (yellow box) (FARO Technologies, 2012).

Figure 6: WebShare

- *Client-based viewer* – Autodesk Navisworks Manage (Navisworks) is an example of a client-based viewer. The software is as web-based viewers dedicated to visualise point clouds and models but with more advanced features to explore, review and animate the viewed models. As it is possible to move around freely in the environment, can import other models (CAD objects), and can animate and review robot's movements and other things (Autodesk, 2016b). For a more detailed review of Navisworks turn to Olofsson & Sandgren (2015).
- *Post-processors* – Autodesk AutoCAD (AutoCAD) and CloudCompare are examples of post-processer software. It is not uncommon that their post-process software is dedicated to different purposes, e.g. modelling, analysing, etc. AutoCAD is mainly used to model with the point cloud (Autodesk, 2016c) and the purpose of CloudCompare is to analyse, process and reconstruct surfaces in a 3D point cloud and mesh (CloudCompare, 2016).

However, Olofsson & Sandgren (2015) presented that in recent research has it been identified that every developer creates their own file format for competitive reason, which cause issue for users that wish to switch between software from different developers as all software had its advantages and disadvantages. This issue was the birth of the file format .e57 for 3D Imaging Data Exchange (Olofsson & Sandgren, 2015). However, until the market matures, a solution can to minimise switching between file formats by selecting a developer that offers a wide range of solutions which are fulfil the required needs.

2.2.3 Current methodology

In research projects founded by VINNOVIA (Swedish Agency of Innovation Systems), did both Lindskog et al. (2014) and Olofsson & Sandgren (2015) attempt develop the 3D laser scanning methodology with two different models: the LAMDA-cycle and the 7 flows of manufacturing.

Lindskog et al. (2014) presented and applied the LAMDA-cycle (Look, Ask, Model, Discuss and Act) which is a problem solving approach within Lean product development. In Figure 7 can the LAMDA-cycle be seen. LAMDA is an improved version of the PDCA-cycle (Plan, Do, Check and Act) (Olofsson & Sandgren, 2015) which is an iterative learning cycle to solve problems applied during continuous improvements projects (Lindskog et al., 2014). The five steps of the LAMDA-cycle will be described in detail below (Lindskog et al., 2014, pp. 559; Olofsson & Sandgren, 2015, pp. 12):

- Look – go and see for yourself,
- Ask – get to the root cause,
- Model – use engineering analysis, simulation or prototypes,
- Discuss – with peer reviewers, mentors and developers of interfacing subsystems, and
- Act – test your understating experimentally.

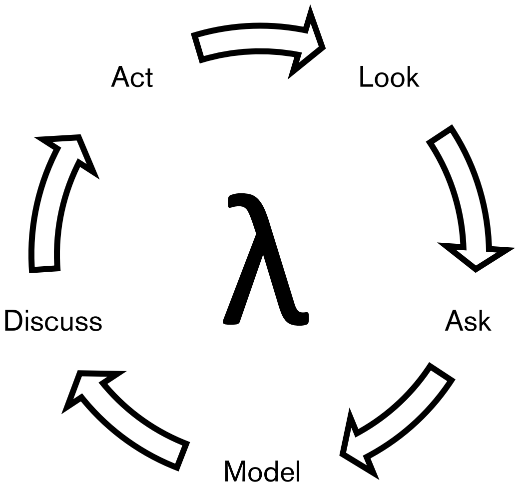


Figure 7: The LAMDA-cycle (Lindskog, 2014)

Furthermore, Olofsson & Sandgren (2015) expanded the 3D laser scanning methodology with the 7 flows of manufacturing model (7 flows) which can be applied in order to gain a complete understanding of the system. By observing and analysing the 7 flows for the development project it is possible to acquire data from multiple stakeholders which can be used to make the right decisions (Ibid). The seven different flows in the model will be presented below (Ibid):

- The flow of raw material,
- The flow of WIP,
- The flow of finished goods,
- The flow of operators,

- The flow of machines,
- The flow of information, and
- The flow of engineering.

2.3 Facility layout planning

Lately, factory layouts have had a central part in change projects to discuss new improvements or plan new layouts. The procedure normally starts by creating concept layouts, and then evaluating the layouts before one candidate is detailed (Johansson, 2008). Moreover, factory planning is facing future challenges such as increase of planning frequency, planning speed, handling unclear database and parallel disciplinary planning cycles (Weindahl & Herández, 2012).

2.3.1 Large layout planning life cycle

According to Phillips (1997) it is better to follow a layout planning procedure that start from macro to micro through a number of phases to achieve better results and less rework. The layout planning procedure cycle aims to help production engineers to plan an efficient arrangement of the required operations using the required area foot print of each operation. Moreover, the concept of the layout must be satisfactory before the operations are planned in detail (Zandin, 2001). Three different layout project life cycles have been reviewed in publications by Muther (1974), Phillips (1997) and Zardin (2001). All layout planning life cycles differ slightly with either an additional phase in the beginning or ending. However, all planning life cycles have four identical common phases: location, general layout, detailed layout and implementation, as can be seen Figure 8.

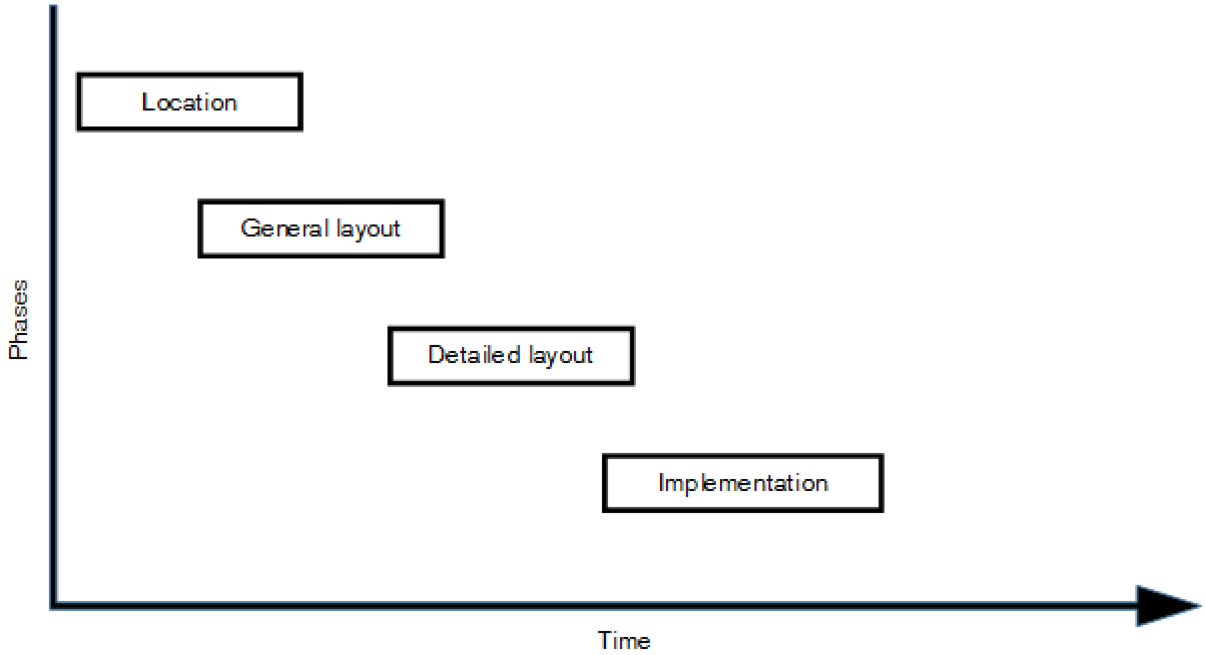


Figure 8: Core phases of factory layout planning life cycle

Location consists of determining the location where the layout is to be laid out. It can concern about designing a new plant, but redesigning an existing plant or rearranging several locations is more common (Muther, 1974; Phillips, 1997).

General layout consists of establishing the general arrangement of the operations as a block layout in the selected location (Muther, 1974). In this phase, the basic flows patterns and area allocations are determined in such a way that it roughly establishes the general size and configuration of each area and the relationships and major flow patterns between these areas (Muther, 1974; Phillips, 1997). Zardin (2001) also mention that this is the main planning phase where the business strategy and focus are integrated to block layouts. Muther & Wheeler (1962) argues that optimal efficiency cannot be reached without having a correct block layout, because moving the details later cannot fix what was missed in the block layout. Block layouts are also known to be the output from *the facility layout problem (FLP)* (Singh & Sharma, 2006) which purpose is to plan the physical structure of the production system using either optimal or suboptimal algorithms or manual planning methods.

Detailed layout consists of arranging all the equipment or physical features within each block (area of an operation) in the block layout as well as creating utilities and services (Muther, 1974; Phillips, 1997; Zardin, 2001). The difference between detailed layouts and block layouts is that detailed layouts are operational (Zardin, 2001). According to Phillips (1997), detailed layouts can be visualised by either drawings, layers of 2D CAD models, or even 3D models.

Implementation consists of planning the schedule to implement the new production layout to minimise disruption for other ongoing production operations and then actually implemented it. The major part of this phase is the planning (Phillips, 1997).

2.3.2 Success-promised planning principles

In order to handle the future challenges, Weindahl & Hernández (2006) outlined nine success-promised factors for factory planning which are aligned with the goals of efficiency, attractiveness and transformability, which are essential for future factory planning. This success-promised principles can be seen Figure 9.

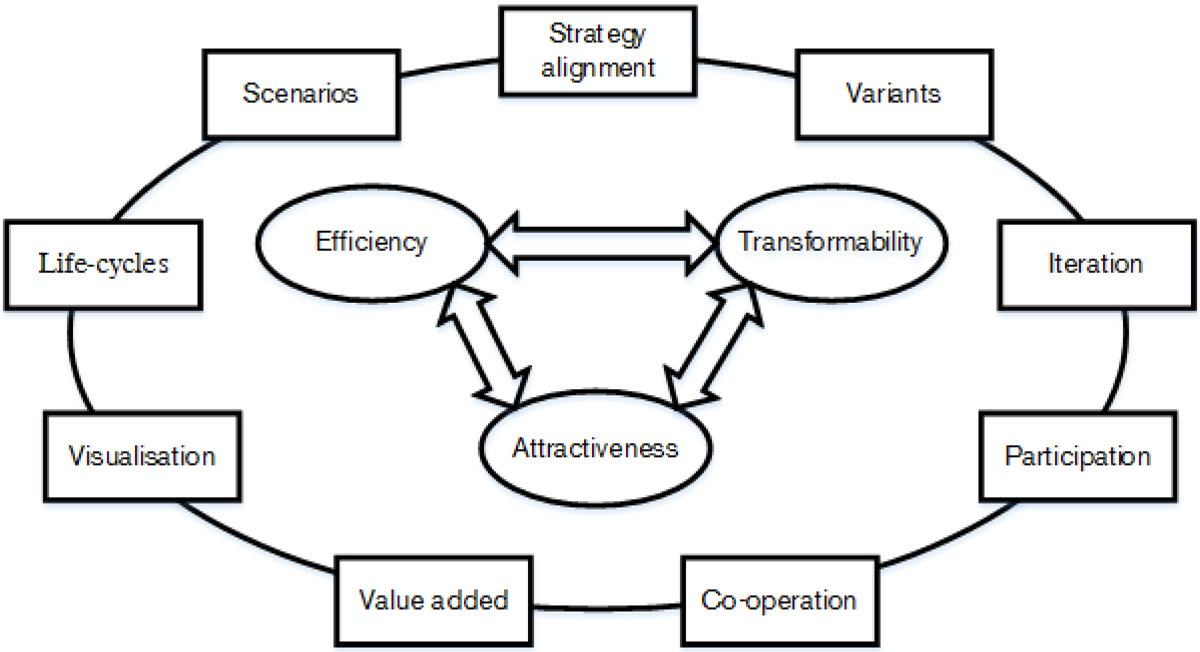


Figure 9: Success-promised factory planning principles (Weindahl & Hernández, 2012)

Principle of strategy alignment concerns about translating the business-strategy and visions into factors that can be used on a factory planning level in order to achieve the overall strategy (Ibid). *Variants* mean that it is important to plan many different realistic solutions which are transformed from an ideal solution due to internal restrictions (Ibid). With *iteration* means that the planning procedure should be stepwise that grows in detail based on previous results and it should be easy to return to prior steps for corrections (Ibid). *Principle of participation* concerns about the importance of involving co-workers especially in the fine tuning in order to decrease planning time and gain acceptance of the results (Ibid). *Co-operation* also aims to decreases the planning time by synchronizing the different discipline through cross-functional workshop planning to deal with the dynamic environment (Ibid). *Principle of value added* is rooted in Lean production as it concerns about aiming to decrease waste when planning to layout to achieve a better solution with lower throughput time (Ibid). *Visualisation,* as previously mentioned, concerns about that it is important to visualise the results from each planning step (Ibid). *Principle of life cycle* means that it is important to consider all the future life-cycles when planning the factory, e.g. life cycle of product, building and manufacturing processes. *Scenarios* mean that the factory should be planned for future scenarios so that the layout can be adjusted for potential changes in the future (Ibid).

2.4 Simplified systematic layout planning

Simplified systematic layout planning (SSLP) was created by Muther & Wheeler in the 1960 and is one of the most applied layout planning methods (Johansson, 2008). SSLP is a stepwise planning method which is divided in six planning steps (Johansson, 2008; Muther, 1974; Muther & Wheeler, 1962), which follows a logical sequence and cover the core parts of any layout planning project (Muther, 1974). The SSLP workflow is briefly visualised in Figure 10 and will be described more in detail below:

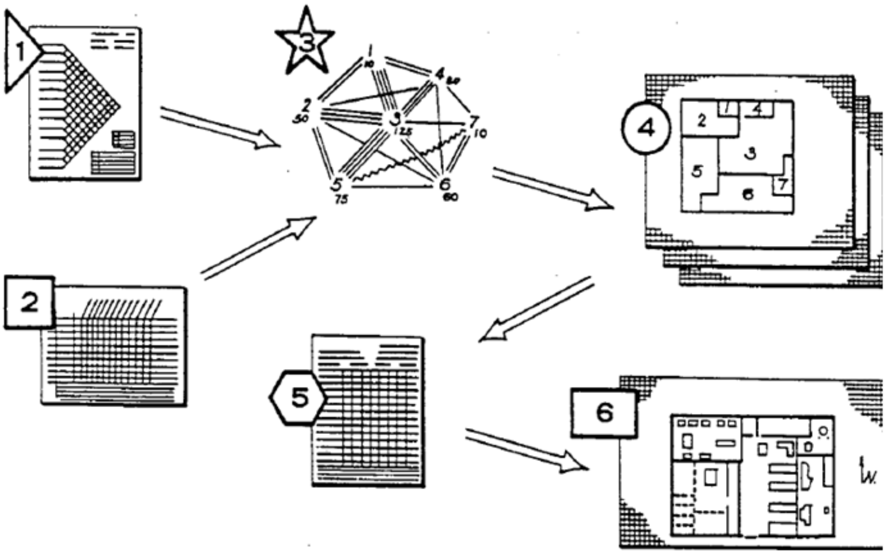
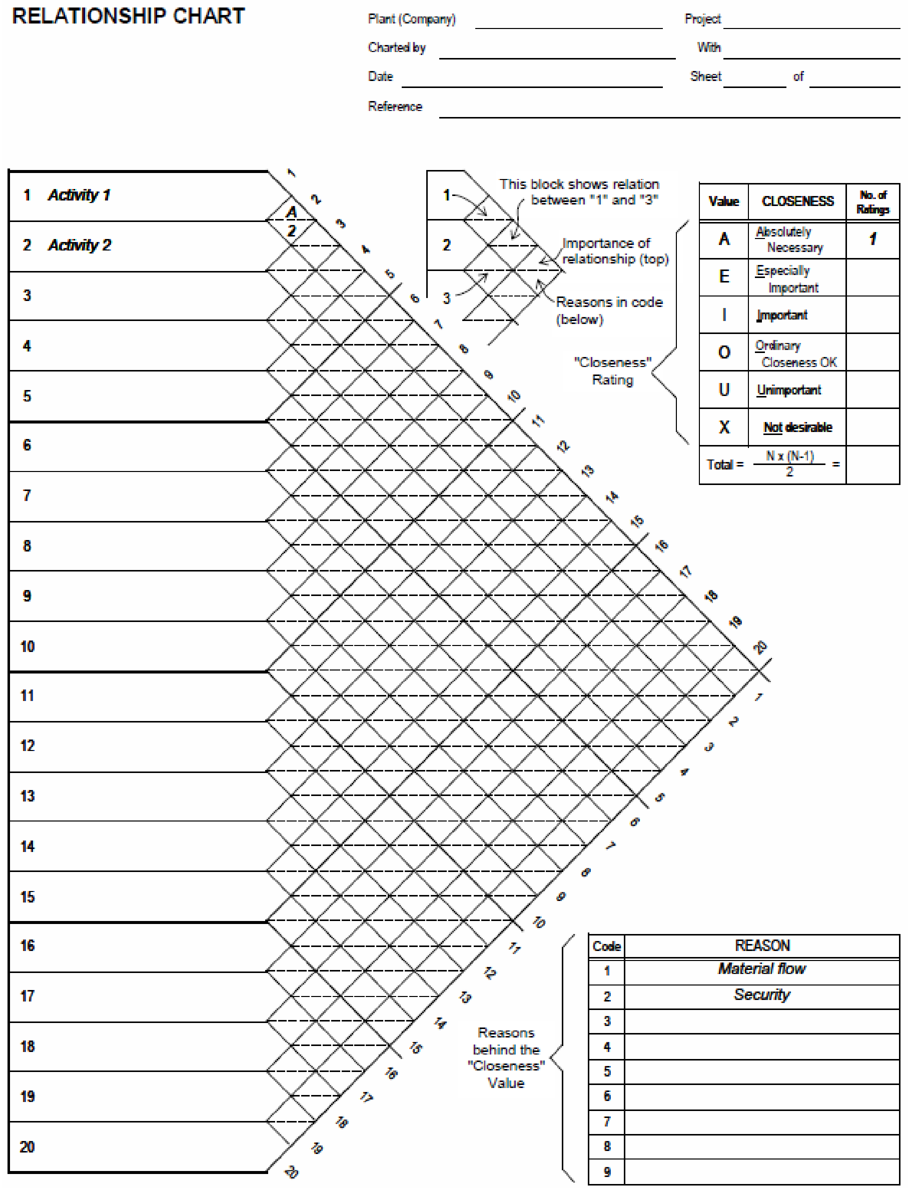


Figure 10: The six steps of SSLP (Lindskog, 2012)

2.4.1 Step 1 – Chart the relationships

The first step is to determine the relationship between functions, i.e. determine the closeness to one and another (Muther & Wheeler, 1962). This is achieved by mapping all the concerned functions and inserts them into a relationship chart, which can be seen in Figure 11. In the chart is the desirable closeness of each activity pair rated in the upper triangle. The rating system used is the vowel-letters A (Absolutely necessary), E (Especially important), I (Important), O (Ordinary closeness) and U (Unimportant). Also, the letter X (Not desirable) is used to show a relationship that should be avoided. Each rating is documented with a control number, in the lower triangle, which represent the underlining reason of the rating. Muther (1974) stated a guide line or common occurrence is that approximately 75 percentages of the relationships will be rated U due to the common nature of production flows. By documenting the closeness and the underlining reasons creates a dependable process, which makes it possible to document and control the ratings later (Ibid).



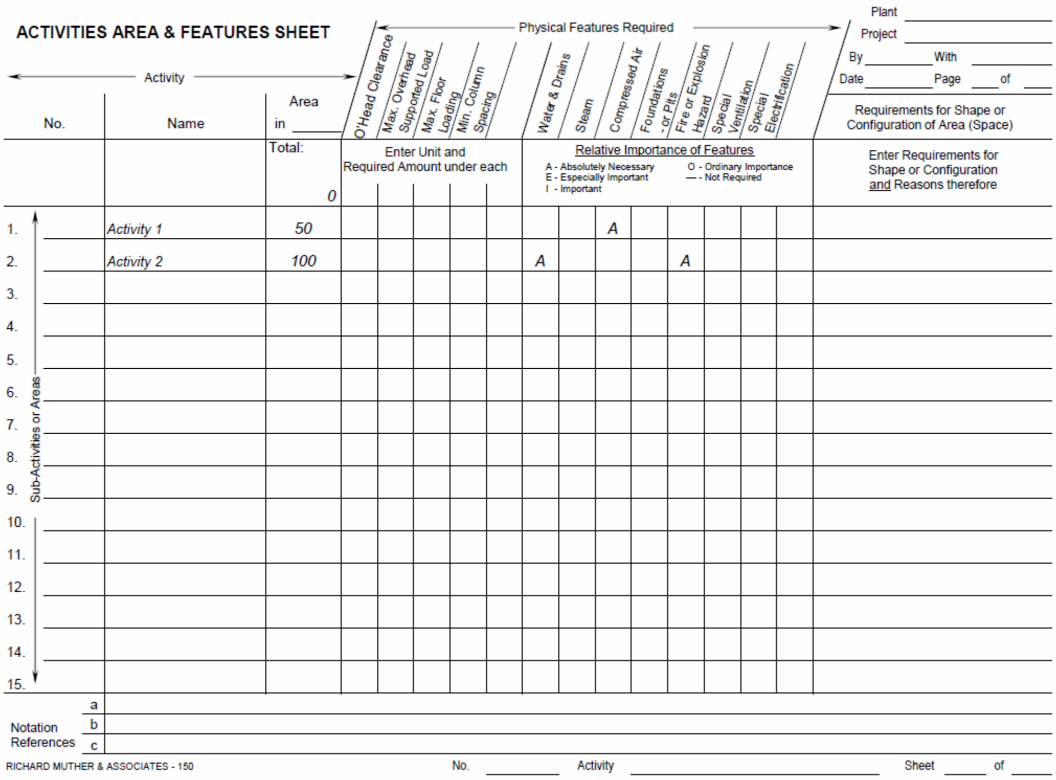
Value	CLOSENESS	No. of Ratings
A	Absolutely Necessary	1
E	Especially Important	
I	Important	
O	Ordinary Closeness OK	
U	Unimportant	
X	Not desirable	
Total = $\frac{N \times (N-1)}{2}$ =		

Code	REASON
1	Material flow
2	Security
3	
4	
5	
6	
7	
8	
9	

Figure 11: Relationship chart (Muther, 1974)

2.4.2 Step 2 – Establish activity requirements

The second step is to determine the activities requirements, e.g. area, height, gas line, water, compressed air, etc. (Muther & Wheeler, 1962). This is achieved by inserting the same functions as in step 1 in the activities' requirement sheet, which can be seen in Figure 12. In the sheet the area needs to be established and documented for each function. Moreover, the special facility requirements are documented, e.g. overhead clearance, max floor load, etc. Then the special utilities and equipment that are required to operate and maintain the functions are documented, e.g. gases, water, special electricity, etc. Lastly, the shape of the area is specified for each function (Ibid).



ACTIVITIES AREA & FEATURES SHEET

Plant ____
Project ____
By ____ With ____
Date ____ Page ___ of ___

Activity: No.	Activity: Name	Area in ____	Physical Features Required: O'Head Clearance	Max. Overhead Supported Load	Max. Floor Loading	Min. Column Spacing		Water & Drains	Steam	Compressed Air	Foundations or Pits	Fire or Explosion Hazard	Special Ventilation	Special Electrification		Requirements for Shape or Configuration of Area (Space)
		Total: 0	Enter Unit and Required Amount under each					Relative Importance of Features A - Absolutely Necessary E - Especially Important I - Important O - Ordinary Importance — - Not Required								Enter Requirements for Shape or Configuration and Reasons therefore
1.	*Activity 1*	*50*								*A*						
2.	*Activity 2*	*100*						*A*				*A*				
3.																
4.																
5.																
6.																
7.																
8.																
9.																
10.																
11.																
12.																
13.																
14.																
15.																

Sub-Activities or Areas

Notation References
a ____
b ____
c ____

RICHARD MUTHER & ASSOCIATES - 150 No. ____ Activity ____ Sheet ____ of ____

Figure 12: Activities' requirements sheet (Muther, 1974)

2.4.3 Step 3 – Create activity relationship diagram

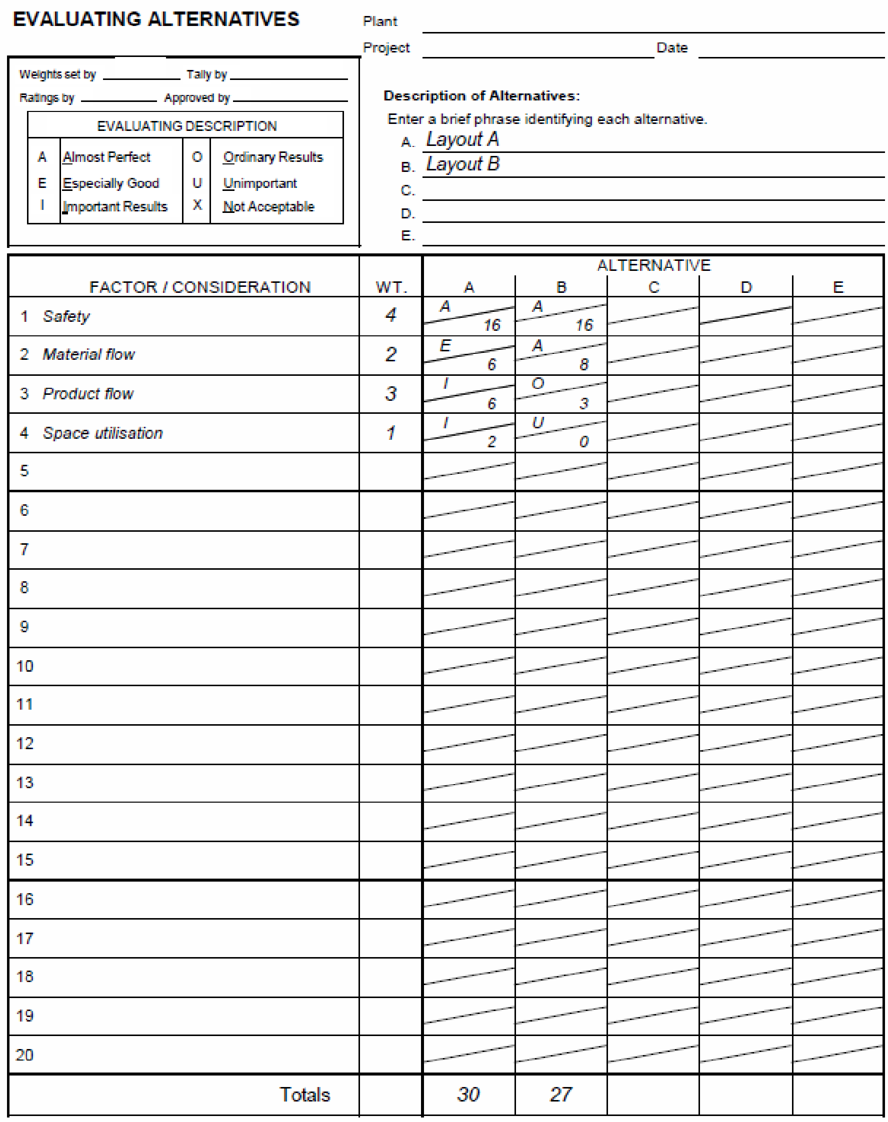
The third step is to conclude and visualise the relationships of the system and create a base pattern of the layout (Muther & Wheeler, 1962). This is done by drawing an arrangement of the activities based on the relationships chart where the closeness rating should be represented in the diagram, i.e. the ratings should be drawn in the order as the importance decreases. Start by selecting a symbol for the activities and then start drawing the relationships with A-closeness, which are represented with 4 parallel lines. Then add all relationships with E-closeness (three parallel lines). Then continue with adding the relationships with I-closeness, (two parallel lines). Then continue with adding relationships with O-rating (normal line) and X-rating (wave line) to the diagram. However, if there are a lot of X-ratings it can be better to draw them earlier. Then the relationship diagram is rearranged until all activities are placed as good as possible. Lastly, in the diagram is the specific area requirement for each activity noted (Ibid).

2.4.4 Step 4 – Generate different layout arrangements

The fourth step is to produce different block layouts based on the relationship diagram (Muther & Wheeler, 1962). This is done by creating a template of the available area. Then expand the relationship diagram with the noted areas and realistically fit the diagram into the available area. Then continue to redraw different solution based on different modifying factors, e.g. sewers, pillars, walls, general flow pattern, transport aisle, etc. Three to four different solutions are normally sufficient before moving to the next step (Ibid).

2.4.5 Step 5 – Evaluate alternative arrangements

The fifth step is to determine the most sufficient block layout for the production system (Muther & Wheeler, 1962). This is done by evaluating the layout from step four using the evaluation worksheet, which can be seen in Figure 13. First it is important to define and weight the evaluation factors that are important for the company and production layout. The factors should be weighted in a descending manner, where the most important factor is the weight value. The different layouts are named in the evaluation sheet and should be marked with the corresponding letter, A, B, C, etc. Then the solutions are rated for each factor using the same vowel-rating system, A (Almost perfect), E (Efficient), I (Interesting), O (Ordinary), U (Unimportant) and X (Unwanted). After the rating is performed are the factor scores concluded by multiplying the factor weight with the rating A=4, E=3, I=2, O=1, U=0 and X=-. Then all factors are summed up and the block layout with the highest value is the best candidate to be detailed in next step. This way of evaluation ensures that no important factor is forgotten (Ibid).



EVALUATING ALTERNATIVES

Plant ____________________

Project ____________________ Date ____________

Weights set by ________ Tally by ____________

Ratings by ________ Approved by ____________

EVALUATING DESCRIPTION			
A	Almost Perfect	O	Ordinary Results
E	Especially Good	U	Unimportant
I	Important Results	X	Not Acceptable

Description of Alternatives:

Enter a brief phrase identifying each alternative.

A. Layout A
B. Layout B
C.
D.
E.

			ALTERNATIVE			
FACTOR / CONSIDERATION	WT.	A	B	C	D	E
1 Safety	4	A 16	A 16			
2 Material flow	2	E 6	A 8			
3 Product flow	3	I 6	O 3			
4 Space utilisation	1	I 2	U 0			
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
Totals		30	27			

Figure 13: Evaluation sheet (Muther, 1974)

2.4.6 Step 6 – Detail the selected layout plan

In the sixth and last step is the best ranked block layout detailed to a complete layout, which can be used as material to implement the new layout (Muther & Wheeler, 1962). This is conducted by drawing the selected block layout in an appropriate scale. Then name the functions in respective area and highlight the structural features, e.g. walls, pillars, etc. Then start planning the work area in detail by drawing and identifying all necessary equipment and machines. Moreover, insert the scale and important measurements. The final layout should be so detailed that the implementation team does not need additional documentation to complete the physical layout (Ibid).

3 Current practices and Atlas project

This chapter will briefly present the current development practices at the company and production engineering department, as well as the Atlas project. The underlining reasons which initiated this thesis and shaped the research methodology are also presented.

3.1 Practices on company level

Danfoss Group has developed a standardised project methodology called Danfoss Milestone Plan, to locally guide Product Development Program (PDP) projects within Danfoss Group. The Danfoss Milestone Plan can be seen in Figure 14. The methodology is built up by mandatory milestones (red diamonds), critical integration points (yellow circles) and tasks in between. Moreover, the main purpose of the milestones is to act as check-points where crucial data are provided to the management for decision making in implanting the project.

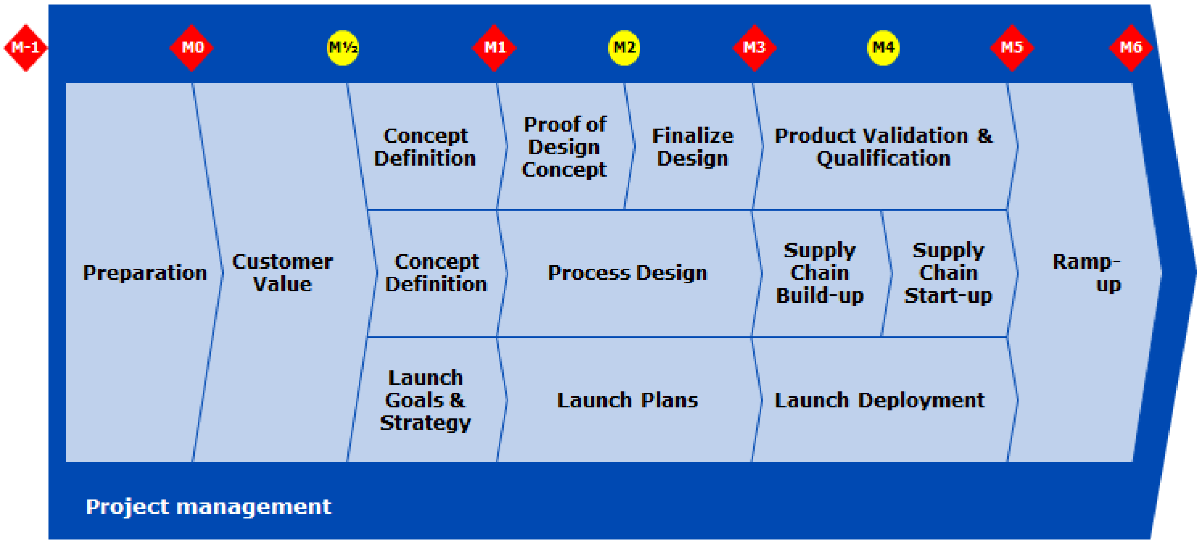


Figure 14: Danfoss Milestone Plan

The first phase between M-1 and M0 can be categorised as the preparation phase, where the project groups, workshops teams are formed and the supply chain strategy are settled. Next phase between M0 and M1 can be categorised as the concept phase, which starts with gathering and mapping customer data. Afterwards, the work flow is divided into three parallel work flows: the top flow is the product development where the research & development (R&D) department is the main driver with the supports from other related departments; the middle flow is the supply chain development where the production engineering department together with logistics and purchasing are the main drivers with support from other functions; and the bottom flow is the launch development where the marketing and sales departments are the main drivers. The phase between M1 and M3 can be categorised as the detailed phase, where the supply chain and product are detailed and the launch plans are created. The phase between M3 and M5 can be categorised as the implementation phase, where the production and supply chain are built and validated. Last phase between M5 and M6 is the ramp-up phase, where the new supply chain system is ramped-up before full production is started and the project completed.

Danfoss Milestone Plan provides a clear overview of the project procedure. The plan is then further detailed into standardised deliverables for the different work streams and this thesis will focus on the supply chain work stream and the production engineering department. The deliverables have instructions which state the purpose, definition and actions for each task. Moreover, the instructions state the roles and responsibilities of involved parties and also the authorized parties to approve the results. As seen in Table 3, the production engineering department is responsible of (re)designing the supply chain from strategy to ramp-up (Danfoss's definition of supply chain is equivalent to production system in this thesis). However, most deliverables are carried out cross functionally to align all work streams, i.e. production engineers drive the assignment with support from necessary functions for the deliverables in action to ensure that the production system, product and launch plans are aligned throughout the PDP projects, e.g. product design engineers, advanced quality engineers, logistics, launch owner, supply chain controller, etc.

Table 3: Supply chain work flow deliverables at Danfoss

Work stream	M0	M1	M3	M5
Production Engineering and Manufacturing	Supply Chain Strategy	Supply Chain Concept	Supply Chain Design	Production Process Qualification
		Supply Chain Technology Assessment	PFMEA	Updated PFMEA
				Control Plans (Production)
				H+S Assessment
Strategic Purchase		Critical Suppliers Identified	Supplier Evaluation, Approval and Agreement	
Logistics			Ramp-up Plan Including Capacity and Capability	Update Ramp-up Plan

3.2 Practices on department level

The production engineering departments within Danfoss have access to a set of production engineering tools called *"Toolbox"* to assist daily production development and also during PDP projects. The *"Toolbox"* is a Danfoss Group standard which can be accessible at any time through the internal website. The contents of the toolbox are developed and managed by Lean experts in a centralised and global production development unit within Danfoss Group. The unit regularly visits the global factories to conduct the Danfoss Productivity Program (DPP), which has the purpose to reduce stocks and increase productivity, capacity and quality by locally applying the toolbox and training the company in the tools, philosophy and principles within the toolbox.

The production engineering toolbox is mainly based on Lean production and has been divided into six categories, which can be seen in Figure 15. Foundation category decides how to manage and audit the production and set production goals. Flow category consists of how to create lean production flows with the main tool called MIFA (Material and Information Flow Analysis), Danfoss's version of Value Stream Mapping (VSM). Organization category involves of spreading a lean DPP philosophy and culture of continuous improvement. Problem solving category has tools to measure and monitor the daily production and how to identify and eliminate the root cause of daily deviations. Quality contents category concerns about how to deal with quality issues and improve processes and work environment. Stabilisation category has tools and methods that concerns about how to handle and improve Standard Operating Procedures (SOP), maintenance, machine breakdowns and changeovers.

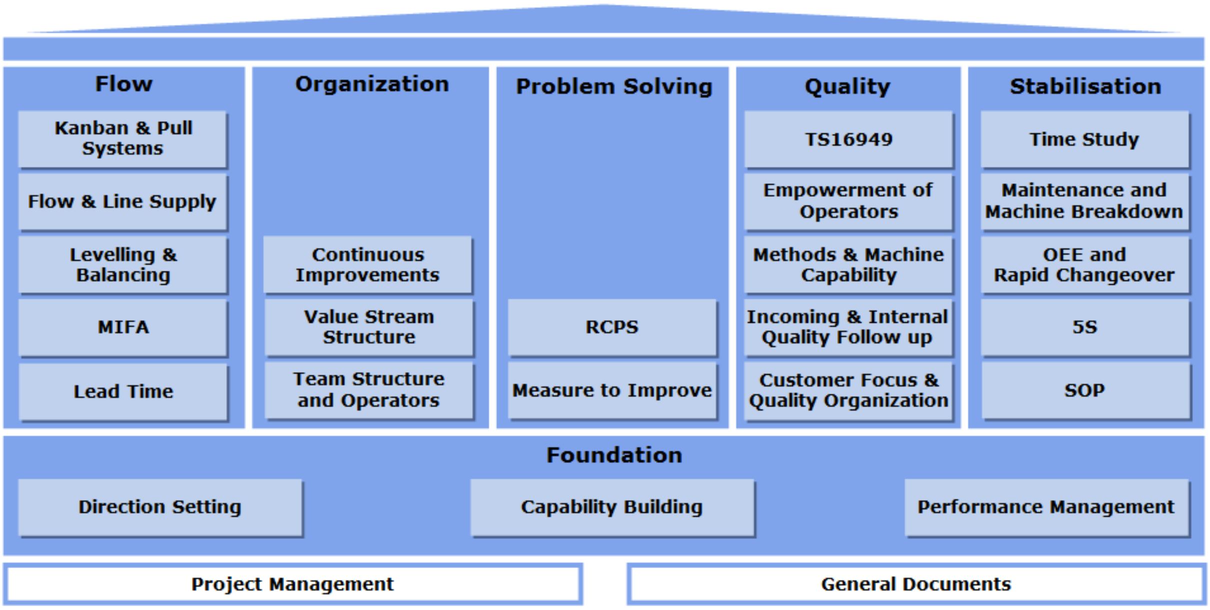


Figure 15: Production engineering toolbox at Danfoss

The production engineering department at the company, which will be referred as the department here on, consist of one manager and four engineers. The department's procedure for daily production development projects are conducted in a "use what is required" manner with the assistance from the toolbox. However, the common practice for all production development projects within the department is that the production engineers are assigned to lead and drive the project from problem incurred to new implementation. The lead engineer normally has supports from other production engineers as well as other departments during the development process. The collaborations are mostly conducted in workshops in order to obtain the right inputs and take right decisions. The co-operation commonly increases in number of people and workshops depending on the project's complexity and size.

During discussions with the production engineers, it was expressed that currently the department lacks experience and a structured layout planning method especially for large layouts. Since the production system are remodelled approximately every fourth to fifth year because the production system can often be reused by only changing tools and fixtures when a new product family is introduced. The production engineering manager and production engineer three expressed that this situation has most likely increased planning costs and time. Production engineer one expressed that this situation has most likely made them forget certain important things, which have forced them to focus on correcting the layout for long period after the implementation, instead of doing it right from the beginning. However, it was expressed that mostly the planning process starts with brainstorming ideas on the factory floor. Afterwards, different suggestions are generated and the engineer selects the potential solution based on the highest confidence level or *"gut-feeling"*. Afterwards, the selected layout used to be detailed and verified with physical mock-ups made of simple materials, e.g. pallets, boxes, etc. Previously, the department has utilised different techniques and templates to generate block layouts, e.g. Visio, whiteboard, paper, AutoCAD, etc. Production engineer one and three expressed that the 2D CAD drawing of the factory has previously been used to generate layout proposals. However, sometimes the 2D drawing was incorrect which has forced the process to restart while building the physical mock-up or implementing the layout. Also, currently only production engineer one is confident working with the 2D CAD drawing.

3.3 The Atlas project

The Atlas project was initiated to develop the next model of geothermal heat pumps. Due to the current production system suffered from both capacity and change constraints, the project management had decided that concurrently with the product should a new production system be developed. This thesis was started approximately midway into the task "Concept definition" and was intended to last until M3 with the focus to plan the Atlas layout while developing a suitable planning method which the department can obtain to complement the toolbox. Moreover, to further develop the methodology for 3D laser scanning by extending it with the concept phase. As previously mentioned, the underlining reasons for the focus are due to the department had little experience of major layout planning and the toolbox lacked a structured method to guide the department. In Figure 16 have the Danfoss Milestone Plan been updated with a black rectangle to highlight the duration and focus area of this thesis.

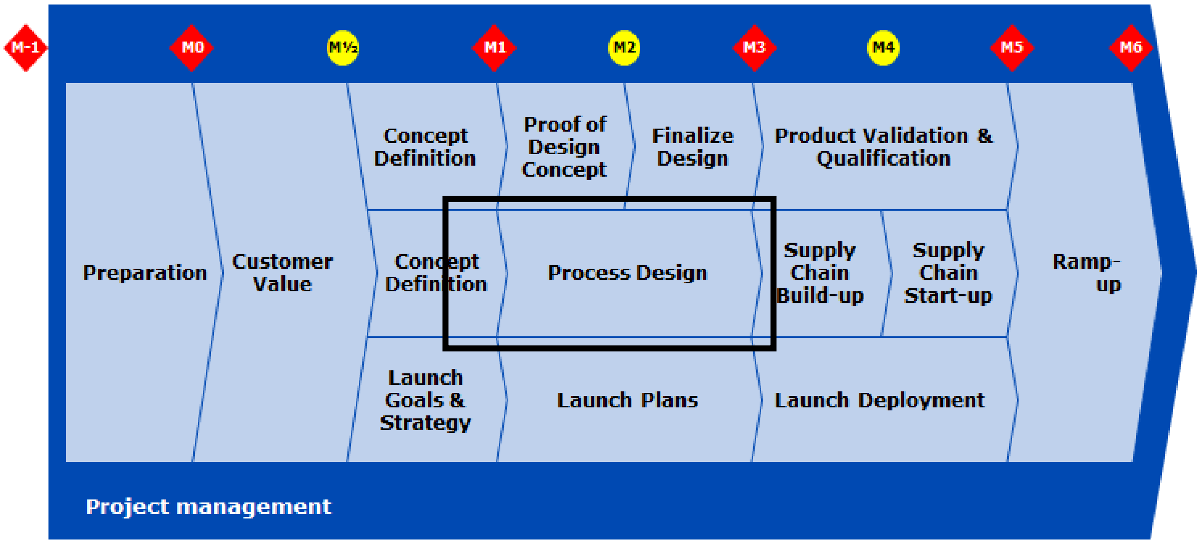


Figure 16: Thesis alignment with the Atlas project

4 Research methodology

This chapter will describe the designed research methodology conducted in this thesis to plan the future production layout and answer the research questions. Before the procedure started, the research methodology was presented to the department which was openly acknowledged and supported.

4.1 Research approach and method

Research is defined as a systematic and scientific investigation to discover new knowledge in a specific field or topic. The purpose of research is to answer the research question(s) (Kothari, 2004).

The research methodology in this thesis has been carefully designed based upon the thesis purpose and current state in order to achieve the thesis objective. Prior to the research started, the research methodology was presented to relevant parties and gained highly acceptance and support. The research methodology will be described in detailed in the following sections.

4.1.1 Qualitative approach

Qualitative approach enables the researcher to collect opinions and personal data from participants at the site where the issue is experienced. Moreover, qualitative research is emergent meaning that the processes can evolve during the procedure (Creswell, 2014).

Qualitative approach was selected for this thesis to able collecting in-depth data from workshop observations, documents and personal interviews in order to understand factors and contexts that influence layout planning and visualisation so that the research questions can be answered and both 3D-SSLP and 3D-Block can be further developed. Moreover, the research approach had to be emergent as action research was the required method.

4.1.2 Action research method

Action research is known as participatory action research and the purpose is to learn through actions. The researcher has to use a range of skills to achieve the purpose such as careful planning, listening and observation, evaluation and critical thinking (Koshy et al., 2010). The strength of action research is the focus on solving practical problems by involving practitioners in the research, development and implementation (Koshy et al., 2010). According to Kemmis & McTaggert (2000) is action research best conducted in collaboration with co-participants and the process itself is social, educational, critical and reflective. Ideally all participating researchers should be involved in the research steps before applying the findings, i.e. collecting data, analysing data, planning and implementing actions, and reflecting (Koshy et al., 2010). Moreover, action research is situation-based or context specific (Kemmis & Mctaggert, 2000; Koshy et al., 2010). The action researcher act as facilitator, hence, the researcher does participate, influence and contribute in the research. As the researcher is involved on an intimate level makes the research account the participants' daily practices or day-to-day routine work (Koshy et al., 2010). The model for action research has been defined in different ways and the chosen model for this thesis is a progressive iterative cycle defined by the four following steps: planning an action; act and observe the process; reflect on the outcome; Revise old action plan or plan new action (Kemmis & McTaggert, 2000). The chosen action research model can be seen in Figure 17. However, action research reports depend on reader's consideration of the human context, hence, it is important to include contextual details (Koshy et al., 2010).

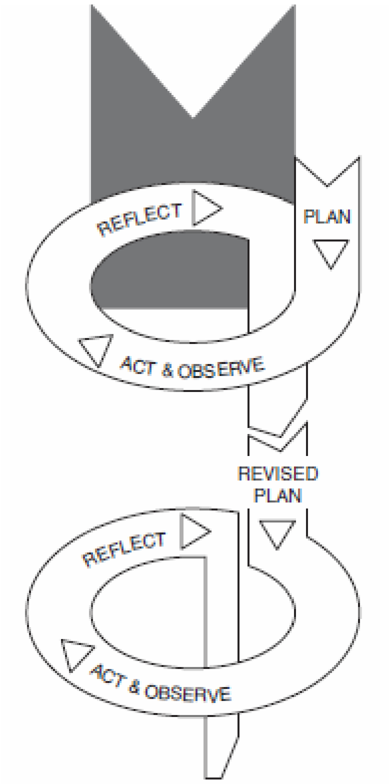


Figure 17: Action research spiral (Kemmis & Mctaggert, 2000, pp. 278)

Action research was necessary to be applied in order to achieve an emergent study where the employees were trained throughout the procedure to fill the knowledge gap and to ensure the research was flexible to handle the company and department context and practices. Moreover, the iterative and emergent action cycle made it possible to naturally develop 3D-SSLP and 3D-Block according to feedback from the participants in pilot session of the layout planning steps.

4.2 Research procedure and data collection

The research procedure was conducted in 15 steps together with a literature review and current state mapping. A summary of the research procedure is visualised in Figure 18. The steps were categorised in four categories: preparation, training, planning and evaluation. Preparation steps were conducted by the project leader to gather data and prepare material to drive the procedure forward and make the steps efficient. Training steps (pilot sessions) were done to train SSLP and 3D laser scanning as well as test and refine the planning steps based on the design team's feedback. The planning steps were conducted to plan the Atlas layout using the revised version of the training step. The planning steps were performed with both the design team and cross functional team. Initially, the duration of two hours was allocated for each workshop. The evaluation step was performed using personal interviews with the design members to obtain in-depth data from the research procedure in order to answer the research questions and suggest further development.

The author's role was assigned to be the leader for planning the Atlas layout, which will be referred as the project leader here on. In addition, the project leader developed, planned and moderated the steps and trained the design team simultaneously. The project leader was also responsible to ensure that all documents were timely updated. The production engineering manager acted as an assistant project leader to clearly understand all steps of 3D-SSLP (both planning and preparation steps) and give feedback for further improvements. The production engineers acted as the design team since the department was responsible of designing the Atlas production system. The design team was attended during the training and planning workshops to collectively present data and ideas. According to the discussion among the design team, it was concluded that the logistics department was required to be involved with the project in order to obtain sufficient material flow data for the Atlas layout. Thus, a cross functional team (design team and logistic department) was formed to gain additional material flows data during the first planning step (Step 3). The following sections will in chronological order motivate and present in details the conducted data collection and steps.

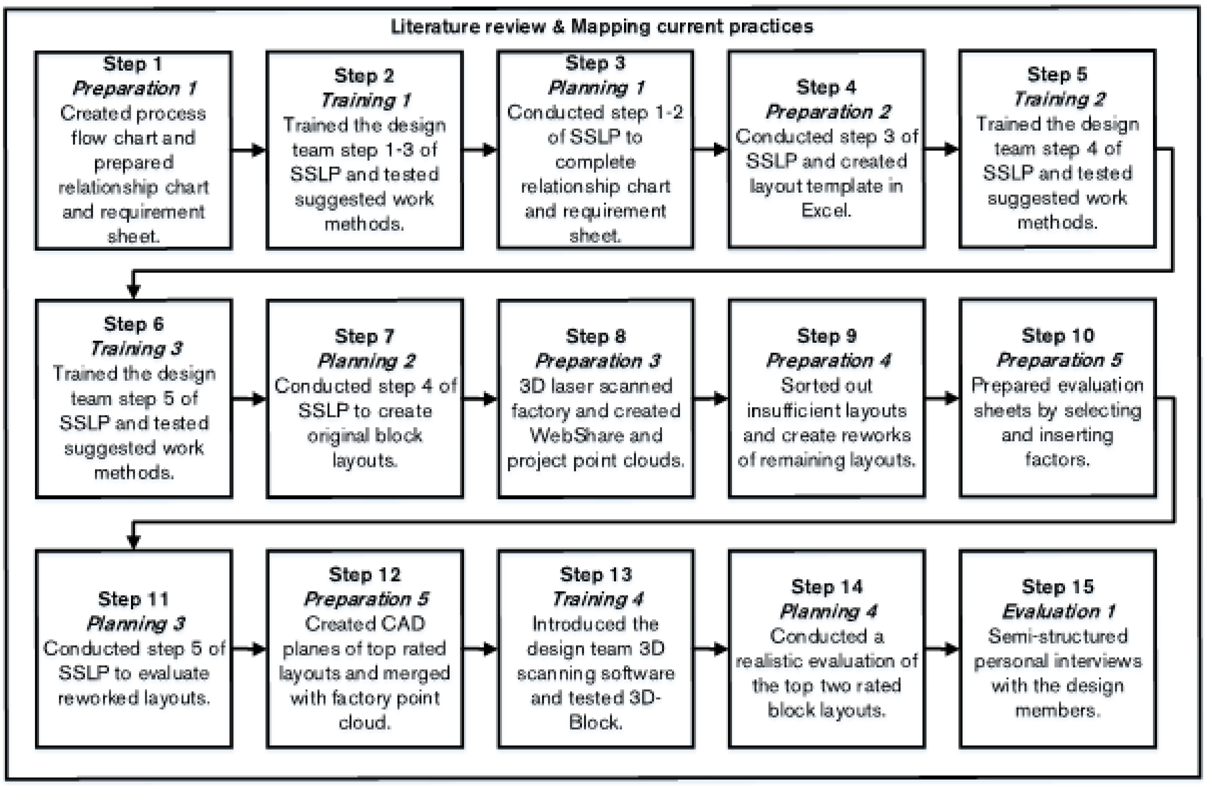


Figure 18: Summary of the research procedure conducted in this thesis

4.2.1 Literature review

The literature review was conducted in parallel with mapping the current state and the research steps in order to gain necessary knowledge required to plan and perform an adequate study. To create and design a sufficient procedure, it was crucial to study different research designs and methods. Moreover, it was necessary to gain deep insight in current methodologies for layout planning and 3D visualisation to contribute to the field of study. SSLP was reviewed in details to create a well-planned block layout and grant proper training for the production engineers to sustain the knowledge within the department. Furthermore, manuals for different software were studied to ensure smooth processing and modelling during the project.

4.2.2 Mapping current practices and Atlas project

The current development practices were mapped throughout the thesis to understand the work processes and project management within the department and the company. The reason for mapping the current state with Atlas project was to understand how to adapt and introduce a layout planning method that was aligned with the current development approach. The data collection was primarily done by attending and observing project meetings and employees daily routine. Secondarily, internal documents from the database were reviewed to gain broaden understanding of the organisation's project management approach and the applied production engineering tools. Moreover, the discussions were continuously conducted with the production engineers in order to confirm the observations and understanding.

4.2.3 Workshop method

Workshop method was selected to form a platform for training the design team. This approach was also applied to collect and align the planning data for the Atlas layout as the method pro-actively engage participants to participate, share and evaluate the topics through open discussions. Moreover, the department and company had previous experiences of conducting workshops during development projects. Moreover, workshops facilitated the success-promised planning principle of *participation* and *co-operation,* see Section 2.3.2.

The training workshops were performed to ensure that the participants obtained the *"Learning-by-doing"* training and also were able to assist in developing the layout planning method by gathering the participant's feedback. This will assist in creating a practical and efficient method for the industry.

The planning workshops were conducted to ensure that all ideas were presented so the right decisions and trade-offs could be made for the production layout. The planning workshops were conducted both with design team and cross functional team. Moreover, the design team was aware of the layout concept and involved from the beginning of the design procedure. This resulted in a positive effect on the quality of the feedback during the evaluation (Step 13). Lastly, it provided a platform to align the view of the future layout among all design parties which simplified further development.

There were two risks identified and handled before the procedure started which are first the time management of planning session, there was a risk that the procedure will be prolong as it was quite challenges to manage the time to align with the participants' schedules. However, it can be eliminated by preparing complete input data before sessions and also conclude and share the output after sessions; this resulted in shortening the length of the sessions. Second, there was a risk that the participants were not comfortable to share ideas and be straightforward during the sessions. However, it was solved by creating an open and layback atmosphere within the design team and project leader.

4.2.4 Simplified systematic layout planning

SSLP was selected to plan the new production layout and to integrate with 3D laser scanning to develop and evaluate the new proposed methods of 3D-SSLP and 3D-Block. The method was selected because the author had previous experiences of the method from the education and knew it was time-efficient, practical and suitable to *"Learning-by-doing"*, which were suitable for the company. SSLP does not include and start with the comprehensive material handling analysis as the full version Systematic Layout Planning (SLP), but it still includes the intuitive planning steps and the material flows can still be considered in the relationship chart. SSLP can always be expanded to SLP for future requirements and changes. Moreover, SSLP facilitated the success-promised planning principles *iteration*, *variants* and *visualisation* through the method itself, but also the relationship chart could be used to plan the relationships based on the principles *value added, strategy alignment* and *life cycle*, see Section 2.3.2. Thus, SSLP was a sufficient method to close the knowledge gap and be the base for 3D-SSLP.

However, some modifications were done to SSLP because it was intended to use 3D laser scanning to add a realistic evaluation step for the evaluated block layouts. The modification was that the fifth step of SSLP was not going to produce a final block layout but only rank the block layout based on the scores instead and make another evaluation using 3D-Block. Moreover, during the middle of the thesis, the Atlas project got shut down, because the product design became too expensive. Thus, there were no resources to carry out the sixth step of SSLP as initially intended which was to conduct cross-functional workshops with production employees and 3D-Block to detail the layout. Thus, it was also aimed to examine whether SSLP and 3D laser scanning could be integrated to create a modern layout planning method that is practical and efficient for the industry.

4.2.5 Step 1 – Preparation step 1

The procedure started by mapping and creating a flow chart of the Atlas process flow in order to gain understanding of the production system and make the first workshop efficient with input data. The process flow data was gathered by reviewing documented project data regarding to the Atlas production system. The department had created a supply chain strategy and concept of the production system prior to the thesis started. The future state was the main reference for producing the flow chart. Moreover, the flow chart was drawn into details based on the Atlas workshops and meetings with the related parties. Once the draft was completed, the flow chart was reviewed by one design member to ensure that all details were accurate and easy to understand. Lastly, the process flow chart was reviewed and approved by production engineering manager. Moreover, the area of each process was documented to make the first planning workshop more efficient. The area data was gathered by measuring current processes with assistance from a design member. The area data was reviewed and approved in the same way as the flow chart to ensure the validity of the data. In addition, before the procedure began were a SSLP guide and required worksheets for SSLP (relationship chart, requirement sheet and evaluation sheet) acquired from Muther & Wheeler (1962) and Muther (1974) as they were to be used during the procedure. Lastly, a shared project folder was created on the internal server so that the guide, worksheets and planning data was accessible to the design team throughout the procedure.

4.2.6 Step 2 – Training step 1

Pilot four sessions were performed to train the design team and test for the workshops' duration and structure. As the project leader and author of this thesis was inexperienced as a workshop moderator and design team were inexperienced with large layout planning and SSLP, training sections were held to ensure that all participants were familiarised with the method and procedure before focusing on planning the Atlas layout.

During the first training workshop, the three first steps of SSLP were trained (gathering and visualising the in data) and the relationship chart and requirement sheet were reviewed. The session started with presenting and explaining the steps and work templates. Afterwards, a process flow chart, relationship chart and requirement sheet was distributed to each participant. Then the design members individually performed the steps for a sub-flow to the Atlas production system with the assistance from the project leader. The design team openly discussed and gave feedback about the work method which was continuously noted by the project leader to adjust and improve the step execution before the planning workshop.

4.2.7 Step 3 – Planning step 1

During the first planning session, the relationship chart and activities' requirements sheet were completed for the Atlas layout. Based on experiences and feedback from the first training workshop, the relationship chart and requirement sheet were prepared by inserting all the future processes and area requirements. Also, the requirement sheet was customised with additional columns to be able to document utilities that were special for this production. Moreover, the session was started by reviewing the process flow chart to confirm the process system and align the data with all the participants. Afterwards, the project leader lead the session by presenting the worksheets (starting with the relationship chart) using a projector and updated the worksheets in real time while the cross functional team discussed and provided inputs about the processes' relationship and requirements.

4.2.8 Step 4 – Preparation step 2

The activity relationship diagram was created by the project leader based on output from the first planning workshop, in order to be more efficient based on the experiences from the first training workshop, as it was not considered efficient to conclude the diagram with five people. Moreover, a layout template was created to assist design members in generating layouts more easily. The layout template was concluded by manually measuring the available area with a laser distance measurer and making a representation using Microsoft Excel as it had a natural grid system where one square represented one square meter to simplify the drawing process. In Figure 19 are the layout template presented. The fork-lift truck paths are visualised with dark grey, occupied areas with light grey blocks, structural pillars with black squares and lastly the white colour represented the available area. Also, the activities that already existed and were not going to be relocated were included. Furthermore, the maintenance department (bottom left corner) started relocating to the available area before the second training session and no one was able to predict the final size of the department. As a result, the planning session was postponed until the template was updated more precisely.

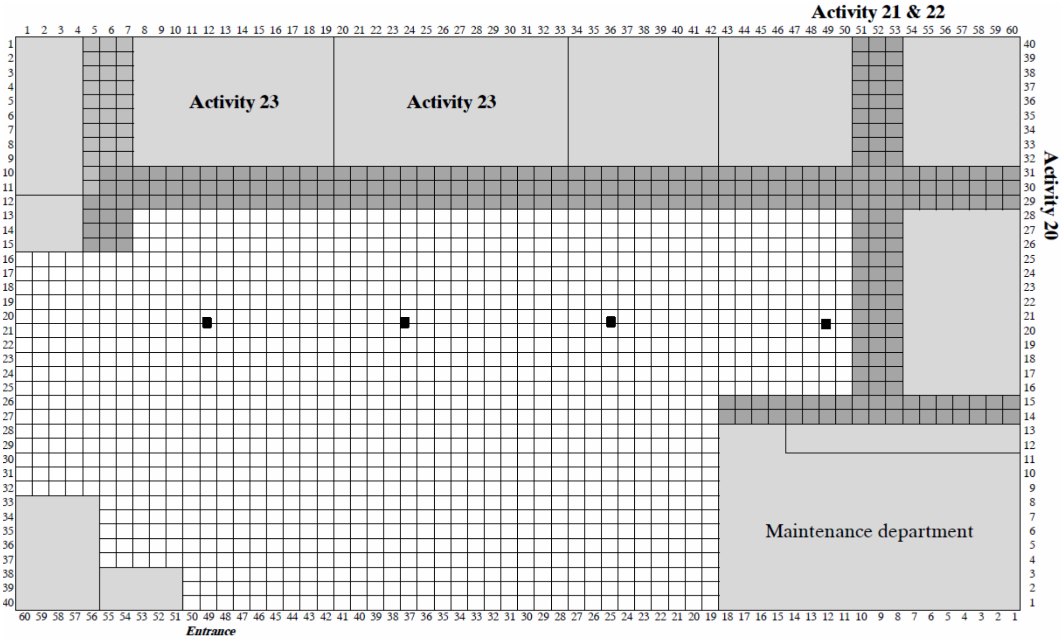


Figure 19: The updated version of the Excel-template

4.2.9 Step 5 – Training step 2

During second training step, the fourth step of SSLP (generating layouts) was trained and two drawing techniques were presented. In order to make the session more realistic to the planning step the project leader decided to practice directly with a large system instead of a sub-flow as in the first training session. Thus, the activity relationship diagram based on the first planning workshops was used to train. The session started with a brief introduction of the steps and two suggested drawing techniques. The first option was to directly draw on the printed layout templates. Whereas, the second option was to cover the layout template with a plastic folder and use whiteboard pens and then document the completed layout in a printed template. This option was more flexible to make changes in an attempt to reduce wasting papers. Then the relationship diagram was distributed and the participants got to choose a drawing technique. Afterwards, the design team practiced generating block layouts based on the relationship diagram. After the session were all the block layouts documented digitally and together with the layout template uploaded on the project folder to enable people to continue practice and make changes.

4.2.10 Step 6 – Training step 3

During the third training step, the fifth step of SSLP was trained and different commonly used evaluation factors were presented. In total it took four hours to complete the step, i.e. it required two sessions. The first session was started by the project leader distributed to the participants the evaluation worksheet, a document with the block layouts produced during the second training session and a document with commonly used evaluation factors which had been concluded by the project leader based on Muther (1974). Then the project leader briefly presented the fifth step of SSLP. Followed by the design team together reviewed the evaluation factors and discussed which factors were suitable for their production and the Atlas layout. Afterwards, the participants selected relevant factors and started practice evaluating the generated block layouts from the second training session. However, a lot of time had been spent involving the evaluation factors so the training step had to be extended with an additional session to complete the evaluation training.

4.2.11 Step 7 – Planning step 2

During the second planning session, the design team generated different block layouts for the Atlas layout in the same manner as the second training workshop with the additions that the layout template was updated by the project leader as the relocation of maintenance department was finished and the participants had access to use the computer to generate layouts as assistant project leader wished to directly utilise the computer, for more details, see Section 5.1.2. After the session, the Excel-template was replaced with a Visio-template, which can be seen in Figure 19. In the Visio-template, operator paths were included with yellow colour.

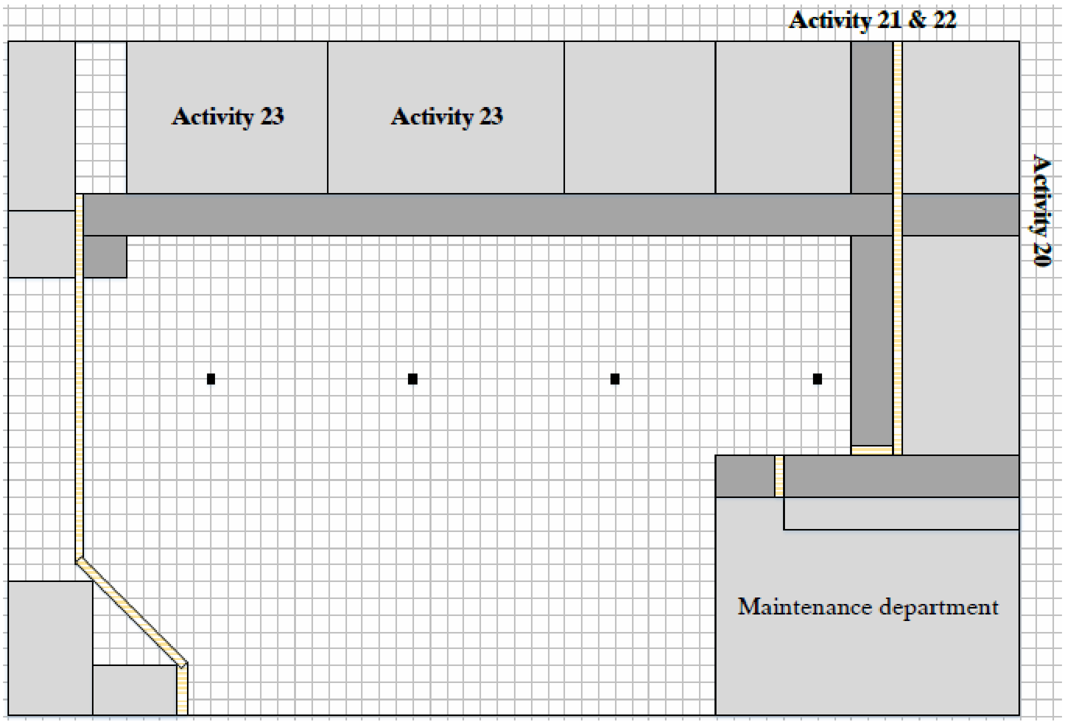


Figure 20: The Visio-template

In additional to the new template, pre-made activity blocks were drawn in the same scale and the different sub-flows were assign a different colour, which can be seen in Figure 21. The template and pre-made blocks were design based on the feedback and request from design member four, the reason will be presented in Section 5.2.3. The template sheets were shared to the design team so additional layouts could be created while the project leader performed step 8 which was expected to take a while

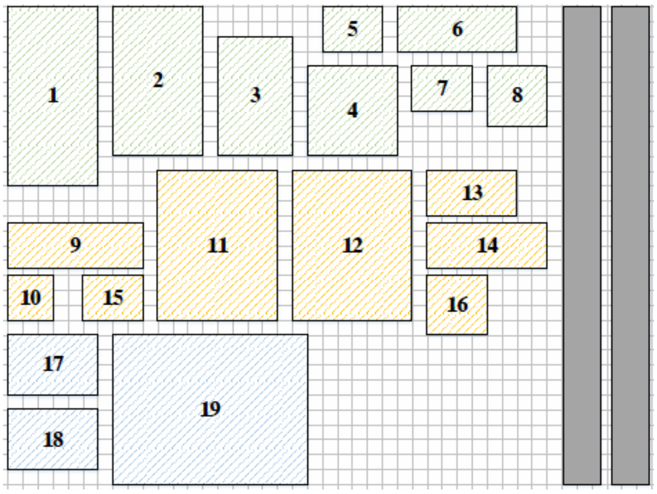


Figure 21: The pre-made activity blocks to move around on the template

4.2.12 Step 8 – Preparation step 3

In order to test and develop 3D-Block and 3D-SSLP, the factory and critical machines were 3D scanned. Further, the raw scans were processed to create project point clouds and WebShare data.

4.2.12.1 3D laser scanning of the objects

The 3D laser scanning was performed on 19th January 2016 with assistance from the supervisor, Jonatan Berglund. Berglund's role was to operate the laser scanner and consult with planning the scan positions and processing the raw data. The company had no internal reference system in the current CAD drawing of the facility, thus it was decided perform the scanning using natural reference objects in order to cover a larger area in lesser time. The scanning procedure was limited to three objects of interest: the available factory area and two critical test machines.

The available factory area was one large workshop area of approximately 2,400 square meters, see Figure 22. At the time, the company lacked warehouse space so the available area was used as a spontaneous material storage of old equipment, scrap material and final products, which will be referred as stored objects here on. Days before the 3D scanning were the stored objects that blocked line of sight to important structural features, i.e. pillars and roof beams, moved from the available area. As it was important to accurately scan pillars and roof beams because they had the potential to hinder the placement of large equipment, i.e. the test machines. The stored object that did not block structural features were not moved from the available area but instead stacked together or moved along the walls to simplify removing the unwanted points from the data set afterwards.

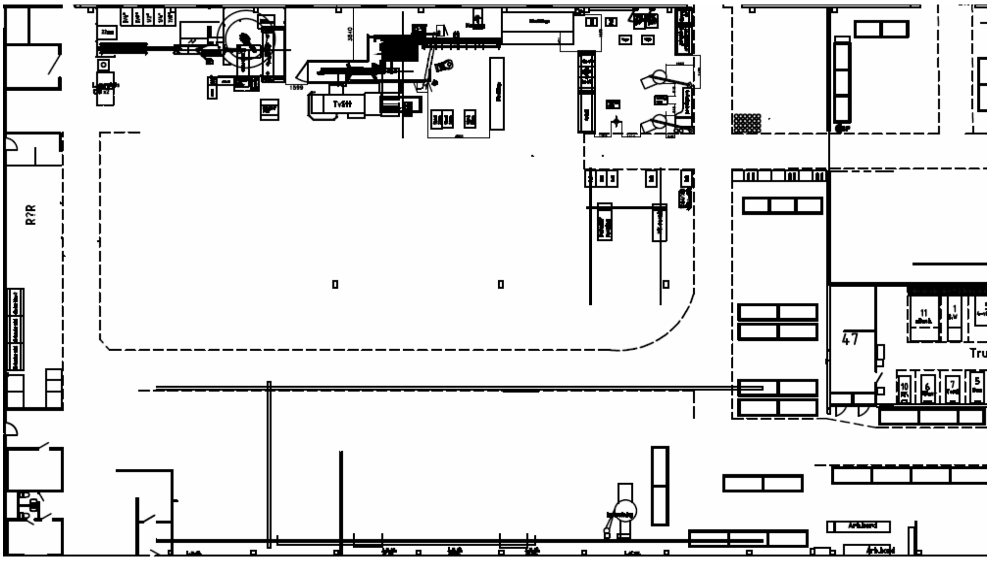


Figure 22: The factory facility for the Atlas layout (inaccurate schematic)

The two critical machines were scanned to ensure that no structural features interfered with the units and also to investigate the possibility to raise the machine units from the floor on a platform and only have the machine component that interacted with the product and operator still on the factory floor. This was an attempt to decrease the required area foot print of large processes to reduce the overall required area and simplify the product flow.

The scanning procedure began by planning the scanning of the first test machines (Machine A) and it was decided to use the handheld scanner, FARO Scanner Freestyle^{3D}. After the handheld scanner was calibrated, the scanning proceeded smoothly, however, Machine A were too high to scan the top side of the machine unit. After Machine A was scanned, the procedure continued by preparing the scanning of the available area with the terrestrial tripod scanner, FARO Laser Scanner Focus^{3D}. After planned the scan positions, grouped stored objects on the floor and warmed up the tripod scanner, the scanning proceeded without any problems and 15 scans locations were required as a lot of stored objects still remained. The different scan locations can at the available factory layout can be seen in Figure 23. Lastly, the second test machine (Machine B) was scanned with the tripod scanner and required four scan locations but due to narrow space was the data capturing of machine side limited. The 3D scanning of all objects were complete in approximately four and a half hours.

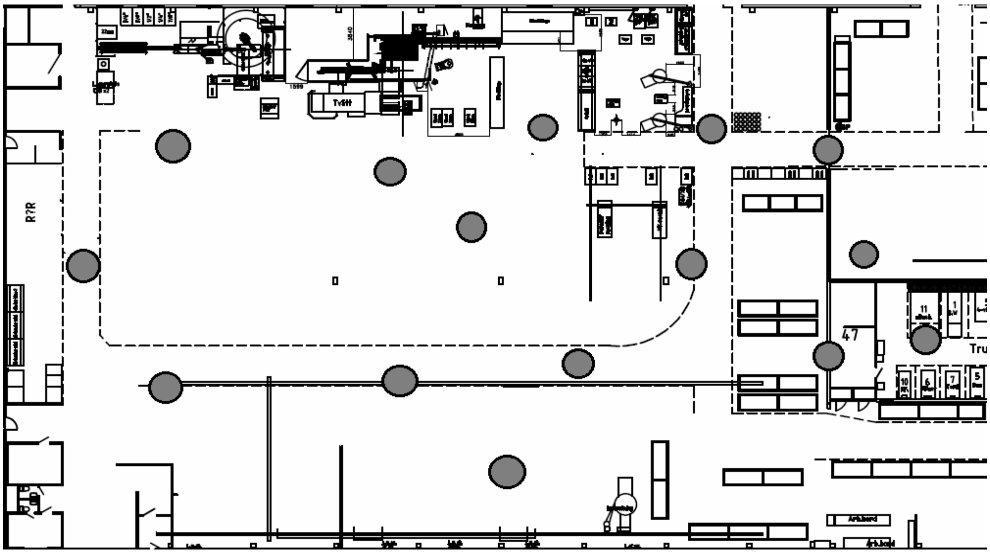


Figure 23: The scan positions in the factory facility (inaccurate schematic)

4.2.12.2 Processing the scan data

After capturing all the scan data of three objects of interest, the processing and registration continued on-site by importing the raw scans from each scanner into SCENE, starting with the handheld scanner and then the tripod scanner.

Firstly, the scans were pre-processed to eliminate faulty and unnecessary scan points with different filters, i.e. dark scan point filter, distance based filter and stray filter. Afterwards, colour was added to the scan points before the scans were combined in a registration process. For more information regarding the pre-processing and registration, read FARO Technologies (2012 & 2016b). Lastly, the respective unified data set and coordinate system was aligned before exporting it as project point clouds in file format .e57 to easily transfer data and use additional software. Moreover, WebShare data was created of the unified data set from the tripod scanning so it was possible to visualise the available factory area. The on-site pre-processing and registration took approximately one and half hours, hence, the scanning procedure took in total seven hours to perform.

Furthermore, the project point clouds were polished through post-processing before the actual modelling as they contain unnecessary points and the factory area was scanned with extensive amount of unwanted stored objects, which can be seen in Figure 24. The company already used AutoCAD and Inventor from Autodesk, hence, it was decided to mainly stick to Autodesk products to minimise the file format problem, i.e. ReCap360, Navisworks and AutoCad were used. However, the software lacked some required features so CloudCompare was also applied to edit the project point clouds. The software had to be taught concurrent with the post-processing process.

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Figure 24: The factory point cloud with unwanted stored objects

The point clouds were polished by removing the unwanted and unnecessary scan points in ReCap360. Moreover, the factory area and Machine B were included in the same point cloud and these were separated to have three independent project point clouds, i.e. Machine A, Machine B and the factory. Also, a fly-through video of the factory point cloud was created to show the virtual model and software feature to the design team. Then factory point cloud was exported from ReCap360 and imported into CloudCompare to fill and repair the empty areas in an iterative process using the software features segmentation, cloning and merging to increase visual effect. The iterative fill and repair process can be seen in Figure 25.

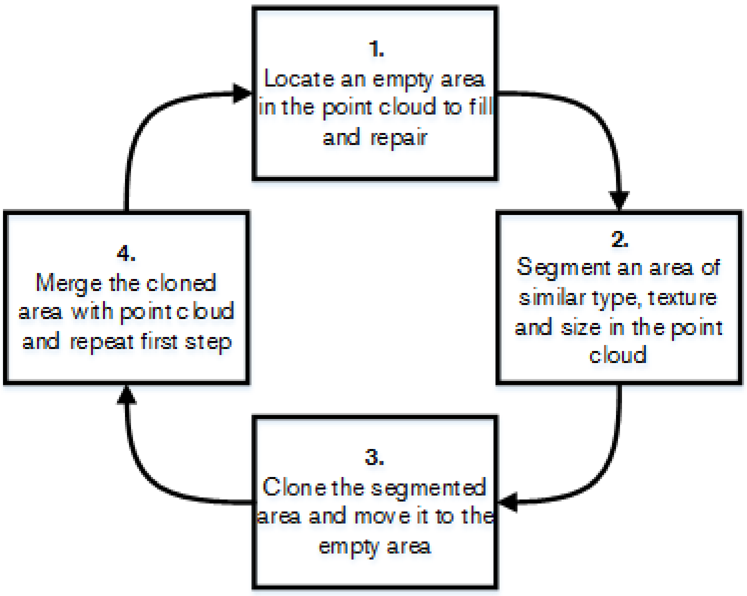

Figure 25: Iterative fill and repair cycle using CloudCompare

Moreover, as mentioned earlier, Machine A & B had some complications while capturing the data which resulted in defects where it was possible to see-through the point clouds as no points were managed to be captured, which can be seen in Figure 26. Thus, the point clouds were imported into AutoCAD filled with simple 3D modelling which had its benefits for later in Navisworks. The final point clouds will be presented in the section 5.2.5.

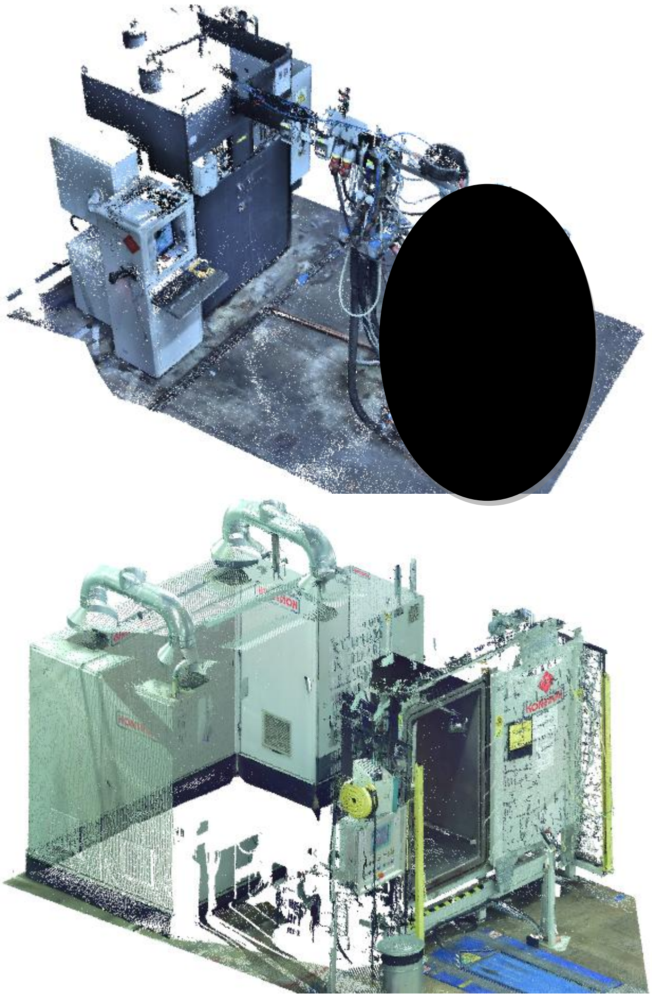
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Figure 26: Point cloud defects of Machine A & B

4.2.13 Step 9 – Preparation step 4

Based on the learning outcome form training step where the design team generated and evaluated layouts (step 5 & 6), it was necessary that the project leader and assistant took on more responsibility to increase the quality of the end result by adding a screening and reworking step where the rough brainstormed block layouts got optimised before evaluation. Since according to Muther & Wheeler (1962), it is important to create a proper block layout from the start as it sets the limit, see Section 2.3. Moreover, it was not satisfactory to add more workshops to familiarise more with the data as the design members had other development projects in parallel.

The screening process took one to two hours and was conducted in two phases. Project leader and assistant performed the screening together to increase the objectivity. As design member four nicely expressed *"It is philosophically impossible to be objective to your own solutions"*.

The first phase was aimed to sort out layouts that significantly deviated from the relationship diagram and three layouts were eliminated. The second screening was stricter to the relationship diagram and also the general flow pattern was weighted between the layouts until only three candidates remained.

Lastly, the three remaining candidates were then polished in a rework process. The rework process was mainly conducted by the project leader during a week because the assistant project leader had a tight schedule. However, the project leader and assistant conducted two workshops (two hours per session) to discuss, share ideas and create reworks. The polished block layouts were generated using the Visio-template to directly draw on paper and moving the blocks in Visio.

4.2.14 Step 11 – Planning step 3

During the third planning workshop, the ten reworked layouts were evaluated. Based on the leaning outcome form training evaluation layouts (step 6), beforehand the evaluation sheet was prepared and the factors defined and documented. The session started with distributing the settled factors to the design members so the factors were understood and reviewed for changes. Then the design team discussed the weight scale and rated the factors' weight. Afterwards, based on the learning outcome from the third training session, the project leader started presenting the block layouts using a projector so the design team collectively viewed and evaluated the same block layout one by one throughout the process. As it was experienced both ineffective and inefficient when all block layouts were distributed to each participant.

4.2.15 Step 12 – Preparation step 5

To test 3D-Block and a proposed realistic 3D evaluation step for 3D-SSLP, it was necessary to create CAD planes of the two best ranked block layouts (from step 11). To create the CAD planes, AutoCAD and CATIA 5V were tested in order to find the software that provided the best visual result after merged with the factory point cloud inside Navisworks, which was the selected and applied presentation software as it offered effective and simple presentation features and navigation (Olofsson & Sandgren, 2015). Afterwards, the CAD plane was merged inside the factory point cloud to create 3D-Block. An example of 3D-Block can be seen in Figure 27. The scanned machines were also later prepared and merged inside Navisworks in order to evaluate the height requirements and discuss solutions for raising the machine units.

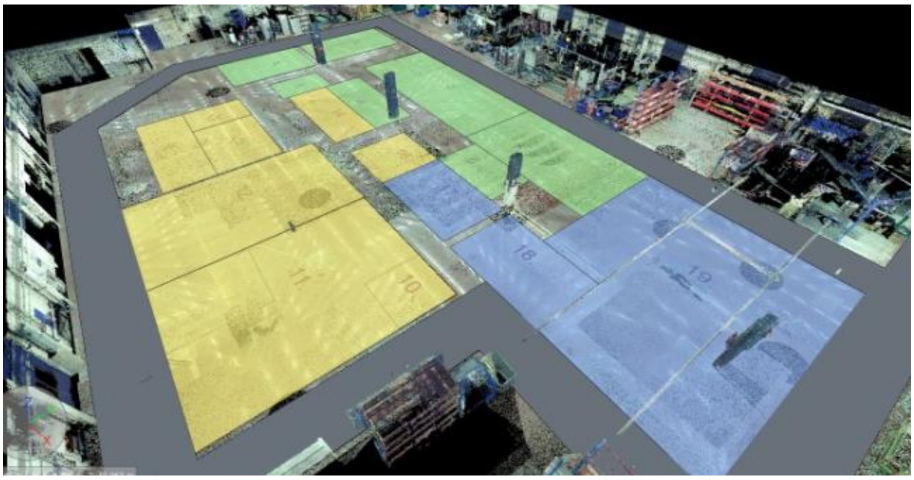


Figure 27: Example of 3D-Block

4.2.16 Step 13 – Training step 4

During the fourth training session, 3D-Block and potential of realistic 3D evaluation step were reviewed and software used to model and visualise point clouds and block layouts were presented. The project leader moderated the workshop as well as navigated in Navisworks while the design team discussed and provided feedback.

First, the factory point cloud was introduced and reviewed in Navisworks. Then, a CAD plane representing the block layout was unhidden in Navisworks to review 3D-Block as visual support instead of an empty point cloud when visualising and planning the detailed layout during cross-functional workshops. Afterwards, the scanned machines were unhidden in Navisworks to test if a realistic evaluation had any potential to be developed and added to 3D-SSLP.

4.2.17 Step 14 – Planning step 4

Based upon the positive feedback from the fourth training step about 3D scanning and 3D-Block, it was decided to extend and try a realistic 3D evaluation step to see if there were any differences between evaluating in 2D and 3D. Only the two best ranked layouts were used due to time limitations so before the session a CAD plane of the runner-up block layout was created in the same way as the previous one. The session began by discussing which additional evaluation factors were relevant in 3D. Afterwards, the layouts were reviewed one by one and evaluated according to the 2D evaluation session (step 11). Based on the learning outcome from the previous step where the 3D-Block and 3D evaluation was presented (step 13), different viewpoints had been prepared in Navisworks to avoid as much navigation as possible as it was hard to follow and made the participants tired.

4.2.18 Step 15 – Evaluation step 1

Personal interviews were conducted with the design team to acquire necessary data to answer the research questions and further develop 3D-SSLP and 3D-Block. The interviews were semi-structured and divided into three parts which lasted in total approximately one hour. The main questions for each part were broad and open so the interviewees were able to rise up their ideas and then the interviewer further steered the interviews into details to gain a wide spectrum of data of all relevant components.

The first part started by greeting the interviewees and explaining the purpose of the interview to create a relaxed atmosphere between the interviewer and interviewees. Afterwards, the interviews proceeded with the interviewees presenting past layout planning approaches and experiences to gain an understanding of the interviewee. That way the questions and probing could be adopted so that interviewees could relate to create a flow in the conversation and when evaluating 3D-SSLP and 3D-Block.

The purpose of the second part was to gain feedback of 3D-SSLP and further development potential. It started with recapping the layout planning approach used in this thesis. After 3D-SSLP had been recapped, further questions were asked to gain a deeper input of SSLP, workshops and 3D laser scanning.

The third part of the interview was dedicated to primarily acquire data of the visualisation techniques: block layout, physical mock-ups and 3D-Block. Also, evaluate if 3D-Block can replace physical mock-ups and if it is satisfactory to create a 3D-Block before moving into the detailed planning phase. Moreover, investigate what visualisation technique and template are preferred during the different planning steps and phases. Also, additional 2D-templates that could be produced from the scan data were evaluated by the interviewees to compare with the Visio- and Excel-Template. The two of the scan data templates can be seen in Figure 28 & Figure 29. The third part finished by letting the interviewees expressed their opinions regarding the application and usefulness of WebShare.

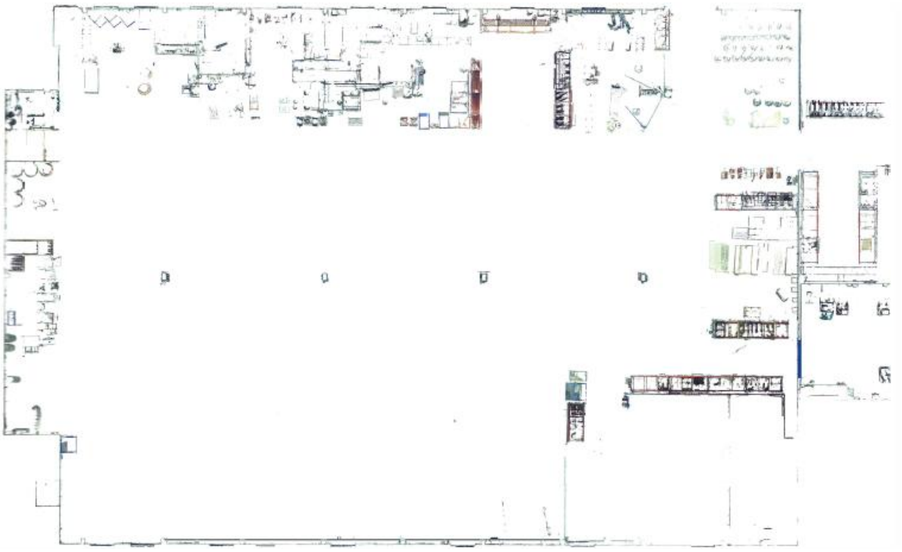


Figure 28: 2D-section of factory point cloud without floor

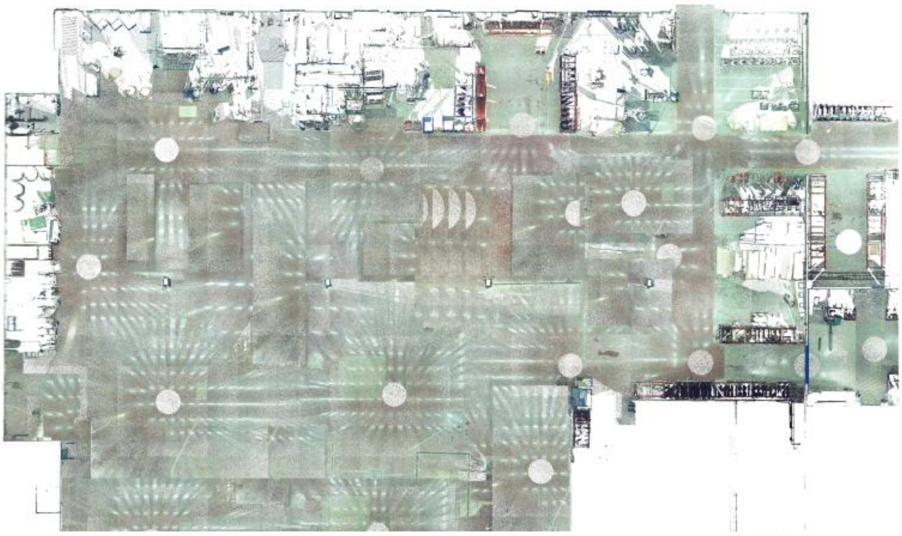


Figure 29: 2D-section of factory point cloud with floor

5 Results

This chapter will present the results from the research procedure. First, the experiences and results from training workshops are presented. Then, experiences and results from the preparation and planning steps are presented. Lastly, the interviews are presented and summarised.

5.1 Training steps

This section will present the experiences and feedback of the workshops' content and structure during the training session.

5.1.1 First training step

During the first training workshop, the three first steps of SSLP were trained and the relationship charts and requirement sheets were reviewed. The participants' overall reactions were positive during the session, even though the project leader was self-critical of the session development and preparation as it was the first performed workshop with tight schedule.

While participants were training the first steps of SSLP, two participants noticed a process improvement while reviewing the process flow chart while concluding the relationship chart. This situation caused problems as certain data had to be changed. Thus, the learning outcome was to thoroughly review the process flow chart before starting the steps to avoid late changes. Most design members experienced that it was good to visualise the process flow while applying the relationship chart because the details can be easily omitted. Moreover, the relationship chart was experienced valuable as it assisted the participants to think in new ways. However, the assistant project leader expressed that it was difficult to be completely objective and not fall back on old ideas. Also, it was time-consuming before the participants understood and got familiar with the mechanics of the relationship chart. The activities' requirement sheet was experienced to be a very useful way of working and it was suggested that the document should be uploaded in the server folder so the design members could continually update the sheet since it was experienced difficult to remember all requirements at once without any help. The assistant project leader expressed that it was hard to understand and create the activity relationship diagram. However, the participants tried to map the whole diagram in their minds before drawing instead of following the instructions, which made it more complicated.

5.1.2 Second training step

During the second training step, the fourth step of SSLP was trained and two drawing techniques were presented. Each design members managed to produce two block layouts before they felt exhausted. The produced block layouts were all unique and varied a lot in quality. All participants expressed that the first layout was hard to produce because there was no reference which could be followed. The participants tried to create practical layouts directly instead of creating an ideal layout. Participants started thinking of what-if scenarios or did not plan ahead during the first attempt which resulted that the relationship diagram was not followed, i.e. changed areas and ignored relationships. Thus, the moderator had to intervene to explain and encourage the participants to follow the relationship diagram data and the second attempt showed promising block layouts.

The participants preferred and selected different drawing techniques; half of the group selected the plastic cover method mentioned in the methodology whereas the other half selected to draw directly on the layout templates. However, assistant project leader expressed that he preferred to directly use the computer to generate the block layouts as he considered him poor at drawing and it took him extra time to draw and calculate the areas accurately, hence, assistant project leader expressed he got inpatient as it was experienced to be double as efficient with a computer.

Due to the mix of quality in the drawn block layouts, the project leader and assistant project leader discussed and suggested that in some way it would be good to extend the generation step in order to increase quality of the end result when planning the Atlas Layout. Moreover, as the maintenance department was currently relocating, the planning workshop was suspended until the layout template can be accurately updated.

5.1.3 Third training step

During the third training step, the fifth step of SSLP was trained and different commonly used evaluation factors were presented. It was intended to manage all training during one session. However, it consumed too much time to present and review the commonly used evaluation factors and therefore an additional session was required to complete the training.

The participants thought that 11 out of the 20 commonly used evaluation factors were relevant for the company and Atlas layout. To view the 20 commonly used evaluation actors, see Muther, 1974, pp. VI-1. It was quite hard to decide which weight range was satisfactory for the factors. During the evaluation, it was experienced ineffective to document the worksheet and design member number three suggested that the evaluation worksheet should be prepared beforehand by inserting the factors and weights. Only two out of ten layouts were evaluated during the first session. During the extra workshop, the remaining eight layouts were evaluated. It was experienced hard to settle the average rating level of the first evaluated layouts which resulted in that the average rating became too high. This caused problems later in the evaluation as there was no room to differentiate layouts that were better than the first as it already was rated E, i.e. as the only rate factor left was A (Almost perfect) and solutions X was better and Y, but both got rating A. Towards the end of the evaluation, the participants acknowledged this problem by themselves and pointed out that it was because of inexperience and no reference point. However, the project leader had taken notes during the session so the ranking was adjusted and the final results were concluded and visualised. Another set up was that the relevant factors from Muther (1974) were blindly selected and not adjusted. As the evaluation factors were widely defined, it became unclear what should be assessed and some factors were impossible to assess in 2D. The learning outcome was that the settled evaluation factors should be assessable in 2D, defined concisely and have a representative name to make it apparent for what the participants should assess. Moreover, during the session, a document containing all block layouts was distributed to all participants. This caused some participants to look around on all layouts instead of collectively address one layout at the time. The learning outcome of this situation was that the digitally stored block layouts had to be presented using a project so that each block layouts were collectively addressed one by one by all participants.

5.1.4 Fourth training step

During the fourth training session, the result from the 3D laser scanning and modelling was introduced and proposed visualisation technique 3D-Block (representing the best ranked block layout) was presented. The participants experienced that the 3D laser technology was a great tool for visualising. Moreover, 3D-Block was experienced very helpful and increased the understanding as it provided the viewer with better perspective than a block layout. While visualising the best ranked block layout inside the point cloud, the different machines were added to give more perspective and evaluate if the machines units could be raised from the floor. The participants experienced that it was possible to raise the machine unit after reviewing it in the 3D model and start discussing different solutions. Moreover, the design team got more and more interested in the 3D technology and started discussing how they can continue utilising the 3D scan data and which software and hardware were required. However, as a project leader, it was a challenge to both navigate the 3D model while acting as a moderator. Moreover, a lot of navigations were done to show different features which made the participants tired as the model was constantly moving in high pace. The learning outcome was that suitable viewpoints should be prepared when visualising in Navisworks with other participants to minimise the navigation.

5.2 Planning procedure

This section will present the results from the preparation and planning steps for the Atlas layout. The result has been depersonalised so that no sensitive data are disclosed.

5.2.1 First preparation step

The procedure began with mapping the process flow which was required for Atlas production system. In Figure 30, the mapped process flow of the new production flow is visualised. The Atlas production flow (dotted box) is divided into three sub-flows which are connected by two supermarkets (Activity 8 & 16). Two warehouses (Activity 21 & 22) supply all the activities in the production flow with components and Activity 23 process raw material to Activity 1. The products are tested and approved at different locations (Activity 3, 6 & 14) to ensure high quality and no hazard risks. Finally, the finished goods are transported from the production flow before delivering to customer.

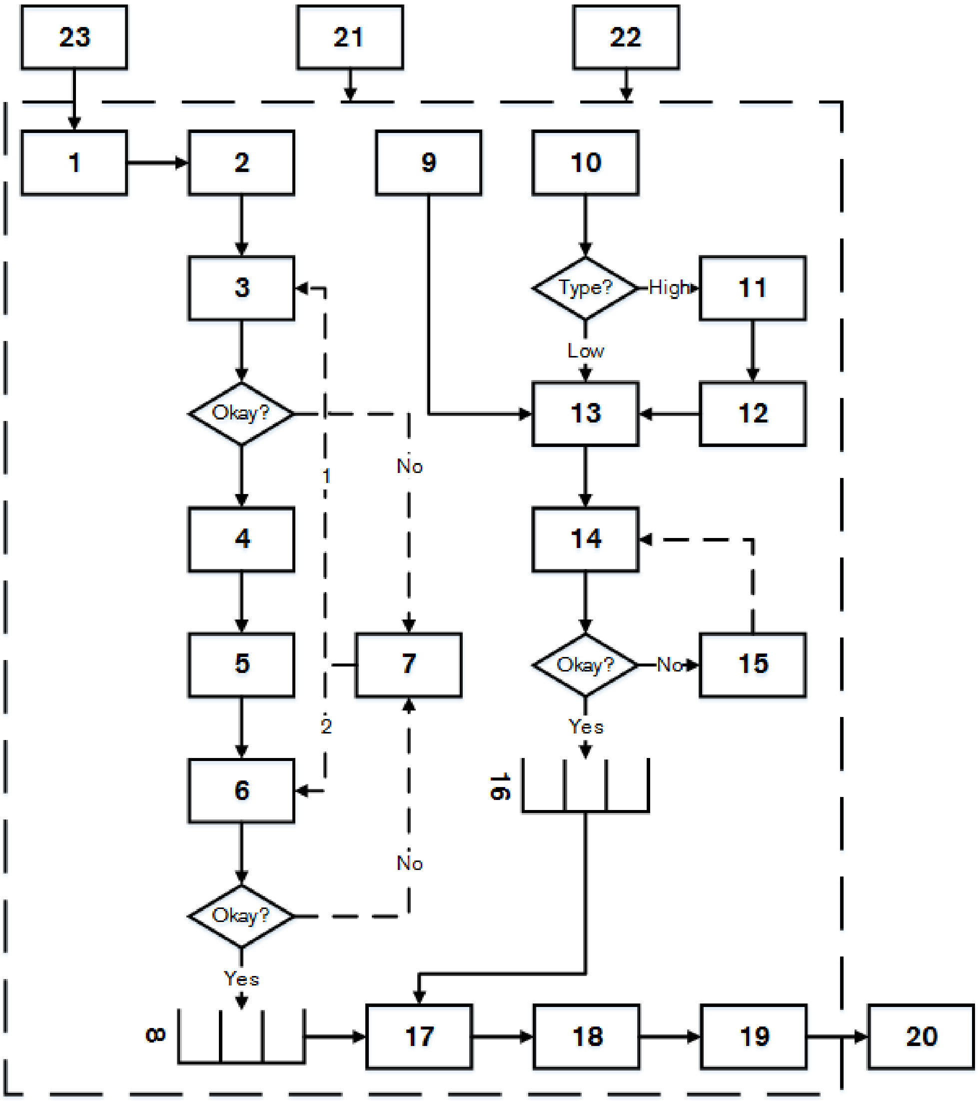


Figure 30: Process flow chart

5.2.2 First planning step

During the first planning session, the relationship chart and activities' requirements sheet were completed. The overall feedbacks of the sessions from the participants were positive, but some participants felt frustrated with the low contribution from the Logistics department and some participants lost their focus at the end of the session.

The views regarding the material flows were collided during the session. According to Logistics representative, the relationships between the Atlas production processes and the different warehouses were rated as unimportant, even though the other participants did not agree because the design team wanted to improve the material flows for the Atlas production system. However, Logistics representative argued that *"Currently, there was a bigger issue as there was no available warehouse space for raw materials required to produce the Atlas product family. Thus, if this problem was not solved, the raw materials are required to be stored off-site and the in-house material flows will become negligible, except the flow from the processing Activity 23 and the flow of finished goods to Activity 20"*. However, the design team was sceptical as they had higher expectations and tried to discuss with the Logistics representative to reconsider the relationships, but Logistics department were responsible of designing the material flows.

Later, the Logistics representative and design member number three lost focus towards the end of the session. This could have been because they were tired as the workshop was scheduled in the late afternoon or the Logistics representative did not see any more value of the process as all material flow from the warehouses (Activity 21 & 22) were to be considered as unimportant. As the above mentioned, the unfocused participants made the rest of the group more tired and passive which might have affected the rating towards the end. The project leader encouraged the design team to focus to achieve consistent ratings with previous arguments and relationships.

5.2.3 Second preparation step

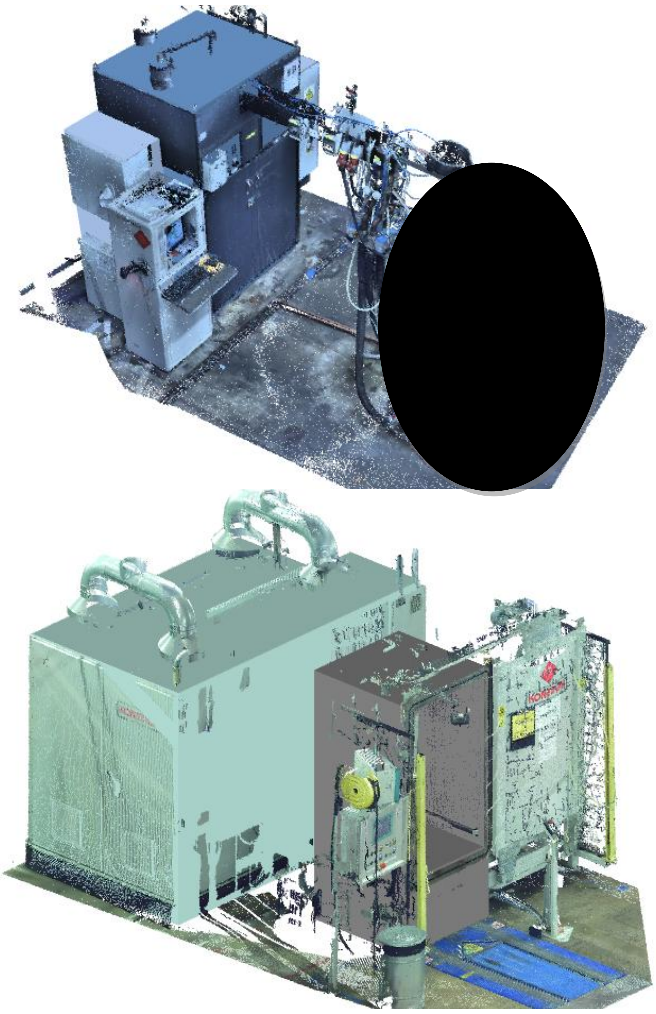
After the first planning step, as mentioned before, the relationship diagram and Excel-template were created by the project leader. Measuring the available factory area was experienced very inefficient and the accuracy different and had to be repeated to ensure that the layout was somewhat accurate. The measurements varied for some structural features which were not satisfactory to visualise in an Excel-template so the measurements were round to the nearest whole meter or half meter. Moreover, the fork-lift truck paths were two and a half meter and that is why the upper path was rounded to three meters wide and to compensate for the extra half meter the lower path were visualise as two meters wide. This was a downside when using the template in the second planning workshop.

5.2.4 Second planning step

During the second planning step, the participants managed to produce in total seven original block layouts. In addition, the project leader contributed with three original block layouts. The computers were accessible but no one chose to use it to create block layouts. Moreover, design member number four chose another technique to produce block layouts by cutting out paper blocks of each activity to move around on the template. However, the design member faced a problem and noticed that the supposed squares in the grid net did not have the same height and width length. Thus, blocks became inaccurate if turned in the layout. Thus, the Visio template was created as it offers better drawing options and flexibility. Excel was initially used as the project leader did not have access to Visio at the time of the first generation workshop.

5.2.5 Third preparation step

As mentioned before, the 3D scanning and pre-processing took approximately seven hours and afterwards there was still a need for post-processing as the point clouds had some defects to be corrected, see Section 4.2.12. The post-processing took longer time than necessary due to the software had to concurrently be taught. Moreover, there were some setbacks as the computer hardware used barely fulfilled the minimum software requirements which were a drag. Simple CAD blocks were extruded inside Machine A & B to eliminate the see-through defects, which can be seen in Figure 31,



[redacted]

Figure 31: CAD blocks with point clouds of Machine A & B to take away visual defects

Furthermore, as mentioned before, the unwanted stored objects on the available factory floor were eliminated and replaced, which can be seen in Figure 32. Overall the factory point cloud became better and usable but there were still many visual defects but they were insignificant for the project and in the end it started to become time consuming and demanding for the computer hardware. Thus, it was decided to move on after post-processing for approximately three weeks.

Figure 32: Unwanted stored objects removed from the factory point cloud

5.2.6 Fourth preparation step

The screening process continued until three satisfactory candidates remained and this process took approximately one and half hours. Out of the three candidates was one generated by design member two and two were created by the project leader. The candidates were then reworked by the project leader and assistant. A rework example can be seen in Figure 33 & Figure 34. The candidate was produced by design member two and had an overall good flow patterns which were similar to U-flows, which the company looked for, and in the middle there was a lot of unused area which could be used to eliminate waste. By making the U-flows more compact it was possible to eliminate movement distances and create a more visual flow. Moreover, the visual effect of the Excel-template and Visio-Template can also be visualised. In the Visio-template, the sub-flows got different colours and necessary operator walk paths were added. Block with dashed line indicates preferred location but is flexible within the parent block, e.g. block 2 & 7.

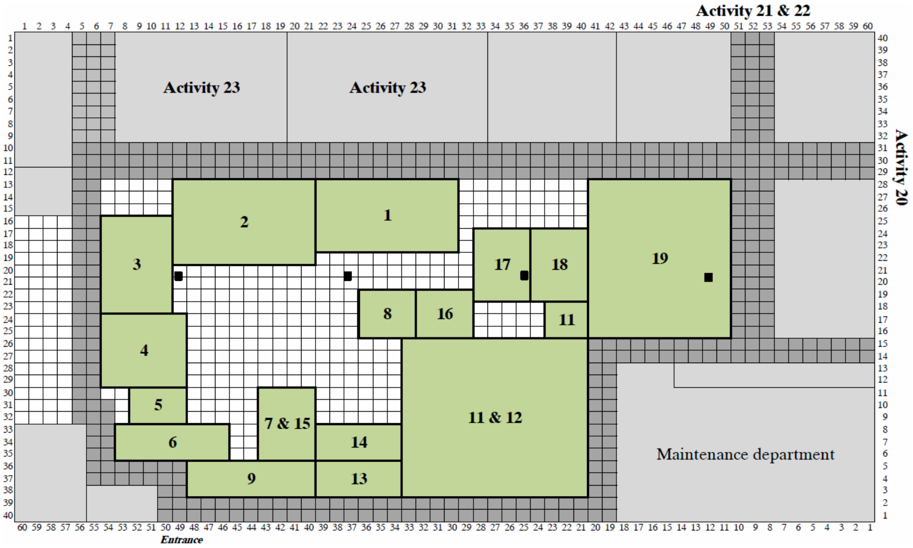


Figure 33: Original block layout 5 (Excel)

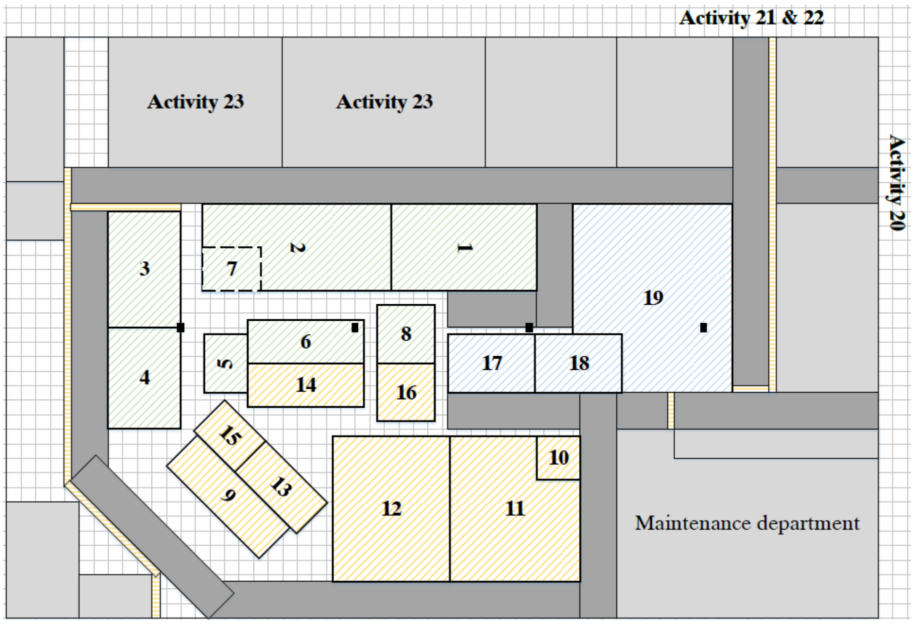


Figure 34: Reworked version of block layout 5 (Visio)

Afterwards, the project leader and assistant discussed and defined what factors that were important for the Atlas layout in a one-hour workshop, see Table 4. The project leader assistant pointed out that safety is always the most important factor as no accident should occur. Thus, it was important to ensure the operators and vehicles are separated as much as possible and that the operators had enough space to move around. Then there was a focus on the production flows, both the material and product flows were divided into two factors to make it more justified to the parties it affected. Also, flexibility and space utilisation were considered.

Table 4: Important evaluation factors

Factor	Guiding question(s)
Safety	-How well are the truck paths and operator flow separated? -Any space for operator paths in the detailed layout?
Material flow	-How well are material available for operators (block configuration)
Material movement	-How well can logistics operators provide the activities with material? -How well are logistics flows and product flows separated?
Product flow	-How well does the layout configuration support visual flow and control?
Product movement	-How long distance does the WIP have to be moved?
Flexibility	-How easy is it to change the layout without costly machine relocations? -Is it possible to combine current system solutions with new? -Is it possible to fit current test machine design?
Space utilisation	-Is there additional free space and is it possible to utilise it? -Do previous activities need to move because of the layout?

5.2.7 Third planning step

During the third planning session, the fourth step of SSLP was conducted to evaluate the reworked block layouts. The design team reviewed and understood the aim of the evaluation factors. No changes were made as they were considered sufficient by the design team. The weight scale ranged from seven to one (instead of ten to three as it would be with SSLP) as it felt more natural for the design team, the factors weights can be seen in Section 5.2.9. Moreover, it was decided that it was not in the design team's interest to continue with a block layout that received a factor evaluated as X (unwanted), if this occurred the block layout was excluded from the evaluation. The evaluation proceeded efficiently and all ten block layouts were evaluated. Layout D were the winners and Layout F the runner-up. The layouts can be seen in Figure 35 & Figure 36. Layout D consisted of two U-flows (green & yellow sub-flows) which converge into a straight flow (blue sub-flow) while Layout F consist of two L-flows and the same straight flow. Moreover, during the session was it concluded that the fork-lift truck path into the production layout (black rectangle) for the two layouts were considered to decreased the safety, hence, they were replaced with addition material space for Activity 10 & 11 in Layout D and for Activity 2 in Layout F. Moreover, it was concluded that the configuration of Activity 19 was better in Layout D, so it was applied for Layout F too. All these changes were made before the 3D evaluation with realistic visualisation.

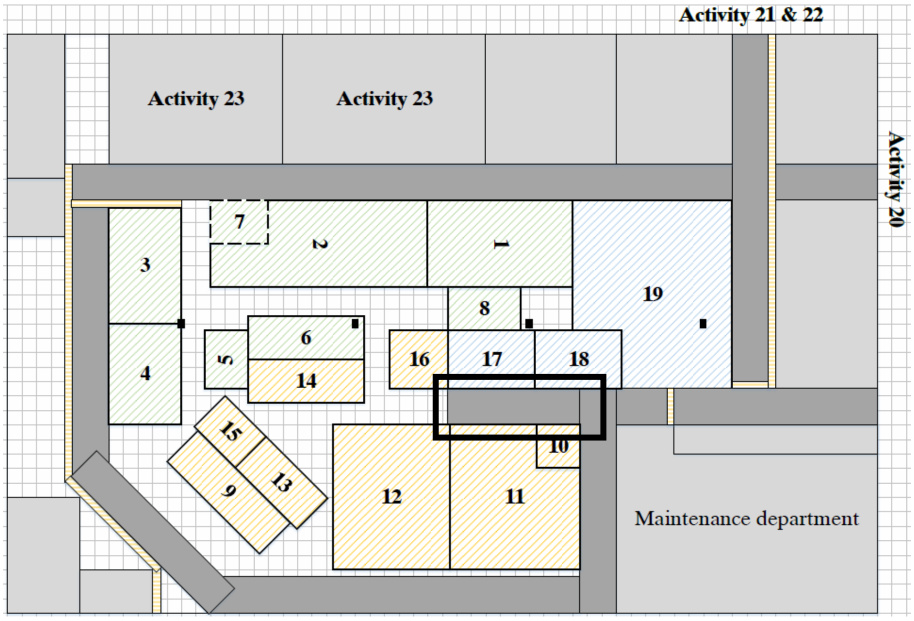


Figure 35: Best Block layout D

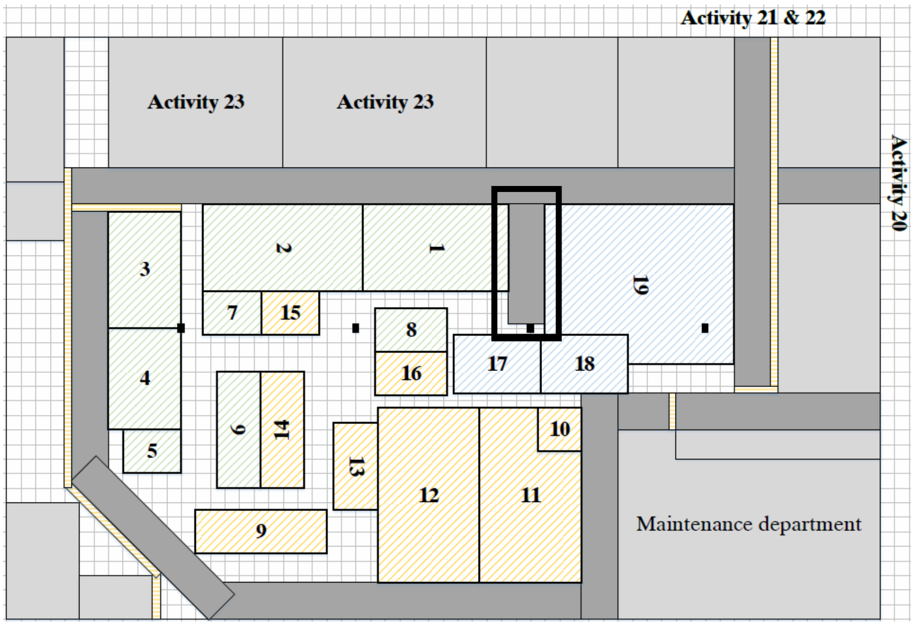


Figure 36: Runner-up Block layout F

5.2.8 Fifth preparation step

After testing the compatibility, it was experienced that Navisworks and AutoCAD had the best compatibility in comparison to CATIA V5 (the modules *"Mechanical Design"* and *"AEC Plant"* were tested). Moreover, it was an advantage working in AutoCAD as it was possible to attach the point cloud so the block layout was merged at the correct location from the beginning instead of spending time moving inside AMN. However, one disappointment between AutoCAD and Navisworks was that the group function in AutoCAD did not follow into Navisworks, which made it inefficiently to move around the blocks as it was hard to smoothly select all three components representing a block, i.e. drawn lines, extruded box and inserted activity number.

5.2.9 Fourth planning step

The result from the 3D evaluation became a little more detailed than normal 2D evaluation but the change for safety was because removal of the fork-life truck path and not due to better visualisation, see Table 5. Layout D remained the best layout but only with one point. No additional factors were added during the 3D evaluation even with the option to evaluate the height requirement and convenience/cost of raising the machine units, because the design member had the attitude to get the best layout rather than cost or building convenience as it was meant to be a long lasting layout and the additional cost of raising the machine units between the layouts would be insignificant in comparison to the total investment sum.

The results of the 2D evaluation were visual during the evaluation. Moreover, the design members had a tough day and were exhausted at the time of workshop and in addition the Atlas project had long been terminated, which made the design members a bit passive and often referred to the old result rather than in-depth discuss the factors again. However, it was expressed during the session that if more simple digital mock-ups can be added before the 3D evaluation it will be priceless as it will easier to determine such as the general flow patterns and such in the layout.

Table 5: Comparison between the 2D and 3D evaluation

		2D evaluation		*3D evaluation*	
Factor	**Weight**	**Layout D**	**Layout F**	**Layout D**	**Layout F**
Safety	7	E	E	A	A
Material flow	3	I	I	I	I
Material movement	2	I	I	I	I
Product flow	6	A	E	A	A
Product movement	5	E	I	E	I
Flexibility	4	E	A	E	A
Space utilisation	1	O	U	O	O
Result		**83**	**75**	**90**	**89**

5.3 Personal interviews

This section will present the data from the personal semi-structured interviews as well as a summary of the interviews.

5.3.1 Production engineering manager & Assistant project leader

The interviewee thought that overall it was a good planning method and it was a good approach to do the steps in workshops. The method steps were logically sequenced and balanced between preparation and planning steps. *"It is a good planning method for large layouts or if you are inexperienced in layout planning, I am absolutely positive to apply it in the future for next design project".*

However, in the aftermath of the procedure, the interviewee thought that it would be good to define and document the evaluation factors earlier in the planning process so the design team can strive towards a common goal and know what is important throughout the process. Moreover, a VSM should be used to complement the process flow chart so that the planned layout can be verified with the VSM.

The interviewee expressed that a problem with the Atlas project was that the product team could not conclude different design options that affected the process flow so the production concept that was created was uncertain before and while planning the layout. At Danfoss, the concept design of the product and production system begin at the same time, whereas, the product concept has been more settle before the production design begin at previous companies. It caused a lot of problems to have a *"Rough detailed"* production layout ready at the same time as the product concept is settled, *"This is nearly impossible"* the interviewee expressed. This situation caused some uncertainty and doubt of the design members during the workshops. The overall workshop duration was experienced sufficient. However, the interviewee personally felt that it will be more efficient to conduct more workshops with shorter period of time (approximately one hour) rather than long period workshops because he became tired and unfocused during the last hour.

Furthermore, the interviewee really appreciated the relationship chart because it made the users consider all the relations in a structure way and he felt that it could even have more benefits on a detailed level, i.e. designing a block within the layout or isolated work station. The interviewee experienced that the reason why the result of the chart had to be polish throughout the procedures were because the result was diminished as the design team were novices and the logistics department was not that interested in the process. However, the interviewee thought that if the chart was repeated, the result would become more accurate from the beginning.

Furthermore, the interviewee experienced that the relationship diagram was confusing to create with four, three, two or one line, which made it feel like rocket science and superfluous. Interviewee expressed *"I might be over thinking about the relationship diagram but why did not we directly use the relationship chart and activities' requirement sheet?".*

The second workshop was really appreciated when the design team sat down and everyone focused on creating different layout solutions. However, the interviewee expressed that drawing blocks were not his expertise and he did not have patience to draw when he thought that it could be done more efficiently using a computer. Thus, the interviewee proposed that each member should do it at their work station so that the computer is an option for those that prefer it.

The interviewee thought that the screening and rework steps are necessary to early eliminate unsatisfactory solutions and polish potential solutions, but the steps might not be needed for a very experienced and competent group. The interview thought that the only obstacle of implementing the method fully is the investment in 3D laser technology. The interviewee expressed *"if I had 500,000 SEK today to put on measuring technology, then I would instead spend it on a laser measuring arm to verify produced components and raw material from suppliers, which would currently generate more returns into the company. Today, the company is quite small and majority is manual assembly with few machines. However, the company is constantly growing and when it reaches a moderate size, then there will be a room to invest in less prioritise tool and then 3D laser scanning is absolutely interesting. Because I believe it would be "gold worth" even for small changes to have collaborative workshops with other functions, to show how our department think to gain feedback and do real time changes before implementation".*

The interviewee thought that the strength of 3D laser scanning and modelling is that the solutions can be shown to a group to discuss solutions, and gather everyone on the same train. The interviewee expressed *"From experience I have noticed that if I draw a square and show it to you, it is not exactly necessary that you recognise it as a square, but instead as a jet plane. It is very hard to draw an idea for others sometimes and then they confirm that they have understood. However, once you start implementing your idea, all problem raises, because you and the other persons had different ideas of that square"*.

As for visualisation, the interviewee thought that when generating new layouts, it is more preferable to focus on quantity rather than quality. Thus, based on the department's experiences, competences and sometimes resource prioritising, it is most efficient to work in 2D than 3D, because it is fast and simple. Currently, we do not have the competence to efficiently start working in 3D without training design members. The interviewee would prefer to work with Visio rather than Excel, but personally the interviewee liked AutoCAD since it is very easy to move things and take measurements. However, Visio was preferred to create material for discussions due to its simplicity and the interviewee expressed *"In the beginning, it concerns about sketching new ideas to generate more ideas form discussions"*. The interviewee thought that the template depends on which technique or software that is utilised, but both the Visio-template and the 2D-section without floor was sufficient for generating layouts. The interviewee thought that using a 2D-section with visual roof beams and ventilation might have application for factories with very low roof height.

During evaluation of layouts, the interviewee thought that 3D evaluation with all the equipment would be incredibly good. It offered amazing visualisation and it would become very clear of what had been designed, which would not be possible in 2D with blocks. *"In 2D, you do not get that the perception of what one meter right here will impact. If everything has been scanned, you will be able to see how one meter plus or minus in a direction will impact if you can move the item around, which you do not get from just a top view"*. In 3D, it is easier to understand how the placement of items would affect operators and flows. However, there was experienced not that big of a difference between 3D-Block and block layout when evaluation the conceptual layout except the height requirement. Interviewee, however, thought it would have been outstanding if more details could be added in 3D-Block before evaluation. 3D laser scanning was experienced as a great tool to communicate a solution upwards in the company to gain support and investment capital. Moreover, in the aftermath, the interviewee thought it would have been great if we had the possibility to scan the current work stations to make the 3D-Block more detailed and visualise small improvements afterwards. The interviewee expressed *"We would have profit from getting more 3D figures in the model"*.

The interviewee experienced that physical mock-ups have previously been efficient on a detailed level, because you gain basically the same benefits as in a 3D model. However, the interviewee expressed *"It requires that the factory floor have to be empty, but that is only possible during low season. For the rest of the year, it would have been good to utilise the 3D-Block"*. The interviewee thought that point clouds are more satisfactory than physical mock-ups for large layout planning projects since it provides a better overview of the whole system. The interviewee expressed *"The integration between block layout and 3D model can absolutely replace physical mock-ups, provided that the layout is later further detailed through modelling or scanning and merging* *current functions. Since for large layouts it cannot be demanded that the factory floor should be empty to do physical mock-ups".* 3D-Block was experienced a necessary improvement from empty point cloud when starting to detail the layout during workshops with operators and other functions.

WebShare would have been very nice to have of the whole factory to eliminate factory visits because all visiting sales people want to see the factory production. It would be good to be able to show the factory virtually on a project using WebShare because it would decrease operator disturbance, increase safety, more time efficient and deliver professional impression. The tool can be selected to review and estimate production process requirements, e.g. areas, utilities, etc., based on the current system in a workshop. Moreover, WebShare can be shared with hired third parties responsible of implementing certain facility features, e.g. gas lines, pluming, fire safety units, ventilation, etc., to increase sustainability, flexibility and efficiency of the planning phase as it can eliminate a lot of travelling.

5.3.2 Production engineer & Design member 1

The interviewee thought the integrated planning method was good because the procedure became structured and transparent, so everyone know what is required and it eliminates the risk of forgetting something. The method provides documentation which can be communicated within the company and used for continuous improvements for future layouts. The order of the steps procedure and division of responsibilities were sufficient. The interviewee thought it was satisfactory to apply workshops for the different planning steps since it forced the project to move forward and involve with all relevant parties. Moreover, the interview expressed *"It is important that one or two design leaders prepare the workshops because if we had done them spontaneously, it would not have been as efficient".* The workshop duration was reasonable but design members got tired during the second hour. The interviewee expressed *"There is no obstacle to implement the method today except the fear that it might take longer than current practices depending on the size of the layout since we are still novices".* The interviewee expressed *"I am pleased with the planning method and the time has not been wasted. Also, there are parts that I will definitely use regardless of the size of layout (mapping the requirements and follow the structure)".* However, it was experienced that the spirit diminished when the management cancelled the Atlas project but the work still was not wasted and it has been performed very well.

However, on a detailed level, there are always certain parts that have pros and cons with each step. The relationship chart was beneficial because it forced the team to consider all relations in a structured way so nothing is omitted. However, the interviewee thought that relationships are common sense and he felt that with his experience, common sense and Lean-thinking, the same conclusion could be made without the chart. Moreover, the chart is important to do in a cross functional team because the solutions that production engineering team want may not suit to every function. However, logistics department should probably get involved in every step since the material flows are such a big part of the system. Although, the department do not care or cannot contribute that much, it is important to keep them updated. The interviewee really appreciated the activities' requirement sheet as it was conducted in a collaborative workshop. The sheet gives a good overview of what is required and ensures that nothing is omitted. He expressed that *"Gas lines were normally forgotten* *and considered late in the planning phase"*. With the collaborative workshop, the process was very time efficient and it made the design team consider everything from the beginning. The layout generation step is a bit like playing in AutoCAD but here you had given areas and made it a very easy way to visualise. During the evaluation training workshop, we felt that all twenty presented evaluation factors were good. However, the most important factors that were measureable in a 2D layout was defined and prepared before the planning workshop. This was another positive attribute for the evaluation since it forced participants to really evaluate and motivate all factors for each block layout. The 3D laser scanning was very beneficial for the visualisation and was a great complement to 2D and physical mock-ups. However, the issue is in order to continue managing the data in the future, it requires the company to invest in the technology. The interviewee expressed *"500,000 SEK to utilise a 3D scanner is not that much money if you consider the potential result"*. The interviewee, however, expressed that the technology probably provides more value for companies in an industry which demands rapid and large production system changes, e.g. automotive, etc., but historically the company only made large production system changes every fourth to fifth year. Thus, to utilise the technology, the first step and cost effective way is to hire a consultant to do the scanning to gain the raw data for modelling.

For the visualisation during generation of layouts, the interviewee expressed that working in 2D is the most sufficient because it is simple, faster and easier. Also, people can work closely within the group. The interviewee would prefer to use 2D-section without floor as a template because it accurately shows the available area, obstacles and transportation lanes. The interviewee thought the template of the 2D-section with roof beams and ventilation was interesting as it is easy to forget how the roof is constructed. Moreover, the interviewee preferred generating layouts with a flexible technique that makes it possible to easily move around blocks either virtually or manually.

To evaluate block layouts, the best visualisation method is 3D since it provides best overview and space awareness of the block layout in comparison to 2D. However, 2D is better to briefly discussion many different solutions since it can be faster created and handled. Physical mock-ups are not suitable to evaluate block layouts because it does not provide a good overview and requires large floor space especially for large layouts. However, if there is available, physical mock-up it is the best option to detail and evaluate on a small manual system, e.g. assembly station, etc. The interviewee thought that 3D modelling cannot replace physical mock-up on a detailed level for manual assembly because it is not possible to achieve the same space awareness and feeling in a virtual environment. The interviewee expressed *"In a 3D model it is hard to evaluate questions like: how many times do I need to turn to assembly the part? Can I properly reach the tools or materials?"*. Thus, the interviewee perceived that it is easier for an operator to relate to a physical mock-up rather than a 3D model, since it is like the natural work environment. However, Interviewee thought that 3D modelling is more suitable than physical mock-up if the production has a high level of automation (LoA) or are machine intensive since suppliers can provide detailed 3D models of the equipment which saves modelling time and increases the level of details. The interviewee summarised that the best visualisation methods along the process were to generate layouts in 2D and than evaluate them in 3D with 3D-Block, and then continue to detail the best block layout with 3D modelling. Lastly, each function should be verified one by one by building a physical mock-up before implementation. As a physical mock-up is very easy to build when it has been detailed and evaluated virtually.

The interviewee considered WebShare useful as it can be used earlier in the procedure to efficiently measure and estimate area and view utilities to complete the activities' requirement sheet either individually or in group during a workshop.

5.3.3 Production engineer & Design member 2

The interviewee had no experience in planning a large layout before and expressed that it had been a very interesting process and he had overall positive perspective towards 3D-SSLP and especially appreciated the addition of 3D laser scanning. Overall, it had been a positive and absolutely practical method. However, the interviewee thought it was a pity and unpleasant that Atlas layout was not continued as the Atlas project had to be terminated as the individual wanted to go further into details and build something totally new. The interviewee expressed that *"It had been interesting to scan the whole current production system and made a case for it to see how we can improve that area when nothing happened with Atlas".* Some small changes will be implemented but normally it takes a few years before something big will happen again. The integrated planning method has been very good as it becomes a tool to ensure that all details are addressed and nothing is omitted, e.g. the relationships, utilities etc. It is good that the method structured the process, since otherwise it is easy that a person just sits down and starts drawing without carefully thinking of what needs to be considered and have to adjust or redo later when you remember that something was omitted. The interviewee thought that it was a natural and logical sequence of steps. Moreover, it was good to do the planning steps in workshops where a group of four to five members worked together when a large layout is planned. As a group composition, the interviewee thought it was sufficient to only involve production engineering and logistics during the relationship chart. However, an experienced maintenance engineer could probably assist during the activities´ requirements sheet as they have knowledge of old gas lines, etc. The duration of the workshops was moderate, however, it was experienced that there had been a bit too much time in between the planning workshops as the interviewer had to do many things in between such as planning, developing and training 3D-SSLP and 3D-Block. Interviewee expressed *"I think it was moderate with two hours' sessions and the time passed very fast. The process was very good and interesting discussions occurred so people could address the issues and solutions".* Interviewee thought two hours provide sufficient data. However, it would be good to double check and verify the data with an additional workshop for each step before continue to next step. Moreover, more time would have been spent on the Atlas layout and continued unless the project was terminated. The interviewee could not express any direct obstacle of implementing the integrated method today. However, it was pointed out that it was necessary to work with the method to gain rotations and experience as there is always a risk that people forget it as large layouts are rarely planned, but when it happens the interviewee expressed *"I absolutely want a structured method during large layout planning otherwise it is a great risk that something is missed so I am open to this method".* Moreover, it is good that the method is flexible and can be conducted for small layout planning, e.g. a work cell or station, by doing this way, the method can be taught and applied for future project.

The interviewee had never worked with mapping the relationships before but expressed it had been interesting to conduct the relationship chart. As it is possible to create a better flow if the relationships between the activities, e.g. use of same personal, flow patterns, etc., are mapped and rated. However, the matrix itself was a bit messy to fill out. For the activities' requirements sheet, the interviewee thought it is good to start based on the current system and it is not necessary having in mind to decrease all areas in the beginning since it is hard to visualise the exact block and it does not need to be a more detailed concept. Overall, it was interesting to see the transformation from the relationship chart to the final block layout. The interviewee expressed *"3D evaluation used a cool technology and that will probably be used in the future"*. The 3D technology has made it possible to get a better overview with volume rather than a 2D picture. It becomes more visual either with or without details when you can walk around in the model as walls, roof and, etc. are visible. Moreover, it is possible to easily take accurate measurements. However, to spend 500,000 SEK on acquiring the technology is probably a bit too much and it would be more suitable to hire a consultant to scan the relevant area and provide the scan data for us to process and model it. Since it would be unnecessary to buy the 3D scanner as it would be rarely used in our situation, it is preferred to hire a consultant service to scan at the beginning of large projects now when we know how it works. However, the technology would be suitable to be purchased and applied by a central development unit within a large organisation, e.g. DDP within Danfoss Group, to supply production sites with accurate facility data, also to support factory planning and modelling. However, the spending of 500,000 SEK which may be used every fifth year would be a big investment that is hard to motivate unless it is a joint purchase with Danfoss Group or it could be used for either something or someone else within the company. The interviewee expressed *"It would not surprise me if Danfoss already had a 3D scanner lying somewhere in the world"*.

As for the visualisation, during generation or "rough sketching" of layouts, 2D is the easiest way to work as it becomes too much information in 3D. However, it would be desirable to work in 3D but on a detailed level. 2D is more practical and sufficient enough for rough sketching. The interviewee would prefer to work with 2D-section with floor from the point cloud as current details are included, but would like to create a measurement grid as in Visio. The 2D-section with roof beam and ventilation is also positive as it is good to have as many details as possible. The interviewee preferred to generate layouts by drawing on paper templates as it was experienced to be the most efficient way for the individual. The interviewee expressed *"I prefer all the 2D templates produce from the 3D scanning (cross-section of point cloud). However, for a totally empty area, it does not matter what type of 2D template is used. But when there are current functions in the facility, it is good with a template from 3D scanning so that all details can be utilised"*.

During evaluation and detailing, the interviewee thought that it is easy to be tricked by 2D in comparison to 3D. 2D only presents an overview of the area but there is more perspective with 3D. The interviewee had never worked with physical mock-up but believed that the method is best for smaller systems, e.g. work station, as it is more visualise of how large it becomes. However, 3D scanning is better in large systems, e.g. large layouts, as it provides a better overview with accurate details. The interviewee expressed that the integrated visualisation method is better than physical mock-up when it is possible to further detail the layout as it probably goes faster to do a complete 3D model by an experienced user than building a physical mock-up of the same level of detail, because it takes time for any user to build all items in natural size using cardboard and similar. Moreover, the interviewee expressed *"3D-Block is a necessity to later detail the activities by involving third parties, e.g. other departments or suppliers, because it would be hard to show an empty point cloud model and expect everyone alone can estimate and visualise the concept system e.g. activity areas, general flow patterns, relationships etc."*. The interviewee expressed that it is possible to learn 3D modelling fast if you use it a lot. However, it is rarely applied at the department and it might be hard to maintain the knowledge as remodelling of new layouts or cells are not frequent happened. The interviewee summarised the visualisation part with *"In turn of generation, I would want to use block layouts. During evaluation, I would prefer to visualise using 3D-Block because it is more visual and height requirements can be considered"*.

As for WebShare, the interviewee thought it was useful to simplify visualisation without repeatedly visiting the production floor every time which would save a lot of time and not disturb the operators. Moreover, it added the possibility to work from another place and can also be shared with consultants hired do to certain facility planning, without the need to constantly travelling back and forth.

5.3.4 Production engineer & Design member 3

The interviewee thought that overall it was a positive and good planning method but it was unusual to work with a structured method since *"Normally, we have an empty space and add items and move them around until it becomes good"*. The method was experienced in details, systematic, and applicable with a logical step sequence, also flexible as late changes have been smoothly adjusted without the need to redo a step.

The interviewee had only one concern about using workshops which was that it can be hard to get coherent decisions within a large group during a workshop and it can happen that the person with the highest voice can force through decisions even if it is not the best one. However, at the same time the interviewee was pleased with the group size (six to seven members) and mentioned that the group size depends on the magnitude of project. Interviewee expressed *"Everyone needs to be involve in the Atlas project since the system shall work for 10 years and will cost approximately 15 to 20 million SEK. It would be too much responsibility for one person so the work needs to be conducted in the group we had"*. As for group composition, it was good experienced that the department and logistics department were involved in the first workshop and thought logistics department should also be involved during later detailing as they shall supply materials to the production system. However, interviewee expressed *"The logistics department was included but the Logistics manger did not show any interest of being involved, which resulted in that some concerned questions were not addressed properly. I think the logistics department should take more responsibility and address the concerns. The relationships between activities might be unimportant for the logistics manager, but not for the personnel that will supply materials"*. Based on the outcome the interviewee suggested that it might be good to involve a representative from the production floor, i.e. production manager, group leader, etc., as it is their personnel that will be affected by the new layout and might have some concerns. The interviewee thought that it was satisfactory with two hours' sessions, but expressed *"It was hard the first time as it took the interviewee one hour before considered himself useful"*. Time was the only identified obstacle and the interviewee thought the department needs to spend time getting used to the method by training on smaller projects to be able to apply it for larger projects efficiently. Otherwise, the process might become more time consuming as they are not used to it and maybe do not have any assistance next time.

The interviewee thought the relationship chart and activities' requirements sheet were detailed and that it was good to get the data documented. However, the chart was experienced hard and it was a thought that more practice should have been performed on smaller systems. Moreover, the interviewee thought that more evaluation should be done thoroughly on the specific areas based upon what can be done to make the current areas more efficient. Furthermore, it was experienced reasonable to let the project leader concluded the relationship diagram. The interviewee thought that it was necessary to do the first step as the size of the layout increases. It was interesting to create different layouts, but it was hard to follow the relationship diagram as the interviewee had a preconceived idea of how only the production flow was supposed to go without considering the relationships. The interviewee thought that adding the screening and rework step was good as *"In the beginning, it becomes more brainstorming with a lot of ideas, some wild and some constructive, so it is suitable to do a qualified evaluation and then polish the constructive candidates between the project leaders, also it is good to involve the manager as he will be presenting the results upwards to obtain understanding and supports".* The interviewee was especially impressed with the evaluation step and thought it was a good way to choose between better or worse solutions. The 3D technology was expressed to be a great complement to 2D drawing as it added the option to evaluate measurements, e.g. heights requirements, without the need to visit the production floor every development meeting. Moreover, it is a good tool to present solutions for management and operators as it is easier to view a realistic representative of a system. However, the interviewee was disappointed on the resolution of the projector which made him tired fast and stated *"If you spent money and time to create and present a 3D scan model, it is important to have a good computer and projector to visualise the result".* Moreover, interviewee expressed that it would have been interesting to scan the current system to insert all stations in the layout to gain even better visualisation during the 3D evaluation. The interviewee thought it was hard to evaluate if the 3D laser technology was worth 500,000 SEK, but thought that the larger the development project and capital investment, the bigger reason to invest in the technology. However, there is always someone else with the wallet and think *"No, we will instead spend an extra week to measure accurately".*

As for visualisation, during generation the interviewee experienced that it is an advantage of working in 2D and it provides simple visual overview which is only needed when arranging all blocks into the available area. The 2D-section without the floor would be preferred as a 2D-template as it visualise current details but without a 3D scanner, a template from Visio or Excel have to be used and they are still good enough.

In general, the interviewee experienced that it is an advantage of using 3D scanning as it provides the viewer with more details and realistic space awareness and it was not harder to evaluate using 3D than 2D. However, interviewee mentioned that during the evaluation for the Atlas layout, the final result turned out the same for using 2D and 3D. The interviewee thought that using 3D evaluation depends of the facility, also if more details from current production system could be merged, it would be perfect as it would be possible to provide more accurately visualised flows. For detailing, the interview expressed *"Now we only focus on 3D and we would need to scan required objects or receive completed models from other companies to create a flow from start to end. Then, present it to the management and operators to explain and gain supports"*. The interviewee thought it was an advantage to apply 3D-Block as it detailed the layout and structured and supported when detailing a layout. Moreover, with visual blocks, it is easier for people to understand the size of a block in comparison to an empty point cloud where anything can be made which increases the risk of running out of space and have to start again. The interviewee stated *"Thus, 3D-Block is better"*. The interviewee was also disappointing that the Atlas project was turned down so the detailed phase never started where operators and other department would be involved in workshops to finalise the Atlas layout. The interviewee did not try WebShare and had nothing to comment about its applicability.

5.3.5 Summary of the interviews

The key data from the semi-structured personal interviews with the design team were highlighted and summarised in a concise bullet point list as follows:

- All interviewees experienced that it was an interesting and good planning method that was structured and systematic. Some interviewees also experienced that the method was detailed, practical, efficient and flexible.
- The workshop approach was experienced good and suitable as it pushed the procedure forward, however, design member number three was concerned that it can be hard to get a coherent decision which is a common risk for group work.
- The total time spent on all planning workshops was experienced sufficient to achieve good results but there were mixed thoughts about the duration of a single workshop.
- The interviewees wanted the logistics department to be more involved and they should take more responsibility in the process. Moreover, after performing the procedure most interviewees suggested other parties that could be relevant to involve in the process, e.g. maintenance engineer, production manager and production leader.
- The sequence of the planning steps was experienced logical. However, the assistant project leader experienced that more tasks can be added or moved to the first preparation step. Moreover, design member number two thought that it could be a good idea to add data verification workshops before moving to next planning step especially while being novices.
- The interviewees had different preferences and concerns regarding to each step in details. Mostly, the concerns were the impact of less practice except the design member number three who highlighted that by using 3D scanning, it is important to have a computer and projector that can support high quality resolution. The added screening and rework process was experienced to be adequate to increase the end result.
- All of the interviewees were willing to apply the method in the future, but they felt that it would require more practice on smaller scale before the department feel comfortable to efficiently conduct the method for a large layout alone.
- All interviewees experienced that 3D laser scanning was very valuable to develop and visualise a production layout or system especially for detailing.

They were disappointed that the Atlas project was terminated so there was no purpose to attempt doing the detailed phase and shape the blocks using cross-functional workshops and 3D modelling as there was a lack of resources to allocate to the project. However, the assistant project leader was the only one who thought that investing in 3D laser technology was an obstacle due to current size of the company, but the other design members suggested that a consultant should be hired.

- Some interviewees thought that investing 500 000 SEK in 3D scanning technology would be reasonable for a company in a rapid and change demanding industry, e.g. automotive, or a central development department in a large organisation, e.g. DPP in Danfoss Group.
- When generating layouts, all interviewees preferred to visualise in 2D as it is mainly faster and simpler. 2D-section without floor from a point cloud was the most preferred template to be used as previous details can be utilised and measurements are accurate. Using both computer and drawing on paper were preferred, thus the assistant project leader suggest that the work should be performed at each work station.
- Most interviewees preferred to evaluate layouts using 3D as it provided a better overview and space awareness, especially if the layout could be detailed more before the evaluation. Moreover, none of the interviewees experienced that it was more complex to evaluate using 3D-Block instead of block layouts. However, design member number one thought that for a briefly discussion for the solution within the group, it is better and faster with simple 2D.
- When detailing layouts, all interviewees preferred to work in 3D. Previously, physical mock-up had been experienced efficient but everyone agreed that 3D-Block was the best option for especially the large systems or high LoA as it provided more visual overview, flexibility, efficiency and does not require that the production floor are empty. However, design member number one thought that physical mock-up was still more suitable for small manual systems, e.g. assembly station, as it provides a more realistic feeling for operators to move around and test. Thus, it was suggested in their situation to use 3D modelling and then verify each station with physical mock-up before implementation.
- To continue with the detailed phase, it was experienced a necessary improvement to start with 3D-Block instead of an empty point cloud as 3D-Block provided more insurance, structure and visual support when involving third parties, e.g. operators, during detailing workshops.
- Lastly, the interviewees thought that WebShare was a useful tool to measure, plan and visualise the production to increase safety, efficiency, professional impression and decrease operator disturbances. Much like a virtual Gemba that could be used when conducting the activities´ requirements sheet either individually or in group.

6 Discussion

This chapter will address and discuss different discoveries and issues that have been presented during the research procedure and results.

6.1 The developed research design

The author of this thesis experienced that the applied research design was the most suitable and necessary based on the research purpose as it was necessary to gather personal data and continuously develop 3D-SSLP and 3D-Block. However, the research approach could have been expanded from a qualitative to a mixed approach if there had been more time, so that an additional dimension can be acquired for triangulation or used to compare the outcome of 3D-SSLP with the current state to see if the method facilitates users to plan better factory layouts. Nevertheless, it would have been too early to only conduct a quantitative study as the research purpose as it would not be easy to gain in-depth data of the factors that influenced the production engineers. Moreover, as the purpose was to develop a layout planning method for the department, it was satisfactory to have a research design which was emergent so that different planning steps could be tested and optimised based on the feedback to fit the users better. Moreover, the author had to be involved to train design members as they had lack of time and experiences of factory planning and the components of 3D-SSLP. Thus, it was more suitable with action research instead of a case study where the researcher is limited as an observer and not a facilitator. However, this might have affected the opinions of the design members as the researcher was involved and shared knowledge. The data gathering methods were selected since they were suitable to gather the data required for answering the research questions. Moreover, semi-structured interviews was selected it was experienced that structured interviews were experienced too inflexible to gain in-depth data in unknown areas and unstructured interviews were experienced to be too challenging to fairly collecting data from all the relevant areas.

6.2 Planning sequence versus research sequence

The planning sequence was overall considered as logical and positive. However, design member two pointed out that sometimes there was too much time spent in between the workshops which resulted in a longer research procedure. As only one author was conducting the thesis, it was hard to carry out steps in parallel to decrease the procedure lead time. The author had to learn, develop, plan, prepare, test and document each step in the sequence which prolonged the time in between certain workshops especially after 3D scanning was performed. 3D scanning was a new technology to handle by the author so a lot of trial and error was performed in order to achieve satisfactory visualisation of the point clouds and 3D-Block. As a result, the prolonged planning sequence may have probably impacted on how some design members experienced with 3D-SSLP in regard to effectiveness and efficiency. However, to increase the efficiency and consistency of the planning method, it is recommended to perform the 3D scanning and processing of the visual models in advance.

6.3 Cancellation of the Atlas project

As the Atlas project was terminated during the midway of the thesis, the research purpose and objective had to be reshaped as it was not satisfactory for the company to allocate resources, i.e. operators and other functions, to attend cross-functional workshops to detail the Atlas layout. However, the department was still interested in continue developing the Atlas layout and planning method until the final block layout. As a result, the thesis only focused on the concept phase to add it with current 3D laser scanning methodology and make a suitable planning method for the department. The new research purpose and objective was remained as before to investigate 3D-Block but also to emphasis more on developing 3D-SSLP (combined layout planning method) to be more practical and robust for the industry, i.e. instead of continue with the detailed planning phase, the new focus is to make the concept planning phase much better since it sets the limit of the final layout. However, the design team have expressed their disappointment with the termination which can have impacts to the engagements during the rest of the workshops as the team was interested to proceed with the Atlas layout.

6.4 Scanning the factory and visual model

The 3D scanning was planned and performed midway into the research procedure due to schedule limitations and unawareness of early benefits. As previously mentioned, overall of the scanning was considered as very successful even if many would consider that it is not satisfactory to have a lot of unwanted objects scanned. However, the 3D scanning proceed with a lot of unwanted objects remaining on the factory floor to highlight the most significant aspect with 3D laser technology, its flexibility which allows users to easily eliminating unwanted objects and replace them by cloning similar parts of the point cloud. However, the users have to analyse and plan which structural features that are important to be visual when planning the production system and move nearby items to get sufficient scans of the features. In this thesis, the roof beam and pillar were important to be scanned accurately and the floor was not considered important so most of the unwanted objects were grouped together on the floor and later removed from the point cloud to save resources for normal production. However, one thing that was learnt from this thesis was that it is a lot easier and efficient to edit and replace parts from the floor than the walls in a point cloud. Thus, to decrease editing time and increase quality of the point visual model, it is recommended for future scans to place unwanted material in the middle of the factory floor for the trade-off of more scans than moving it along the wall. Furthermore, the more time could have been spent to achieve, the better quality of the visual model but since the block layout was not going to be detailed, the decision was to save time as it was limited.

6.5 Early benefits of 3D laser scanning

After using the WebShare and point cloud, the author noticed that both visual models had big potential to improve early preparation and planning steps in 3D-SSLP or any planning method. The potential improvements were also shared by some design members during the interviews. Both WebShare and the factory point cloud provides a photorealistic representation, hence, it was able to work as a virtual Gemba, see Section 2.1, but WebShare have the advantage of photorealistic panorama pictures which makes it possible to clearly visualise small details. Thus, WebShare can be used to either individually or in group, i.e. in a workshop, determine areas and utilities of each activity with higher efficiency, consistency, accuracy and flexibility, in comparison to manually measure areas or memorise all utilities during the workshop. Since two persons were required to efficiently measure the areas manually. Moreover, it was hard to estimate and measure activity in person compared to WebShare that provided a top view too, this resulted that some activities were a little inaccurate. Compact and rectangular activities, e.g. machines, were measured approximately at the same with both techniques. However, other activities were either over- or underestimated when manually measured which can affect the final block layout before starting to detail it.

As for flexibility, WebShare are only required a few mouse clicks to update previous data or to directly discuss a topic. WebShare also have the same benefits to perform measurements to procedure a more accurate layout template. Moreover, from the factory point cloud it is possible to directly create a suitable 2D-template that includes all the current details and the interviewees expressed that the most satisfactory 2D-template was the 2D-section of the factory point cloud of without floor, see Figure 28. However, some interviewees pointed out that it would be preferable if a grid net can be added. This has to be investigated if such a software feature exists or it has to be made manually. The highlighted benefits in this section was suggested that 3D scanning and scan data processing should be performed before starting to plan the physical structure of a production system to increase accuracy and efficiency of the planning.

6.6 3D laser scanning investment

In Section 2.2 was it presented, that the cost of 3D laser scanning equipment is dropping but still scanners can cost tens of thousands of dollar and to ensure proper utilisation is training and software products required. To probe for information regarding 3D laser scanning investment during the interviews, the previously mentioned investment of 500 000 SEK was presented as a reference point to the interviewees. The interviewees had recognised the value of utilising the scan data and digital mock-ups (DMUs) presented in the theory section and previous research work, but even though the interviewees pointed out that in the company's current context the company is too small and the time between radical changes at long to justify investment in 3D laser scanning. The design team, however, already had software products compatible with point clouds and it was widely suggested to reduce the investment cost by only acquiring required computer hardware, additional software (that are not free), and training in order to efficiently utilise scan data and 3D modelling and hiring a third party to perform the 3D laser scanning and scan data pre-processing. However, project leader experienced that it was easy to operate the 3D scanners and recently the pre-processing software products are user-friendly and offer automated solutions. Also, nowadays there are renting services of 3D laser scanners which could be more cost effective solution to use during rare radical changes instead of hiring a third party or buying the scanner equipment. It would provide the design team more flexibility and freedom during the change project to ensure that all important features are included with high quality and the scan data can be updated after implementation to be used in between radical changes for continuous improvement projects, flow planning, and facility management. However, this is something that each company has to investigate in order to find the optimal solution in their own context but until the equipment cost drops even more, it can be concluded that with the company's situation (company size and change frequency), it is still not considered viable to invest in the 3D scanning equipment. However, some interviewees shined a light that the investment could be viable for companies that are in a change demanding industry, i.e. automotive, or if it can be jointly purchased with the organisation or other partner company.

6.7 3D-Block foundation for DMU

It was presented in the literature, that 2D laser scanning is the tool to create large DMU of factories and it is important include the whole layout planning life cycle in order to achieve well planned layouts, see Section 2.2.1 & Section 2.3.1. Moreover, 3D-Block that was created and used in this thesis was appreciated by the design team as it was experienced to enhance the planning through visualisation of the block area in a photorealistic environment when start planning the detailed layout with operators as well as 3D-Block gave a better overview for a block layout rather than a 2D or physical mock-up. In order to successfully use a virtual model, two tables were presented by Rohrer (2000) and Teyseyre & Campo (2009), see Section 2.1. By visualising 3D-Block in a client-based viewer like Navisworks makes the virtual model facilitates the elements: interactivity, realism, flexibility and user-friendly, Navisworks made it possible to easily zoom and pan around the realistic environment and adding new object into the environment. However, the performance varied a lot due to the lack of hardware capacity in computer equipment and the compatibility between Navisworks and AutoCAD functions, i.e. group function, could be improved so it will be more efficient to target and move around the block areas. 3D-Block facilitated all the strengths of 3D visualisation presented by Teyseyre & Campo (2009). Moreover, most of the weaknesses were avoided but as mentioned earlier due to lack of computer hardware, there was a diminish effect in the 3D model inside Navsiworks, i.e. some hidden objects were shown and vice versa. In this thesis, Navisworks was used to diminishing the file format issue, however, there might exist more efficient and effective client-based viewer that can handle more data, i.e. scan points, with lesser computer hardware. The seven years old computer and old projector used in this thesis were experienced to be the main limitation to overcome the weaknesses of 3D visualisation when the data increased. However, nevertheless the interviewee felt it was easy to manoeuvre and understand the 3D model but it would have been smoother navigation with newer hardware during the workshop, which did not make the viewers tired. Moreover, 3D-Block is neutral to which method is used to produce the block layout which is merged with the factory point cloud. Thus, it is possible to investigate other planning methods to efficiently produce sufficient block layouts such as optimal algorithm developed to solve the FLP. By integrated this algorithm as add-ons to CAD software, it would be possible to automate the process from input data to 3D-Block, that would make it possible to make the process quantitative instead of using the sub-optimal manual and qualitative methods. 3D-Block makes it possible to move the research areas 3D laser scanning and FLP to start collaborations to gain the best of best of two worlds: optimal planning algorithms to achieve an efficient block layout; and realistic visualisation to verify and detail the block layout with third parties.

6.8 Workshop method

Overall content and structure of the workshops were experienced positively by the design team. Moreover, in Section 2.3.2 it presented that it is important to facilitate *co-operation* between within the design units and *cross-functionality* in order to gather data efficiently and gain acceptance within the company and department. However, design member one and three explicitly pointed out the importance to have a project leader who prepared, planned and led the procedure otherwise there was a great risk that it lost its systematic structure, which would most likely decreased the efficiency and quality. Thus, the design team needs to practice the procedure on smaller scale in order to conduct it efficiently during next large layout planning project which all the design team mentioned. Moreover, the overall workshop time was experienced sufficient but it is hard to divide the workshop duration to suit everyone and task. As the assistant project leader pointed out in the interview that *"The workshop duration is a personal preference and it is hard to make it fits everyone, but I would prefer one hour* *workshops instead"*. Most SSLP tasks took approximately 90-120 minutes to complete during the workshops and most tasks build up a temporary reasoning or *"Rating average"* during the session. There was a risk that the temporary reasoning did not follow if there was a break in case that the session is cut in two one-hour session with a few days in between which might cause inconsistent and flaw rating. However, it is maybe more important that the design team practice more on a small scale so that the tasks or sessions became more autonomous and efficient without risking the quality by cutting the workshops short, i.e. not complete the whole task at once. Moreover, the author of the thesis acted as the workshop moderator alone. As a result, some workshops became more challenging when the moderator had to lead the session while simultaneously carried out another task, e.g. navigating the 3D model. A future recommendation to both the project leader and assistant is that they are required to train beforehand, so they can divide all the required tasks for the workshop as a moderator to increase efficiency, e.g. one lead the session and another one document data or navigate models.

6.9 Order of the planning steps

The interviewees thought the planning procedure was overall positive as it was logical and systematic. However, assistant project leader suggested it can be good to settle and review the evaluation factors early in the planning procedure by converting the settled supply chain strategy into evaluation factors for the block layout. Moreover, the importance of *strategy alignment* in factory planning was presented in the theory, see Section 2.3.2. Thus, this was considered as a positive contribution as it gave the design team a clear aim throughout planning procedure which could increase the robustness and quality when rating relationships and generating layouts. Moreover, assistant project leader also suggested it can be good to include a VSM to complement the process flow chart when rating the relationships and to verify the final block layout so nothing is omitted, as the process flow chart only includes the flow of: raw material; WIP; and finished goods, while VSM also includes the flow of information and additional production data. This is considered to be a positive contribution to the procedure as it can increase the robustness of the relationships. Moreover, the department already had to conduct a VSM during the preparation phase so no additional layout planning time is required. However, another suggestion can be to complement the process flow chart by applying the 7 flows model, especially for companies that does not utilise VSM, see Section 2.2.3. Thus, the feedback from the assistant project leader is considered as compelling and aligns with the theory and it is recommended that design teams apply one of the two suggested method (7 flows or VSM) in the final planning method based on their own preferences.

6.10 Screening and reworking step

During the research procedure, it was noticed that many generated block layouts did not follow the relationship diagram. An underlining reason has been identified based on the interview data which was that more practice was needed. Design member three expressed *"Project leader should point out more clearly that the relationship diagram needs to be followed when generating layouts. Maybe you did but the design team was too focused on generating block layouts in a structure manner for the first time"*. However, during the workshops it was highlighted by the project leader few times that the design team should use the relationship diagram and start with planning an ideal solution which is then adopted to reality, but it was experienced that the design teams were already too focused on generating block layouts and did not acknowledge the information clearly. As a result, the screening and reworking preparation step was added to the procedure. The step was designed based on what was suitable for the current practices and resources of the department and it put demand on the project leader(s). The interviewees experienced the additional step was suitable as both constructive and wild solutions will be generated especially for an inexperienced design team. However, one interviewee thought that this step might not be required for an experienced design team. Thus, this step might be redundant for experienced design teams. Moreover, there might be more suitable approaches in other contexts to increase the quality for both an in- and experienced design team and that is something that has to be further investigated.

6.11 3D evaluation

It was presented in the theory that realistic 3D visualisation can improve the evaluation process for different layout solutions, see Section 2.1. The ratings for Layout F got polished in the realistic evaluation step but some factors were a direct effect of the updates in the block layouts. There were other factors which could have affected the results. One reason could be that the 2D evaluation results were presented in the evaluation sheet during the 3D evaluation which could have influenced the participants to stand by the old results. Another reason could be that the Atlas project had been terminated so maybe there was little incentive and value to carry out an extra and more detailed evaluation in 3D. Moreover, no additional evaluation factors, e.g. height requirement, ease to build, etc., were not added in the 3D evaluation as it had previously been concluded that it was possible to raise the machine units from the floor. However, the design team expressed during the fourth training session that it was a great idea to present the block layout inside the point cloud as it gave more perspective than just a simple 2D representation of the block layouts. Also, the interviewees did not consider it as more complicated evaluation in 3D than 2D. Moreover, most interviewees expressed that it would be very valuable to add additional simple DMUs (both CAD and point cloud) before the 3D evaluation as it would give more correct representation of the actual flow patterns. As a result, it is of interest to further investigate 3D evaluation as a replacement for 2D evaluation to evaluate block layouts and how it should be performed in the best possible manner.

6.12 3D-SSLP and success factors

Nine success-promised principles for factory planning were presented in the theory, see Section 2.3.2. During the Atlas project, most of these factors were achieved with the components of 3D-SSLP, but the principle of *life-cycle* and *scenarios* were not considered and tested in this thesis due to delimitations in both the research and the Atlas project. However, it can be argued that with 3D-SSLP it is possible to create block layouts for different cases by repeating the first steps of the methods. Moreover, it can be possible to translate the different life-cycles to a relationship level or as evaluation factors so the cycles can be in cooperated into in the different work material i.e. relationship and requirement mapping and block layout evaluation. Moreover, the design team are pleased with the outcome from the planning procedure. Thus, it can be summarised that 3D-SSLP is a satisfactory factory planning method for those that are interested in moving towards realistic visualisation and success.

7 Conclusion

This chapter will conclude the results and discussion in order to concisely answer the research question presented in the introduction as well as present the recommended planning procedure for the concept phase. Lastly, different future efforts suggested to the department and academia.

7.1 Research questions

The research questions asked in the introduction chapter are highlighted with italic font and the answers were presented accordingly in the below paragraph:

RQ1: How can simplified systematic layout planning, 3D laser scanning and workshops be combined to create an efficient and practical layout planning method, which will be referred as 3D-SSLP here on, that can complement current 3D laser scanning methodology?

This thesis has presented an emergent study to develop an efficient and practical layout planning method that can complement current 3D laser scanning methodology. By combining SSLP, 3D laser scanning and workshops, this has been achieved as 3D-SSLP and final block layout had gained positive feedback. Moreover, the appreciated addition of 3D-Block provides a merging point with the current 3D laser scanning methodology as 3D-Block was considered as crucial support when starting the detailed planning phase with cross-functional workshops.

During the interviews, it was revealed that the project leader of the factory layout planning has a crucial role in making the planning procedure efficient and practical. The project leader is the driving force and facilitator, hence, this person needs to have some experience of SSLP, 3D laser scanning and workshops so the methods can consistently be pushed forward without major hold-ups. Moreover, practice was also experienced to be a cornerstone of 3D-SSLP to confidently continue applying without the fear of being ineffective. The screening and reworking process was a good addition for an inexperienced group to increase quality of the final block layout. However, it is required that the practitioners should be able to devote their times to optimise general flow patterns of potential candidates in details. Furthermore, the workshop moderator responsibilities must be delegated between project leader and assistant to facilitate efficient workshops that do not lose the pace. Also, the WebShare and factory point cloud must be performed before the project starts in order to make the layout planning method efficient and consistent during the concept phase. Lastly, it is required that the design team should also have experiences with 3D modelling and have the computer hardware and software to smoothly model and visualise the point clouds.

RQ2: How are simplified systematic layout planning, 3D laser scanning, workshops and 3D-SSLP, experienced?

3D-SSLP was experienced as a good planning method to create a block layout and facilitate the detailing with third parties. 3D-SSLP has been experienced to be systematic, structured, efficient, practical, flexible and detailed. Workshops were a positive and flexible way of working as it involved relevant parties to work collectively and the group can be adjusted according to size of project. SSLP was appreciated as it provided 3D-SSLP with a systematic structure which ensured all details had been considered and not omitted. 3D laser scanning was experienced as a very good addition to the method as it could improve preparation, development and communication when planning layouts as the technology can efficiently generate accurate data to create realistic and visual models. However, it was still experienced not feasible in the current company context to invest in the actual 3D scanner unless it was jointly purchased with the organisation. In the current situation, it is experienced suitable to invest in the computer hardware and software to handle the scan data and hire a third party to perform the scanning for data.

RQ3: How are block layout, physical mock-up and 3D-Block (DMU of block layout and point cloud) experienced? When and in what context are these visualisation techniques preferred during the layout planning life cycle?

Working in 2D view with block layout was experienced to be the best option when generating layouts as it provided a satisfactory system overview for arranging blocks according to the settled requirements and created the general flow patterns. Moreover, block layout could be generated using a range of different generation methods (from simple drawing to advance modelling) which could facilitate everyone to conduct more easily and fast. It was experienced that 2D view with block layout provided sufficient conceptual overview to be the most suitable way of briefly discussing different ideas within the design group as block layout is quickly created and easily shared.

Physical mock-up is experienced to be the best method for small scale systems to evaluate and verify the impact on operators from different solutions before implementation as 3D was preferred for final evaluation and detailing of layouts. However, physical mock-up is experienced inefficient to plan large systems and block layouts as it requires a lot of production floor to be available and it does not provide viewer with a satisfactory system overview in comparison to working with 3D-Block.

3D-Block is experienced to be a necessary addition to the 3D laser scanning methodology in order to facilitate detailed layout planning using workshops with cross functional teams. Moreover, it is experienced that 3D-Block is the best visualisation approach when evaluating and detailing large layouts or possibly machine intensive production system.

7.2 Recommended planning method

Based on the learning outcomes from this thesis, the recommended planning method for the concept design phase has been concluded and presented, see Table 6. The dark grey colourings represent the transition from other phases. The light grey colourings represent the preparation steps conducted by the project leaders and the uncoloured steps are the planning steps where workshops are applied with different teams. The duration times are approximated based on the size of the layout project and process flow in this thesis. Moreover, the preparation steps are also estimated for a project leader that can allocate to the project approximately 100 percentages of the working hours.

Layout planning team is the department or group of employees that are responsible for designing the new production systems and layout.

Project leader(s) is the engineer(s)/manager(s) in the layout planning team that is entrusted with leading and decision making when planning the physical layout of the production system. The project leader(s) should have experiences with workshops, #d laser scanning, SSLP and 3D modelling. The duration for the preparation steps are estimated based on a project leader that focus 100 percentages of the working hours on the project due to its size and impact.

Cross functional team is a group that includes design team and employees from relevant department that are affected by the layout design, e.g. logistics, operators, production manager, etc. This team is responsible to assist the design team to make the best relationship trade-offs for the production system concept.

Table 6: Recommended layout planning method

Step	Task description	Involved	Work method	Duration
0	-Perform 3D laser scanning -Process 3D scan data -Create WebShare -Create and edit point cloud (-Create VSM if company practice)	Tasks that are preferably conducted before starting the concept design phase to decrease the lead time of the phase.		
1	-Create a process flow chart -Acquire required planning worksheets -Insert processes in the relationship chart and requirement sheet -Investigate and settle evaluation factors	Project leader(s)	Self	Approx. >½ week
2	-Review process flow chart, evaluation factors and VSM or 7 flows -Conduct and complete relationship chart considering process flow chart, evaluation factors and VSM or 7 flows	Cross functional team	Workshop until tasks are completed	Approx. 2 hours
3	-Conduct and complete the requirement sheet with assistance of WebShare to view current state	Layout planning or cross functional team	Workshop until tasks are completed	Approx. 2 hours
4	-Create the relationship diagram -Create preferred layout template with assistance from WebShare or point cloud	Project leader(s)	Self	Approx. >2 day
5	-Review the relationship diagram and layout template -Each participant generates around 1 original block layouts per hour	Layout planning team	Workshop with either 1 or hours session(s)	Approx. 2 hours or based on internal preferences
6	-Review the original block layouts and weed out those that are not satisfactory until 2-3 remain -Optimise remaining original block layouts and try to make 2-4 reworks for each original	Project leader(s)	Self	Approx. 1 week
7	-Review settled evaluation factors again -Review reworked block layouts -Evaluate reworked block layouts	Layout planning team	Workshop until tasks are completed	Approx. 2 hours
8	-Convert top rated layouts and critical	Project	Self	Approx. 1

	process solutions to CAD models and merge them with point cloud	leader(s)		week
9	-Review point cloud with 3D scan model -Make a realistic evaluation of the top rated layouts to ensure layout can facilitate the critical solutions	Layout planning team	Workshop	Approx. 2 hours
10	-Plan the detailed layout for each block until the model is able to be used as a schematic for implementation	Either by repeating the steps in 3D-SSLP for each block with cross-functional workshops or read Lindskog (2014) and Olofsson & Sandgren (2015) for more information and suggestions.		

7.3 Future development and research

The recommendation for the department is to nurture the knowledge acquired during this study until next large layout planning project by practicing the layout planning steps on small projects. Moreover, according to different preferences have been presented during interviews, it is recommended for the department to address promptly in order to settle the planning procedure as a standard operating procedure (SOP) and properly document the recommend layout planning method until next radical change.

Recommendation for future research would be to combine 3D-SSLP with the current 3D laser scanning methodology (LAMDA-cycle and 7 flows) to conduct a case study from concept to detailed layout in order to find further improvement areas, e.g. it could be more resourceful to follow the 7 flows while conducting the relationship chart. Moreover, 3D-Block is not depended on which procedure is applied to procedure the block layout. This allows it to be combined with any approach to generate block layouts, so further investigation can be carried out to combine it with optimal FLP algorithms to further digitalise the planning process together with 3D laser scanning.

A task for software developers is to start developing add-ons to existing CAD software or stand-alone programs that can automatically generate block layouts based on certain inputs which can after be merged with point clouds, preferably in the same software to minimise transferred. The layout planning procedure needs a digital make-over with today's computer hardware.

References

Autodesk (2016a) RECAP 306. *Autodesk*. http://www.autodesk.com/products/recap-360/overview. (2016-05-13).

Autodesk (2016b) NAVISWORKS. *Autodesk.* http://www.autodesk.com/products/navisworks/overview. (2016-05-13).

Autodesk (2016c) AUTOCAD. *Autodesk.* http://www.autodesk.com/products/autocad/overview. (2016-05-13).

Bellgren, M. & Säfsten, K. (2010) *Production Development: Design and Operation of Production System*. London: Springer.

Bi, Z.M. & Wang, L. (2010) Advances in 3D Data Acquisition and Processing for Industrial Applications. *Robotics and Computer-Integrated Manufacturing*, 26(5), pp. 403-413.

CloudCompare (2016) Presentation. *CloudCompare – 3D point cloud and mesh processing software – Open Source Project.* http://www.danielgm.net/cc/. (2016-05-13).

Creswell, J. W. (2014) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. Fourth Edition. Corydon: SAGE Publications, Inc.

Dassot, M., Constant, T. & Fournier, M. (2011), The use of terrestrial LiDAR technology in forest science: application fields, benefits and challenges. *Annals of Forest Science*, 68(5), pp. 959-974.

Drira, A., Pierreval, H. & Hajri-Gabouj, S. (2007) Facility Layout Problems: A Survey. *Annual Reviews in Control*, 31, pp. 255-267.

Ebert, D. S. (2005) 39 – Extending Visualization to Perceptualization: The Importance of Perception in Effective Communication of Information. In *Visualization Handbook*, ed. Johnson, C. & Hansen, C., pp. 771-780, Burlington: Butterworth-Heinemann.

FARO (2015) kubit software has been acquired by FARO. *kubit software has been acquired by FARO*. http://www.kubit-software.com/. (2015-05-13).

FARO Technologies (2011) FARO Laser Scanner Focus3D User Manual.

FARO Technologies (2012) *FARO SCENE 5.1 User Manual.*

FARO Technologies (2016a) FARO Scanner Freestyle3D User Manual.

FARO Technologies (2016b) *FARO SCENE 6.0 User Manual.*

Gregor, M., Medvecký, Š., Matuszek, J. & Štefánik, A. (2009) Digital Factory. *Journal of Automation, Mobile Robotics & Intelligent Systems*, 3(3), pp. 123-132.

Gropper, G. L. (1963) Why is a Picture Worth a Thousand Words?. *Educational Technology Research and Development*, 11(4), pp. 75-95.

Johansson, B. (2008) *Framtidsfabriken*. Luleå: Luleå University of Technology.

Kemmis, S. & McTaggert, R. (2000) Participatory Action Research – Communicative Action and the Public Sphere. In *The Sage Handbook of Qualitative Research*, ed. Denzin, N. K. & Lincoln, Y. S., pp. 271-330, Thousand Oaks: Sage Publications Ltd.

Klein, L., Li, N. & Becerik-Gerber, B. (2012) Imaged-based verification of as-built documentation of operational buildings. *Automation in Construction*, 21, pp. 161-171.

Koshy, E., Koshy, V. & Waterman, H. (2010) *Action Research in Healthcare*. Sage Publications, Inc.

Kothari, C. R. (2004) *Research Methodology: Methods and Techniques*. Second Edition. New Delhi: New Age International.

Kusiak, A. & Heragu, S. S. (1987) The Facility Layout Problem. *European Journal of Operational Research*, 26, pp. 229-251.

Liker, J. K. (2004) *Toyota way: 14 Management Principles from the World's Greatest Manufacturer*. New-York: McGraw-Hill, cop.

Lindskog, E. (2012) *Layoutplanering – Vad är en bra verkstad?*, PPU055, Chalmers University of Technology, Gothenburg, (2012-11-01).

Lindskog, E. (2014) *Towards Realistic Visualisation of Production System*. Gothenburg: Chalmers University of Technology.

Lindskog, E., Berglund, J., Vallhagen, J. & Johansson, B. (2014) Lean Based Problem Solving Using 3D Laser Scanned Visualisations of Production Systems. *International Journal of Engineering Science and Innovative Technology*, 3, pp. 556-565.

Lindskog, E., Berglund, J., Vallhagen, J. & Johansson, B. (2013) Visualisation Support for Virtual Redesign of Manufacturing Systems. *Forty sixth CIRP Conference on Manufacturing Systems 2013*, pp. 419-424.

Meller, D. R. & Gau, K. (1996) The Facility Layout Problem: Recent and Emerging Trends and Perspectives. *Journal of Manufacturing Systems*, 15(5), pp. 351-366.

Muther, R. (1974) *Systematic Layout Planning*. Second Edition. Boston: Mass.

Muther, R. & Wheeler, J. D. (1962) *Simplified Systematic Layout Planning*. USA: Management and Industrial Research Publications.

Olofsson, A. & Sandgren, M. (2015) *Utilising 3D Laser Scan Data for Redesigning Production Systems –A Case Study at GKN Aerospace Engine Systems*. Gothenburg: Chalmers University of Technology.

Phillips, E. J. (1997) *Manufacturing Plant Layout: Fundamentals and Fine Points of Optimum Facility Design*. Dearborn: Society of Manufacturing Engineers.

Randall, T. & Philp, D. (2013) *Client Guide to 3D Scanning and Data Capture.* The Building Information Modelling (BIM) Task Group.

Rohrer, M. W. (2000) Seeing is Believing: The Importance of Visualization in Manufacturing Simulation. *Proceedings of the 2000 Winter Simulation Conference*, pp. 1211-1216.

Simonsson, E., & Johansson, J. (2015) *In Context Manufacturing Development Using 3D Laser Scanning at Volvo Car Corporation*. Gothenburg: Chalmers University of Technology.

Singh, S. P. & Sharma, R. R. K. (2006) A Review of Different Approaches to the Facility Layout Problem. *International Journal of Advanced Manufacturing Technology*, 30, pp. 425-433.

Smith, R. P. & Heim, J. A. (1999) Virtual Facility Layout Design: the Value of an Interactive Three-Dimensional Representation. *International Journal of Production Research*, 37(17), pp. 3941-3957.

Staiger, R. (2003) Terrestrial laser scanning technology, systems and applications. *2nd FIG Regional Conference*.

Teyseyre, A. R. & Campo, M. R. (2009) An Overview of 3D Software Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 15(1), pp. 87-104.

Wiendahl, H.-P. & Fiebig, T. H. (2003) Virtual Factory Design – a New Tool for a Co-operative Planning Approach. *International Journal of Computer Integrated Manufacturing*, 16(7-8), pp. 535-540.

Wiendahl, H.-P. & Hernández, R. (2006) The Transformable Factory – Strategies, Methods and Examples. In *Reconfigurable Manufacturing Systems and Transformable Factories*, ed. Dashchenko, A. I., pp. 383-393, The Netherlands: Springer-Verlag Berlin Heidelberg.

Zandin, K. B. (2001) *Maynard's Industrial Engineering Handbook*. Fifth Edition. New York: McGraw-Hill, cop.

Zhou, C., Wang, J., Tang, G., Moreland, J., Fu, D. & Wu, B. (2016) Integration of Advanced Simulation and Visualization for Manufacturing Process Optimization. *Journal of the Minerals, Metals & Materials Society*, 68(5), pp. 1363-1369.