Tampereen yliopisto

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3D LAYOUT DESIGN FOR AUTOMATION SYSTEMS IN PROPOSAL SALES PHASE

Master of Science Thesis
Faculty of Engineering and Natural Sciences
August 2021

ABSTRACT

Tero Perävainio: 3D layout design for automation systems in proposal sales phase
Master of Science Thesis
Tampere University
Master's Degree Programme in Automation Engineering
August 2021

Three-dimensional (3D) software models are becoming more mainstream as deliverables. A demand for 3D solution layouts for automation systems in manufacturing has existed for a while now. Solution layouts are created in proposal sales phase to check that requested system is possible, reasonable and to provide visual support considering sales. The main goal of the Thesis was to identify benefits and limitations that 3D design can offer for this application. The research was set to find out how 3D is used in solution layout design already and how far 3D layouts could be automated. Component library requirements, needed accuracy and improving proposal layout usage in project phase were also to be investigated.

Research approach was the following. First current 3D layout generation was analyzed. Based on previous development projects and their results, the challenges facing 3D design development in solution layouts were identified providing a good basis for selecting methodology. Research methods selected were specialist interviews and model development. The interviews aimed to reveal opinions and knowledge about layout design that is usually not collected in any form. For development phase the goal was to create a 3D model that could be used for making simple flexible manufacturing system (FMS) layouts. Lastly, the development phase implementation was planned on a general level.

In the implementation phase, a series of specialist interviews were held, and a lot of data was received on various subjects regarding 3D layout design. Main consensus from the interviews was that moving to 3D layouts is realistic if a suitable design software is found. Biggest concern was said to be that it takes more time to create a 3D layout than a two-dimensional (2D) one. After reviewing interview data, the development phase was started. The development consisted of component modelling, script writing and model testing.

As a result, from development, a working model was achieved and the set goals for the model were fulfilled. Simple layouts can now be created in 3D for proposal usage. Several features outside of the original scope were also created making the model usage more convenient. The development process and further implementation of the 3D layout model will be continued in the future to allow more complex creations.

Keywords: 3D, Layout design, Automation systems, FMS

TIIVISTELMÄ

Tero Perävainio: 3D layout design for automation systems in proposal sales phase
Diplomityö
Tampereen yliopisto
Automaatiotekniikan DI-ohjelma
Elokuu 2021

Kolmiulotteiset (3D) ohjelmistomallit ovat lisänneet suosiotaan toimitettavina malleina. Tarjouspuolella on esiintynyt tarvetta automaatiojärjestelmien 3D tarjouslayouteille valmistavassa teollisuudessa. Layoutit tehdään tarjousvaiheessa, jotta voidaan tarkistaa, että pyydetty järjestelmä on mahdollinen ja järkevä. Lisäksi niitä käytetään myynnin tukena visuaalisena apuna. Työn päätavoitteena oli selvittää hyödyt ja rajoitteet, joita 3D tarjoaa tässä käyttötarkoituksessa. Tutkimuksen tavoitteena oli selvittää miten 3D on hyödynnetty layoutsuunnittelussa aiemmin ja kuinka pitkälle 3D suunnittelua voisi automatisoida. Komponenttikirjaston vaatimukset, tarvittu tarkkuus ja tarjouslayouttien käytön parantaminen projektivaiheessa kuuluivat myös selvitykseen.

Tutkimuksen lähestymistapa oli seuraava. Ensin analysoitiin nykyistä 3D layoutsuunnittelua. Perustuen vanhoihin kehitysprojekteihin ja niiden tuloksiin, saatiin selville haasteet 3D layout suunnittelussa. Tämä toimi hyvänä pohjana metodologian valinnassa. Tutkimusmenetelmiksi valittiin asiantuntijahaastattelut sekä mallin kehitys. Haastatteluissa pyrittiin saamaan selville mielipiteitä ja tietoa layoutsuunnittelusta, jota ei yleensä dokumentoida mitenkään. Kehitysvaiheessa tavoitteeksi asetettiin 3D mallin luominen, jolla pystyttäisiin tekemään yksinkertaisia FMS layoutteja. Viimeisenä kehitysvaihe suunniteltiin yleisellä tasolla toteutusta varten.

Toteutusvaiheessa järjestettiin haastatteluja suunnittelijoiden kanssa, joissa saatiin paljon dataa liittyen 3D layoutsuunnitteluun. Johtopäätöksenä haastatteluista oli, että siirtyminen 3D suunnitteluun on realistista, kunhan sopiva suunnitteluohjelmisto löytyy. Suurimpana huolenaiheena nähtiin, että 3D layoutin teko vie enemmän aikaa kuin kaksiulotteisen (2D) teko. Haastatteludatan läpikäynnin jälkeen aloitettiin kehitysvaihe. Mallinkehitys koostui komponenttien mallinuksesta, koodin kirjoituksesta ja testauksesta.

Tuloksena kehitystyöstä saatiin aikaiseksi toimiva malli, joka täytti sille asetetut vaatimukset. Yksinkertaisia layoutteja voidaan nyt luoda tarjouspuolen käyttöön 3D:ssä. Useita muita ominaisuuksia kehitettiin myös helpottamaan suunnittelua, vaikka ne eivät kuuluneetkaan alussa asetettuihin tavoitteisiin. 3D layout mallin kehitystyötä ja käyttöönottoa jatketaan tulevaisuudessa, jotta voidaan luoda monimutkaisempia järjestelmiä.

Avainsanat: 3D, Layout design, Automation systems, FMS

PREFACE

I would like to thank everyone at Fastems that participated in interviews and discussions regarding this Thesis work. Special thanks to Antti Ruokonen for the help during the development phase and to Risto Pihlanen for guidance and overall support during the whole research process.

I would also like to thank teachers, friends and family who have supported me not only during this Thesis work but also for the duration of my Master’s Degree Programme.

Nokia, 15 August 2021

Tero Perävainio

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LIST OF ABBREVIATIONS

ALD	Auto Loading Cell
AMC	Agile Manufacturing Cell
CAD	Computer-aided design
CTS	Central Tool Storage
FMS	Flexible manufacturing systems
FPC	Flexible Pallet Container
GTS	Gantry Tool Storage
LS	Loading station
MLS	Multi Level System
MMS	Manufacturing Management Software
PDM	Product Data Management
PGA	Peak Ground Velocity
PLM	Product Lifecycle Management
PNP	Plug and Play
RFC	Robotized Finishing Cell
S/R	Storage/Retrieval
TSC	Tool Service Cell
UI	User-interface
VR	Virtual Reality
2D	Two-dimensional
3D	Three-dimensional

1. INTRODUCTION

Increasing demand and development of three-dimensional (3D) design have been changing the landscape of industrial design from the traditional two-dimensional (2D) design for a while now. Two-dimensional drawing methods have been used for centuries. Even travelling to moon and back on the most complex transportation system ever was all documented in 2D drawings [1].

For many industrial areas 2D drawings are still important but not ideal for demonstrating the product features to customers. They incorporate a possibility of misinterpretation and ambiguity, which can lead to errors and time loss due to implementation of last-moment design changes. Using 3D, geometrically accurate and digital product models, can be created and utilized throughout the manufacturing process. These models can be reviewed and modified collaboratively using the feedback from suppliers, subcontractors, and customers. [2]

According to Moran [3], 3D software models are becoming more important on larger projects as a deliverable. They allow nontechnical staff to have input into the design even with limited experience on engineering drawings.

Companies using 3D to design new products will surpass those still using 2D to design physical products in a competitive market. Not using 3D is going to cost a company in time-to-market, in innovation, and in ability to attract to new employees. [1]

The demand for 3D layouts in manufacturing automation has existed for a long time and the requests are increasing. This Thesis work focuses on solution layout design aspect in the sales phase of a case. Layouts are created for each offer of a new system and for modifications of old delivered systems. The purpose of a solution layout is to check that requested system is possible, reasonable and to provide visual support considering sales. A solution layout includes all equipment to be placed to the available space with dimensions and system information.

1.1 Research questions

Main goal of the Thesis is to find ways for increasing efficiency through 3D layout creation while identifying benefits and limitations. The research questions were set to reflect this:

1. How are 3D solution layouts designed currently with different design software?
2. How much of the 3D layout generation can be automated?
3. What kind of a model library and accuracy is needed at proposal phase?
4. How to further use a proposal layout at project stage through a configuration or directly as a base for the project layout?

1.2 Research limitations

Certain limitations are applied in the research to keep the subject from expanding too much. All software used in the research is currently in use at the company and unfamiliar software will not be tested. As the research focuses on 3D layout design, 2D design methods will not be discussed in detail even though they are used mainly for layout design at the moment.

Furthermore, the 3D layout design research will be focused on Flexible manufacturing systems (FMS). Any development work will be directed to simple systems to start with so that it can later be later expanded on.

1.3 Structure

Structure of the Thesis Work follows the traditional model by first addressing Theoretical background in Chapter 2. This part focuses on explaining the basis, principles, and means on which solution layout design is founded on.

Chapter 3 is centred around explaining the approach and design for the research. The approach will be laid out step by step. Current 3D layout generation is analyzed to provide a good basis for selecting methodology. Methodology will be described in detail as well as planning for implementation phase of the research.

Chapter 4 will convey the implementation phase by first presenting results from interview study where questions were asked about different aspects of layout design. To better evaluate current software suitability in 3D design, a new 3D layout creation model is developed. This development will be presented step by step.

In Chapter 5 the research results are provided. The developed model is presented, and its features are discussed. Future development plans for the model will be outlined as well as other development ideas.

Lastly as a conclusion there is Chapter 6 where the whole thesis work will be assessed. The study questions will be answered, and the suitability of selected study methods will be analyzed. The weaknesses and strengths of the study shall be evaluated. Future aspects of the Thesis work will also be discussed.

2. THEORETICAL BACKGROUND

This chapter focuses on explaining the basis, principles, and means on which solution layout design is founded on. After a general overview of the subject is presented, the scope is narrowed down on design software. Lastly a short overview of automation offering is presented to provide better insight of systems which will be referred to later on.

According to Stephens [4], Layout is the physical placement of production machines and equipment. It also includes locations for workstations, people, and materials.

2.1 The importance of layouts

The layout is the biggest selling tool for a facility planner as it is the visual representation of the data and subsequent analysis by the planner. Layout will be used to present plans to management and referred to when different material and process flows are being depicted. Since the layout is only as good as the data backing it up, combining accuracy and credibility of data with logical analysis of the available information are essential in order to produce a good layout. [4]

Continuous improvement, changes in processes and implementation of new technologies are required to be competitive. Even the most advanced, highly automated, and precisely planned manufacturing systems may encounter unanticipated failures or design mistakes. [4] Layout updates are often required for designing and implementing these modifications.

2.2 General considerations

As the FMS systems are built around a racking structure, the racking structure must comply with standards and principles surrounding storages. It is good practice to work enough on the layout to ensure that the proposed process can be fitted on the available site [3]. This conceptual design can also help in identifying any problems in the layout that need to be addressed in later versions with more detail. Racking structures and other equipment also place requirements to the hall they are intended to be placed.

When designing a warehouse, the intended use must be first specified because it will determine the building dimensions and imposed loading. The function of warehouses is the cost-effective storage and retrieval of items usually stacked on pallets, containers, bins, cartons etc. [5]

The storage may be in racking or shelving, operated by industrial trucks or storage/retrieval (S/R) machines to be cost-effective. A warehouse management system may be integrated as well. Warehouse buildings can be constructed without consideration of end user storage system specification requirements. This can lead to an inefficient or compromised Storage System which may impact the original investment decision. In Figure 1. below, the information flow between warehouse designer, storage system designer and end user can be seen. [5]

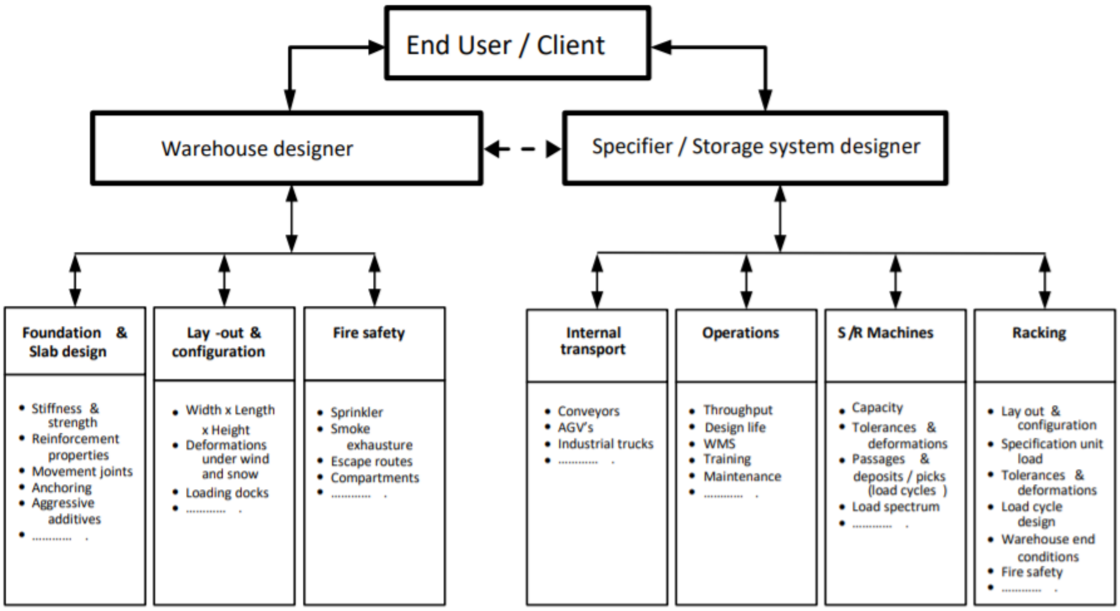

Figure 1. *Warehouse design information flow between designers and end user [5].*

Components in a high-bay warehouse including S/R machines, are subject to tolerances from manufacturing, assembly, and deformations from operation. The S/R machines are designed to safely store and retrieve unit loads with freely selected locations. [6] The stacker cranes in FMS systems are S/R machines.

Too small clearances are a risk to operational safety and may shutdown load handling operations in a warehouse. Too large clearances waste useful storage space. Admissible tolerances and deformations need to be determined to allow optimization of the factors relating to the economical dimensioning, manufacturing, and assembly. This is needed to ensure the safe functioning of a high bay warehouse. [6]

2.3 Earthquake considerations

European Standard EN 16681 (Seismic design of steel storage systems) specifies the structural design requirements applicable to all types of adjustable pallet racking systems fabricated from steel members, intended for storage of unit loads and subject to seismic actions. Guidelines are also given for the design of clad rack buildings in seismic zones, where requirements are not covered in the EN 1998 series. Other generic types of storage structures are not in the covered by the standard. To be more specific, it does not apply to drive-in, drive-through, mobile storage systems, and cantilever racks or static steel shelving systems. [7]

As a ductile material steel is equally strong in tension and compression making it ideal material for earthquake resistant structures. Ductility will prevent substantial loss of strength in a structure when it is subjected to large plastic deformations. [8]

Almost all harm to life can be associated with man-made structures in a disaster caused by earthquakes. As earthquakes cannot be predicted accurately it is important to design earthquake-resistant structures to alleviate the effects of earthquakes. These structures may be damaged, but they will not collapse even in the event of the greatest possible earthquake. The destruction caused can be greatly reduced technically with low extra cost even if removing all damage is impossible. [8] This is why FMS systems also need to be earthquake resistant.

Over the past 50 years the rapid increase of strong-motion recording equipment has enabled creating vast databanks of earthquake records. Peak Ground Velocity (PGA) is represented as a function of magnitude and epicentral distance in the simplest ground-motion models. More advanced models include other parameters to allow for fault mechanisms and different site types. [9]

The ratio between spectral ordinates and PGA depends on the prevalent size of earthquakes in a certain region. Lubkowski and Aluisi [10] provide a simple methodology to define the short period spectral acceleration (S_s) and long period spectral acceleration (S_1) coefficients for a return period of 2475 years. This methodology is recommended to be used only in the early stages of a project and it is not intended to replace a site-specific seismic hazard study. [10] The short period and long period spectral acceleration coefficients are used for checking earthquake requirements for FMS systems.

2.4 Safety and ergonomics

Safety considerations and consequenses must be included with every decision made in manufacturing facilities design and material handling design. Part of the designer moral and legal responsibility is to ensure employee safety. [4]

A workstation layout is determined by workstation design and ergonomics. Workstation design involves safety and health considerations. Ergonomics aims at preventing musculoskeletal injuries in the workplace and has become an important subject in the industry. It studies workplace design and integrating work environment with employees. [4]

Operators stay healthy and work effciently if they can work at the right height, are given enough space for completing their tasks, given the opportunity to work sitting or standing, and having adequate lighting. Decent work height is elbow height plus or minus 2 inches. [4]

Regarding safety a variety of standards are followed in solution layout making for FMS systems. The following standards are European Standards which have the status of a Finnish national standard.

Steel static storage systems. Application and maintenance of storage equipment. (SFS-EN 15635) This Standard defines guidelines for operational aspects applicable to structural safety of storage systems. Such systems are operating with heavy mechanical handling equipment working near static storage equipment. This document aims to minimize the risk and consequences of unsafe operation or damage to the structure. Guidance is given in conjunction with other standards to ensure that the specifier, user, and designer are aware of the constraints in each other's area to allow a safe design to be produced. This standard only applies to steel-made storage equipment that is not used for domestic storage purposes. [11]

Rail dependent storage and retrieval equipment. Safety requirements for S/R machines. (SFS-EN 528:2021). This standard can be applied to all types of Storage and Retrieval (S/R) machines that are restricted to travelling on rails. The travel can be inside and outside the aisles for the storage and retrieval of unit loads and/or long goods and/or for order picking or similar tasks. These machines include lifting means along a mast and may have lateral handling equipment. Machine control may range from manual to fully automatic. This document handles all significant hazards that are relevant to rail dependent storage and retrieval equipment within the context of being used under the manufacturer intended conditions including reasonably predictable improper use. [12]

Safety of machinery. Minimum gaps to avoid crushing of parts of the human body (SFS-EN ISO 13854:2019). This standard advices on how to avoid hazards from crushing zones. Minimum gaps relative to parts of the human body are defined in this document and it is applicable when sufficient safety can be attained by this method. [13]

Safety of machinery. Permanent means of access to machinery. Part 2: Working platforms and walkways (SFS-EN ISO 14122-2:2016). In this part of ISO 14122 the requirements are defined for non-powered platforms and walkways that are part of a stationary machine. This part also applies to non-powered parts of fixed means of access which are adjustable or movable. [14]

Minimum requirements are specified that also apply when as the part of the building, where the machine is located, the same means of access are required. The condition is that the main function of that part of the construction is to allow a means of access to the machine. As an example, specifications for minimum working height, minimum walkway width and escape way are defined. [14]

Safety of machinery. Permanent means of access to machinery. Part 3: Stairs, stepladders and guard-rails (SFS-EN ISO 14122-3:2016). This part defines specifications for non-powered stairs, stepladders and guard-rails that are a part of a stationary machine. This part also applies to non-powered parts of fixed means of access which are adjustable or movable. [15]

Robots and robotic devices. Safety requirements for industrial robots. Part 2: Robot systems and integration (SFS-EN ISO 10218-2). Safety requirements are defined for the integration of industrial robot systems and robots as specified in ISO 10218-1, and industrial robot cell(s). In this part, the basic hazards and hazardous situations are introduced regarding robot systems. Requirements for eliminating or sufficiently reducing the risks accompanied with these hazards are provided. This part also defines requirements for industrial robot systems when they are assembled as a part of an integrated manufacturing system. [16]

Safety of machinery. Positioning of safeguards with respect to the approach speeds of parts of the human body (SFS-EN ISO 13855). In this standard the values for approach speeds of parts of the human body are used as basis for specifying parameters. Methodology is provided to define the minimum distances to a hazard zone from the detection zone or from safeguards or actuating equipment. Approach speed values are time tested and proven in practical experience. [17]

2.5 Design software used in industry

Today layouts are produced using variety of computer-aided design (CAD) systems, which is much more efficient than the old methods of using various templates or other manual aids. Standard symbols and templates can be used to assign walls, aisles, piping, machines or other conceivable entities or factory floor. Extensive libraries of 2D and 3D templates and models have been made to aid the designer. There is also an option to create your own templates that can be stored as a part in private library. [4]

According to Moran [3], it is hard to find published unbiased comparative data on the qualities of the various marketed 3D CAD programs. It is easy to find these claims in sales literature though.

The following is based upon comments received from a survey of users of 3D CAD for plant layout around the world carried out in 2015/2016. All 3D CAD programs have some difference but allow similar functions. These include creation for line and equipment lists, and automated layouts. Line routing, design validation and visualization are also available. [3]

There are common key issues affecting choice of 3D CAD program. Some of these have been listed here: plant size, scope of work, time available, interoperability with commonly used programs/systems, sector-specific preferences, design company size, importance of buildings, drawing versus database priority, budget, ease of use, plant owner data format requirements, onshore or offshore, and software training and technical support availability.[3]

The effect of project size to the 3D CAD software choice is depicted in Table 1. Common 3D CAD software is categorized from small to large project sizes in plant layout design.

Table 1. 3D CAD software used in plant layout design. Adapted from [3]

Project size		
Small/medium	**Medium/large**	**Large**
Autodesk Plant 3D Intergraph Cadworx/PDS	AVEVA PDMS or Everything3D Autodesk Plant 3D Bentley OpenPlant and AutoPLANT Intergraph CADWorx/PDS	Intergraph SmartPlant 3D AVEVA PDMS and Everything3D Cadmatic TriCAD MS

One of the most important elements of a Product Lifecycle Management (PLM) solution is a Product Data Management (PDM) application. A PDM application is used for managing product data during product lifecycle. In PLM environment the PDM applications support many tasks of the lifecycle. These include design, data sharing, sign-off, management of design revisions and product configurations to name a few. [18]

2.6 Design software used at Fastems

Solution layout design requires the use of multiple types of software such as text editors, calculation sheets and CAD-programs. Sometimes more uncommon software is needed like video editors or coding platforms to fill a specific need.

2.6.1 SolidWorks

SolidWorks 3D CAD is a program created by Dassault Systèmes. It has 3 different licence options: Standard, Professional and Premium. [19] Version used by layout design is SolidWorks Professional 2018.

It features properties such as part and assembly modelling, 2D drawings, Design reuse and Automation, augmented and virtual reality, reverse engineering by creating solid geometry from scanned point clouds and mesh data, CAD libraries, and more than 30 file translators. [19]

2.6.2 Visual Components

Visual Components is viewed as a global leader in the manufacturing simulation industry. They offer solutions to design and simulate production lines for manufacturing design, sales, and application development. [20]

Visual Components Professional is a component creation solution where components can be defined and created to simulate in 3D world. It includes everything in Essentials version such as layout configuration, process modelling, CAD compatibility, simple robotics and 2D drawings. [20] Layout design uses mainly Professional licenses of Visual Components 4.2.

Basic CAD features are provided for building new 3D geometries and modifying imported CAD files. With Geometry Simplification file sizes can be reduced and simulation performance improved. Component Modelling allows customizing the building blocks of components: geometry, behaviours, and properties. Wizards are used to streamline the component development process. Built components can be collected into a personalized component library. [20]

Premium version has all features of Professional version with some added things like, automating robot path planning, teaching, and simulating paths of positions with robots and Interactive VR allowing users to interact with the VR environment. [20]

2.6.3 Vertex G4

Vertex G4 is a professional 2D- and 3D CAD-program created by Vertex Systems and intended for mechanical design. The software is designed as a feature-based modeler with good drawing capabilities. Besides handling geometries, the program includes data management such as model libraries and archiving methods. [21]

Vertex G4 is the current choice for the making of 2D solution layouts and 2D drawings in general. It is also used for preparing 2D documents so that they can be used in other design software.

2.6.4 Other software

Aton and SolidPDM software were originally developed by Modultek but after Roima and Modultek company fusion these products are now a part of Roima PLM solutions and renamed RoimaSoftware Aton. [22] At Fastems, Aton is used as for archiving documents together with SolidPDM. Version used is Aton PDM 6.

Ready solution layouts are sent in variety of formats depending on software used, requests and intended use. Standard types currently for 2D drawings are PDF and DXF. 3D models are sent as STEP and 3D PDF.

2.7 Simulation properties with layouts

Simulation can be used as an aid to optimize manufacturing systems by predicting system behavior when tracking interactions and movements of system components. Detailed statistics and reports describing system behavior are generated by simulation software and based on these, physical layouts, equipment selection and other important system characteristics can be considered. [4]

Computer simulation can be used to for optimizing layouts and capacity, material handling, inventory, and logistics planning. Simulation modeling is dynamic when the model is being tracked over time. Random occurrences can be studied using simulation and comparison between different variations and scenarios will help to determine best setup. [4]

Virtual reality (VR) utilizes collection of technologies: 3D displays, motion tracking hardware, input devices, software frameworks, and development tools. Software for creating and displaying VR for consumer level is also progressing rapidly. The main advantage of VR is its ability to convey a sense of depth to the user in the 3D environment. The depth perception is created in VR hardware systems by an appliance known as a stereoscopic display or head-mounted display. [23]

VR techniques can help in creating realistic simulations that are useful for many areas. Simulations have been used before, but VR technology can provide the impression of “stepping in” the 3D world. VR can be used for presenting future product prototypes, projects in architecture, etc. It can be a successful tool at exhibitions for promoting and marketing as 3D projection is still seen as an interesting attraction. [24] Since many 3D CAD software support the use of VR, it may prove to be useful tool with solution layout design also.

2.8 Fastems offering

A lot of Fastems offering will be refenced throughout the Thesis work since solution layout creation revolves around them. This chapter will briefly explain the properties of each product. Without an introduction to them, the concepts and reasoning could be hard to follow for people with no prior experience on the matter.

2.8.1 Pallet handling

FMS is a system based on pallets for automating machine tools and finishing processes [25]. Despite workpiece variety, it enables high productivity and higher spindle utilization thorough automation. This allows bottleneck resource sharing and a constant quality level while decreasing the manpower need per machine. Out of 8,760 hours in a year, stand-alone machines run averagely 2,000 but machines in an FMS can achieve over 6,000 hours. [25]

Flexible pallet container (FPC) is a standardized pallet automation solution for 1-3 machine tools that is more efficient than pallet pools or automated pallet changers (APC). It is an easy and factory tested solution with excellent options for future extensions. [25]

FMS ONE is a standardized solution of flexible manufacturing with good floor space utilization, easy extendibility, and high pallet transfers per hour capacity. Up to 10 machine tools can be automated with possibility to integrate material management. Pallet size can be between 400-1250 mm and up to 2 different 3 to 5 axis machines / pallet types are supported. [25]

Multi-Level System (MLS) is a tailored flexible manufacturing solution. It is basically an FMS ONE with more options and overall customizability making it fit for more demanding and complicated applications.

With MLS, Tool automation, washing machines, finishing processes, quality control and automatic fixture loading can be added. MLS has a wide range of loading and material stations for different purposes. Payloads vary from 500 to 11 000 kg and even more different machine tools models can be automated than with FMS ONE. [25]

RoboFMS ONE is a standardized solution of lightweight robotic flexible manufacturing machine tools with or without automatic pallet changers and zero-point technology. It allows automating 1-10 machine tools with up to 2 different machine types and a possibility to integrate material management. [25]

RoboFMS is like RoboFMS ONE but with added customizability making integrating part washers, marking machines, measuring devices and other process equipment simple and cost effective. This allows more options including additional robotic applications with greater flexibility and extendibility. [25]

2.8.2 Part handling

Auto Loading Cell (ALD) optimizes production through automated raw material loading and ready part unloading with a robot. This allows longer unmanned production periods with stable quality. [25]

Robotized Finishing Cell (RFC) is used to automate grinding, polishing, deburring, and other finishing processes. It is integrated to FMS increasing productivity and unmanned production hours while ensuring stable quality, smooth processes, and lower costs. [25]

Agile Manufacturing Cell (AMC) is a robot-based manufacturing cell that brings the benefits of flexible manufacturing for direct machine tending. It consists of machine tool(s) and other processes such as measuring or marking, suitable material storage solution and automatic set-up change technology for machine tools and robot. [25]

2.8.3 Tool automation

Tool Automation enables the use of small tool magazines and tool sharing, eliminates human errors, and reduces costs from labour. It also provides extended unmanned production hours. Even if all the required tools are not in machine tools magazine, machine control integration allows it to start machining. Real time information of needed tools is always available enabling tool availability just in time. [25]

The Gantry Tool Storage (GTS) is located above machine tools saving floor space. Tools are stored centrally in columns next to the gantry that the robot travels on to deliver machine tools. [25]

The Central Tool Storage (CTS) is designed for larger numbers of tools. The actual tool storage is located on factory floor with robot managing tools while a gantry robot is used for delivering the tools to machine tools. [25]

Tool Service Cell (TSC) is integrated with tool automation extending it to optimize the tool setup process, allowing efficient labour utilization for tool reworking when tool life-times are extremely short. TSC is equipped with a tool carrying robot, ergonomic tool loading station for insert changes, washing, drying and tool pre-setting device. [25]

2.8.4 Manufacturing Management Software (MMS)

All products previously listed use MMS as their operating system. This software enables integrating various elements and features into one automation system with an easy-to-use user interface.

MMS automatically calculates the optimized production workflow and needed resources based on orders. It also adapts automatically to changes in the production schedule and displays information to maintain the production output. By controlling data systems and production machinery from a single source, MMS reduces the manual, repetitive work of inputting production data. It is continuously developed for the changing needs of thousands of manufacturers helping them in reducing costs, perfecting quality, and improving delivery times. [25]

3. APPROACH AND METHODOLOGY

In this chapter the approach and design for the research is presented. Current 3D Layout generation is analyzed. Based on previous development projects and their results, the challenges facing 3D design development in solution layouts are to be identified to provide a good basis for selecting methodology. Methodology is described in detail as well as planning for implementation.

3.1 Approach

The approach for the research was the following. First there was the analyzing of current 3D-layout generation to find out what methods have been already developed and tried. Based on this, the methodology was specified to suit the goals and research methods of this research. The research methods selected for implementation were specialist interviews and model development. To re-iterate, the steps were:

1. Analyzing current 3D-layout generation
2. Selecting methodology
3. Having specialist interviews about layout design
4. Developing a new 3D layout generation model

3.2 Analyzing current 3D layout generation

Analyzing the current situation before getting into development is important because it can reveal aspects that could have critical impact to the development work. This will be done by researching previous documentation and by having discussions with model developers. Different design methods will be discussed thoroughly from outdated to current methods. Goal is to gather information from all used ways of making layouts so that they can be documented to avoid overlapping development and replicating same mistakes as before.

Before analysing the current state of 3D layout design, the layout design process is depicted form start to finish. Understanding the process will be needed for planning the implementation. This will be most useful when setting requirements for model development.

3.2.1 Example 3D solution layout

Before getting into specifics, it is good to reference what a typical 3D solution layout looks like and what different parts of the system generally look like. Currently FMS ONE and MLS solution layouts are made with Vertex G4 in 2D using templates created for each system type. The following example is created with a model used for creating less accurate layouts for visual purposes based on the 2D layout. The example layout below in Figure 2. is an Adaptive MLS-MD featuring one-sided racking (3) with three storage levels. The lowest level contains materials on Euro-pallets, and the two upper levels contain machine loads on machine pallets (2). Inside the racking the stacker crane (1) is located travelling on a rail transporting loads. On the front side of the system there are two loading cells containing a loading station (5) and a material station (6). In addition, the cells have safety doors, safety walls and light curtains. Stations are controlled using Station commanders (7). On the right end of the system there are three generic machine tools (8) with automatic pallet changers and GTS tool automation (9) located on top of machines. On lower left side there is the main control cabinet named CC1 (4).

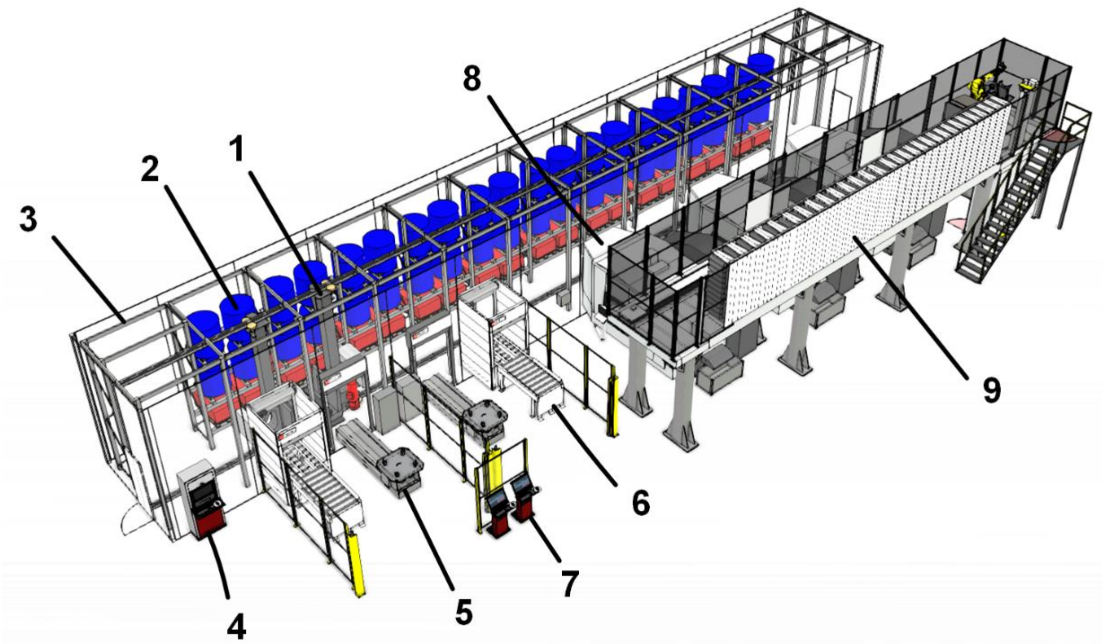

Figure 2. *Adaptive MLS-MD system*

3.2.2 From a request to a layout

In recent years, around 2000 layout requests are handled each year. This includes both part and pallet handling requests. The process starts when a layout request comes from sales as the sales manager is requesting a new solution layout to fill a particular need. At this point, the sales manager has already most likely gone through the layout portal and could not find (or remember) a fitting layout, which will prompt them to make a layout request to proposal and layout teams. This request is then reviewed in collaboration with both teams in morning meeting every workday. There planning on how different technical issues will be solved is done and the request is filtered into a more sensible solution. More than often the requested system might not be the best for intended use due to load properties or process flow.

After sorting out the layout request it will be scheduled and put to the excel worksheet that also collects sales case data from the SuperOffice CRM. Requests are prioritized depending on the request date and a normal handling time is 1-4 days depending on workload. During scheduling a request is assigned to a layout engineer. A common practice is to assign newer iterations of the same sales case to the same designer as there might be some information loss when switching the designer. With a new case, the designer may remember a similar layout and use that as a base for the new request but more often it is simpler and more efficient to start with a base layout template.

When the first version of a layout is created, it is named as XXXXXX-01, where X's are the sales number and -01 is the version number. This enables version control as every version of the layouts must be archived carefully to sales folder as well as internal archives. Any email conversations relevant to cases is also documented so that if the case proceeds into project stage, the information can be easily found and be used to justify certain design features.

The completed layout will be sent to proposal manager for offer creation. This might require a storage rack price inquiry that is outsourced. Requesting a quotation is also the layout engineer's duty as it involves the use design programs and knowledge of the system.

Proposal manager will send the completed offer to sales manager which then discusses it with customer. Usually there will be changes to the layout after the customer has reviewed it and a new request is sent back to proposal and layout teams. This iterative cycle continues until a consensus is reached. This whole cycle is represented in Figure 3. below.

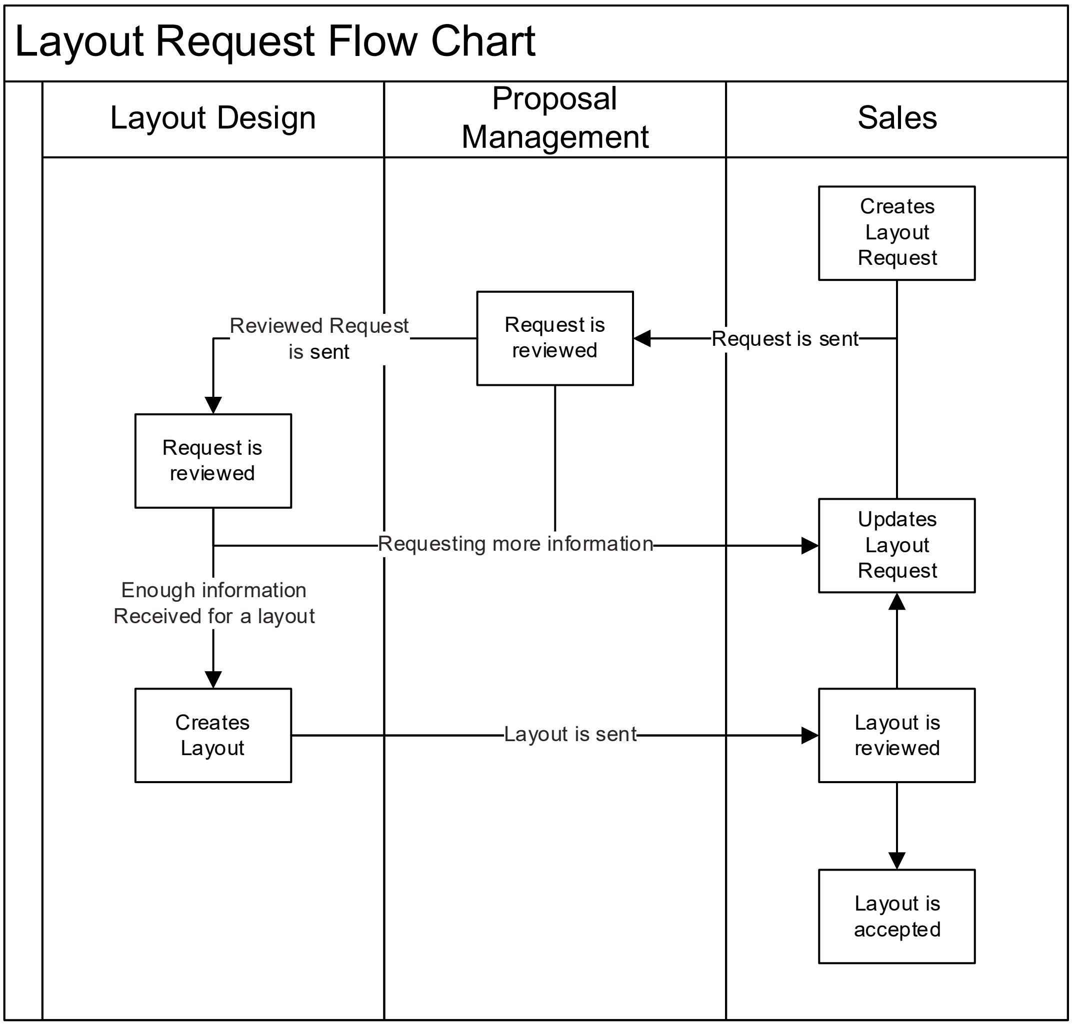

Figure 3. *Layout request flow chart*

3.2.3 Information provided in a Request

As the process was briefly explained, certain parts need closer inspection. The layout requests itself are very important to ensure a smooth sales process. The commonly asked question is: “How much information do you need for a layout?”. The phrasing itself is a bit off as a layout can always be created – even with no prior knowledge of requirements or conditions. The problem is with this approach is that the layout will be completely conceptual: simply a visualization of a general system. There is a proper layout request template that was created to standardize requests, but a problem is enforcing the correct use of this. A badly filled template can be even more confusing than a plain email if the information (system parameters especially) is put to the wrong slot.

Most critical information needed is the machine tool make and model because this determines load handling together with load and pallet information. Different machine tools have, of course, different properties and the first step is checking if load handling seems possible. If it is not, then naturally there is no need to proceed to making a layout with a machine that just cannot be automated with an FMS solution. If there is a high possibility for pallet handling to work, a concept layout is made but most of the time, there is an existing project or a sales case where pallet handling has been checked for that specific machine.

Pallet handling is often complicated by the need of material pallets as they also need to be handled with the same equipment as machine pallets. Materials also rule out some system types as they are not intended for material handling.

Once pallet handling is assessed, according to that and load information a suitable FMS system is picked. Sometimes a system type or reference case is revealed in the layout request but more than often changes need to be made for the requested system type. Sometimes request inform what types of loading stations are needed but this is also limited by system type.

Available space is a common limiting factor when deciding a solution layout. Usually available height is the biggest problem as many older factory halls are quite low and different added infrastructure (like pipes and cranes) will also limit system height. Space limitations length and width wise are also common issues since the customers want to save floor space as much as they can.

More than often customers also have some sort of an idea on how they want the system and its parts to be oriented. These configuration requirements are most easy to comprehend when they are sketched in the available space in relation to existing structures. This will often reduce the extra steps needed to get positioning right.

Other relevant information about given space is the factory floor. Are there cavities or pits to be avoided or is the space reserved for FMS over multiple different floor tiles. Overall, if a hall layout is available by the customer, it will be sent to layout team in some stage as the discussions proceed.

Details of any tool automation requests should be mentioned as they can greatly complicate systems configuration which can take up considerable amount of time. As a rule of thumb any other special needs should be mentioned separately in any types of layout request.

3.2.4 Layouts with SolidWorks

FPC solution layouts are created with SolidWorks using 3D layout base models. There are different models for each size range and configurations to make layout creation fluent. Although the container and loading stations are as 3D models, the machine tool is added as a 2D footprint largely due to fact that up-to-date 3D model might not be available. Even though the layouts are being made with a 3D software, the actual layout will still be a drawing in 2D format (PDF/DXF). These layouts include system top, side, end, and isometric views.

Old FPM (FMS ONE MDR) layouts were done with an excel tool where a user would input needed start parameters like the numbers of loading stations, machines, and pallet places. These values were then sent to SolidWorks that would configure a ready 3D layout. FPM was a standardized FMS product which simplified layout making to minimum allowing the use of configurator.

FPM layouts had limited options for a system:

- three weight categories
- only machine pallets and LSC stations
- one sided racking
- default racking module widths with nominal load sizes

Load handlings are also being checked in SolidWorks if 3D models of machine tools are available. With 2D drawings Vertex G4 is used for preliminary handling checks.

3.2.5 Layouts with Visual Components

Solution layouts for robotics are made with Visual Components. The software will be referred to as Visual for the rest of the Thesis. If there is a need for a 3D MLS layout in proposal phase, these will be created in Visual also. Note that these layouts provide only visualization support and are not accurate drawings like the ones made in 2D. The 3D version is made using measurements and overall configuration from the 2D layout. Tool reach and tool handling checking for tool automation is done in Visual as well as most visualization for marketing purposes.

For robotics, making a layout starts by reading the layout request made by a proposal manager or salesperson. Based on this information the correct templates are chosen as a base for the layout from company library. Most important start information includes the machine tool model, part dimensions and weight.

Pallet handling is practically always done with NSR-grippers. If the pallet is particularly small or large, forks with robots can be used for pallet handling. Forks are usually much heavier than NSR, so they are avoided.

As an example of robotic layout making, the following is a short description on making a RoboFMS ONE layout. After getting the template, the first thing to place is the machine tool in the approximate position next to linear track. Robot handling must be checked that the machine tool is in a position that a robot can reach and place the part (on a pallet) on the machine table. Part size must be then adjusted to correct dimensions by inputting right parameters into part component. Pallet racking needs to be configured to support the wanted part on a pallet. According to request, the amount of machine tools is added, robot linear track lengthened to reach every machine and finally part amount is set.

After that safety walls are adjusted, and system information is generated for email. The component designed for this list components used and calculates values about robot part handling (center of gravity, moment for gripper etc.), safety wall components and linear track length.

Then 3D PDF of the system is created with a DXF top view. Pictures are taken from the 3D model in certain angles (isometric view, close-up on the part, front view) that will be placed in a PowerPoint template. This document is then added to Sales folder.

3.2.6 Project phase

Project layouts are done almost exclusively in SolidWorks. Exceptions to this include special FPC configurations and modifications to old systems, where a 3D project layout was not originally made because a 3D software was not in use back then.

New project layout is started by finding the correct system base model from PDM. This model is used to create a new copy and the new project information is filled to every field. Before the layout will be changed it is good practice to modify storage racking to correct shape. Storage rack will act as the base for the whole layout as most of the critical measurements will be defined with the racking. These include racking length, height, space reservations, load positions and machine locations to mention a few. Designer will use the last version of the proposal layout as a guide on how to assemble the racking and make any needed corrections. Design instructions and safety standards need to be followed also.

When racking has been assembled, load coordination points are checked and modified until all loads can be added to racking. After that safety nets around the racking will be fitted and holes for machine tools, loading stations and other equipment will be defined. The storage rack assembly should now be completed, and the designer can make it into a drawing. Stacker crane dynamics are calculated, and values added to drawing.

As the layout structure is now done, equipment, hall layout and other components need to be added. First loading stations, conveyors and doors are fitted. Then machines and electrical components. In some cases, a foundation drawing is needed for defining needed factory floor construction for the system.

Visualized pictures will be taken with PhotoView360 Add-in. Layout is edited for pictures by using more suitable configurations of components and changing appearances. After settings are corrected with resolution and cameras are added in wanted views, the pictures can be rendered.

3.2.7 3D MLS layout generation models

Making MLS solution layouts in 3D is not a new concept. In the following Sections the earlier attempts of 3D MLS layout generation models are presented. These models were created in Visual and SolidWorks.

The following Sections were composed from documentation made by the developers. In addition, discussions were held and used as material as especially with Visual models there was not enough documentation to go on. Most of these models were neither available for free testing making fair comparison difficult. Having these conversations where a developer could introduce their model would also reduce the risk of misunderstanding or misrepresenting their creation.

Version 1.

As a part of an earlier Thesis work, 3D MLS solution layout creation was tested using SolidWorks. Components and models were developed to be lighter to make layout creation more fluent.

Testing was done using an existing model which was quite heavy. For testing, a completely new rack model should have been created to make it light and quick enough. The model will need further development to make it more accessible. The new model needs both technical sales and project planning involved to gain maximal knowledge for the planning process. From the system and its components, a more suitable and lighter models should be built. Components that are often used should be saved in the library to make them easily accessible to designers. In the beginning, machine tools, stations and equipment should be put to the library. Making ready station groups could be sensible for common cases. Component placing would need building some automation so that the component would find at least the floor level making placement much easier. Rack building should be simplified so that it is quick but still accurate enough that relations between components can be seen. [26]

For proposal layout designs future development, it would have been interesting to interview different departments to find out what kind of development ideas they might have. In this way the layouts could be made more useful for different teams. [26]

After this Thesis work, the development project of The SolidWorks layout design methods was continued. The goal was that making preliminary MLS layouts could be faster by improving the tool for this need. Development should also help the whole MLS layout design process. Lastly, a project layout should be based on an offer layout. [27]

As requirements it was stated that offer layouts need to be made very quickly and sketching was a great part of that task. Major challenge in 3D MLS layout design was fast racking building. Light models were needed to open them fast and making changes was intended to be done without many SolidWorks mates. A storage place for the models was also needed as layout models used by mechanical design were too heavy and had excessive amount of detail for offer phase use. [27]

With the development done, layout generation was tested again revealing results and the outcome. Before viewing the results, examining the model and its usage is showcased.

3D MLS process with created SolidWorks model starts with defining load by editing load sketch. When loads are defined, racking module assembly can be made. Building is started with empty assembly and coordinate points. Pillar-part is added, and system height defined.

Next is adding lowest model part, which includes next level and next module place coordinate system point. After that load parts can be added above another and when the wanted levels are reached, ready assembly is saved. All racking components are in this point saved in SolidWorks library where they are easy to add to layout.

Components are added to empty base layout where is just crane and system nets with layout sketch. From library added components snap straight to coordinate points. If a component is dropped to model, it can be dragged to coordinate point.

Next stations from library are drag and drop to layout coordinate system points. Machine will be added. At this stage needed components are added inside the layout assembly. Same thing with racking module assemblies. First part is end module and after that racking module assemblies can be added that were built earlier. Lastly end module is added.

Components (and system) positioning can be made in first draft just moving components to approximate places. Same style can be used when moving system nets to their right places. After that, measures can be rounded to closest even number.

After model is done and components are in their right places, the drawing can be edited. Drawing takes couple views of model. Some dimensions are added to the drawing and possible section views. The model is now ready, and machines and stations dimensions can be edited at this point if there are errors detected.

The outcomes that SolidWorks layout gives are Model and Drawing. This kind of layout takes about 1,5 h to make. Time depends mainly on how much there is need to modify system components.

Version 2. a)

The code (created by designers at Visual Components) for creating the layout model is quite complex. The model works by input parameters: a user needs to input the amount of loading stations, machine tools, and pallets. System can be one- or double-sided and end areas can also be defined.

The crane model has all its values in a Python script that the module and other components can read and adjust to. These values also contain limits (for example min/max height) that can only be accessed by editing the script. All components have a space reservation, and the dimensions of these space reservations are the key values forwarded to racking modules that then adjust accordingly. The model could be modified to get values directly from a database and generate a layout.

A model aiming for complete layout generation by inputting parameters seems highly ambitious and raises the question that, does the model need to be that advanced at this early stage of 3D layout development? It does not seem so as it is not too time consuming to do the layout instead with premade smart components when all the parts can be modified and probably just using Plug and Play (PNP) connections to attach components together would be enough for current use. Easy connections for machines and loading station should be incorporated in any 3D layout model made in Visual Components.

Another good question is what values in a component would need to be visible and modifiable easily. Of course, most features would need to be modifiable but not every option should be easily accessed because that can overwhelm a designer and lead to unexpected results. Automatic generation would make the layout options very limited and the layout itself quite static, and it could make changes to racking structure hard to execute.

Version 2. b)

As opposed to Version 2.a), this version would rely on modular building utilizing a layout template that would contain a pallet, a storage module, an end module, a stacker crane, and a machine tool. First stacker crane would be selected and connected to racking with a PNP connection. The End module would read values from stacker crane and adjust accordingly. Storage modules can be added with PNP connections and using copy-paste. They could then be multiplied and again connected with PNP. Each racking module can be adjusted separately if needed.

The components would include the usage of Python scripts to allow some automation features. A component could be updated and if it is saved with the same name, it would work with other components just like the old version did. This approach would allow more flexible layout design and a gradual automation development.

Key development steps would be needed to make this type of layout building possible. One would be updating the library with suitable cranes and other needed models. Other key factor would be rethinking components to determine what are the base values used to define components and how the values will be used in different functions.

An issue to be solved would be how to get a usable 2D drawing out of the model. It could also be useful to find out what sales wants from layouts in the future as currently we are thinking about the subject internally.

Version 3.

The need for a new rack building model came when Visual updated and the old model broke as a result. The need for 3D MLS layouts has existed for a long time. Designing was done first by listing on a paper requirements and what parameters will be needed.

These properties were then divided into different tabs in the program. This model was in use a couple of years and then after a meeting the property naming was remade. This was done to make the model more usable for other layout designers.

The model was created without much functionality as the loads are a part the racking module component. The model has properties like beam length, height, upright values, and depth that can be fitted for wanted system. Other qualities include clone-function used for multiplying racking modules, Left-hand/Right-hand configuration, and the ability to change the racking module to end module. Load type, shape and size can also be edited as well as fork spacers and space reservations. Currently there is no automation to set space reservations and level heights correctly.

When creating racking the first step is to define an end module and then add as many storage modules as wanted. If different load types and modules are needed each can be modified independently. Making a double-sided system is done by creating two separate halves, assigning them opposite to each other and snapping them together with PNP connection. Loading stations can be dragged from component library and connected with PNP as well.

A challenge is to find a needed accuracy that is still enough for 3D model geometries. True CAD models are very heavy because they often contain many round shapes that create an excessive number of polygons in Visual. The model is also very static and for animation purposes a load must be created separately as the default loads are a part of the racking component. There were no Python scripts that were utilized in the model. A more usable version would have components communicating with each other. For example, when using PNP connection with a module to another, it would absorb the parameters from the previous one. Even though the model properties were once renamed, the user interface (UI) has expanded completely with too many parameters. For a new user, the model can be confusing to learn and use.

Version 4.

This model was made for Digital Manufacturing usage that simple layouts can be generated quickly. It is only useful for making simple layouts as modifying a single rack module is not currently possible because the model generates all rack modules into one component. The model currently relies on Layout model version 3. and the Python code is used for modifying different parameters. Coordinate points are generated automatically with a Python script so that the MMS will know how to place the pallets. Rack size and pallet places can be adjusted making a one-sided system. All Loading stations and machines have their own coordinate points and Python scripts that contain their behaviors and properties.

The model functions have been distributed for different controllers. SimulationController can be used to order scheduler view from MMS that is practically a data package with couple days of production. It reads the package and arranges it to priorityQueue to be fed into stacker crane. Package is then run with the model to discover how long the production cycle took really compared to estimation given by the MMS.

CraneController handles crane load and unload for pallets wherever MMS tells the pallets to be located. StorageController is used to handle the storage and modify it. It also does machine and pallets placing onto storage keeping track of every pallets state. If the state changes from unfinished to finished, the color will change from blue to green for example.

Virtual FMS messagebroker handles messaging when MMS server address has been given to it and online/offline state has been defined. With WebSocket, it is connected to DataProvider service in MMS. The communication format between these two is json. messagebroker can either be connected with an ethernet cable to Station commander or to a cloud server to get MMS communication.

Using CAD model geometries makes the whole system heavy to use so reducing polygons is critical. Because if this, the idea is to use generic MC components whenever possible.

Virtual model making would be much simpler if all MLS layouts were made in 3D with Visual already. It would also enable rapid virtual testing through simulation which could be shown to a customer. Simulating production and showing usage rates for machines could also be used as good sales arguments.

No further development plans have been made as the model is working in a desired way. Some minor updates may be implemented later if seen necessary. The usage of the model is currently limited but if the layouts would need to be made daily, it would require more optimization.

Some other issues can also be seen. The model heavily relies on Python, which makes it slower than it would be with more efficient coding languages like C++ as an example. The license pricing is quite high with Visual and the customers would have to buy it for using the model. This could prove to be an issue as customers often have the software for only limited use-cases such as checking simulated system statistics.

3.2.8 Conclusion of models

Extensive effort has been in creating different models with different uses and background. All models have had their flaws and upsides but based on documentation and comments, the SolidWorks model has had most development done not to mention that there the goal had been set in proposal layout making to replace the 2D format. Despite all the work already done, the model has proved that the software is incapable of filling the requirements set by quick paced proposal layout making. After optimization, the sketching properties and overall rack building still takes too long to be usable in proposal stage where radical system type, equipment, load information, and configuration changes are daily. Time schedule is also fluctuating constantly as changes are sometimes requested with varied time stamps during the same workday.

With that said, based on models created in Visual, it seems more sensible to guide effort to developing the new 3D MLS layout generation model to Visual. It has been received well in robotics and has proven to be a valuable tool which has not yet seen optimization for MLS offer layout purposes.

Model versions 2.b) and 3. seem like the best candidates to offer a base for a new model as they focus mostly on the layout building and allow more complex creations. Version 2.a) aims for automatic layout generation which is highly ambitious at this stage and can only support systems with very limited options. Version 4. has a different purpose but it could be useful to keep this model in mind when creating a new one. Ideally the new model should allow similar interoperation as the models 3. and 4. currently have.

3.3 Methodology

Methodology selected will be explained in the following chapters. The justification and proposed means will be presented. The methodology will be separated into interviews and development.

3.3.1 Interviews

Interviews were selected as a research method because they can reveal information that is not usually documented anywhere. Naturally, if an experienced person happens to switch jobs and valuable information is not collected, the knowledge can be lost for good. Interviews also help in guiding the development into right direction as the interviewees possess a lot of experience in regards of layout design.

The interview type will be semi-structured to follow a question form. Semi-structured in this case means that the questions will aim to be open so that in most cases a simple yes or no answer will not suffice. This should challenge the interviewees to think about the subjects and their answers more providing meaningful data. All data collected will remain anonymous.

Interviewees will be people in Fastems who are creating layouts or are directly involved with them some other way. Only staff from technical side will be interviewed to keep the conversations on a more practical level.

3.3.2 Development

Development work will be a concrete way of testing the proposed solution for 3D layout design. The model will be the most practical way to provide answers to research questions. All the research before this stage will be used for guiding the development.

According to previous models, the 3D development for solution layouts should be focused on Visual because it is currently in use for robotics and has proved its capability on that area. It also cannot be yet dismissed as an option since the optimization and development for this use-case are severely lacking. Therefore, Visual will be selected as the platform on which the development will be executed.

The development will most likely require some experience on modelling and coding so previous model developers will be consulted at least in the beginning to get started in the correct direction. Models 2.b) and 3. will be studied in detail level to see which components could act as bases for new ones. Existing features will be reviewed as they may prove to be useful. It is also good to recognise which qualities are not wanted.

Component geometries will be mostly created with modelling tools in Visual, but some will need existing models to be imported. Component modelling and creating most features will rely on different tools provided in Visual. Creating automation will require the use of code scripts.

3.4 Development Phase Planning

Development phase was set to have the goal of allowing smooth generation of simple FMS ONE type layouts with limited options. The start point would be similar to earlier mentioned FPM configurator although the actual layout making would still involve manual component placement to ensure its flexibility for future use. The important thing would be keeping the model as such that any design features would not hinder the future development. After all, the final model should be able to handle all situations that the current methods can.

Two different cranes and system types were chosen for development, as this would allow testing created models when changing system type to another. Chosen systems were commonly requested FMS ONE MD and FMS ONE MDR. The systems can be one- or double-sided meaning that the racking should be designed accordingly. The values of system parameters would be compared to correct ones obtained from internal technical specifications for racking and cranes.

Similar to current methods, the layouts would be created using a template. Layout template would include end module, racking module, crane, and aisle equipment, CC1 and a load. Other components would be dragged from company library which is a folder structure. In the library, specific folders and components assigned for layout creation purposes will be located in the future.

The idea is that components would be created first using simple structures and with most values to be set as properties. The values, which were constant, would not be added as properties as they would not need to be changed when making a layout later. The automation seems best to be made later as it could interfere with the functions and connections that would be created later on. This could also make backtracking easier as often an idea might prove to not work as initially planned.

The UI should be easy to use and contain only the important parameters needed for layout making. This should be done to avoid uncontrollable expansion in the number of parameters that are controlled through UI.

Aside from software and hardware, a good industrial designer should be thinking about how the product will be used since the very beginning of the project. A user-focused design should be implemented to account for having potential users from several different backgrounds. The product should also be well thought from the perspective of formal and informal use. The characteristics should be defined carefully together with usage of the product with proper documentation and training. [28]

4. IMPLEMENTATION

Chapter 4 contains the implementation phase of the research work. This includes results achieved from interviews and the model development for a new 3D layout model. Interview part contains the data from specialist interviews that has been grouped under similar subjects. The development part will describe the process of developing a new 3D model for layout generation in proposal phase. Defining component relations, modelling, coding, and testing are presented.

4.1 Interviews

First the interview data will be reviewed. Interviews were conducted with 10 people in the company consisting of layout designers, solution architects, proposal managers and a mechanical lead. With this group, working years at Fastems ranged from 1,5 years to 20 years with average being 8.

These interviews were semi-structured following a question form (Appendix. A). Interviews were conducted via Microsoft Teams and recorded for data collection. The questions were selected to provide an overall view of the whole layout process and moving to 3D.

Interview answers are filtered under different subjects in the following sections. As there were a variety of answers regarding different topics, the most common answers are presented here. The answers were based on individual opinions, so it is hard to say which opinions reflect the reality the best. Therefore, the answers were prioritized based on how common they were.

4.1.1 Layout requests

Layout requests in MLS side were deemed to have always stayed similar in quality but bigger changes have been happening in offered systems, which have been getting more complicated. In robotics, the requests have been getting more detailed.

The time schedule in requests has always been similar and mostly realistic. In robotics there are rarely any request dates given. Usually, layouts are made within given time.

Both time schedule and quality are also depending on the salesperson. Good requests are being received both with email and with layout request Excel template but since during the existence of request template its usage has been low, a different approach was introduced. Instead of an Excel template, it could be just an email template.

4.1.2 Layout software experience

Many different 2D and 3D software have been used or tested in the company over the years. For making MLS solution layouts the 2D Vertex G4 was deemed best for its flexibility, quick sketching ability, and layout library properties. SolidWorks was said to be too slow but visually better.

For robotics Visual was named best and other 3D programs used were slower, unsuitable, or inconvenient to use. Visual would need further development to be more effective as a layout building tool.

4.1.3 Previous development

With both MLS and robotics, libraries have been developed and components updated. For MLS side, the layout making speed has stayed the same, but the team's internal knowledge has improved.

In Visual parametric components are more common and there are much more components than before. Library has expanded but it also has become harder to find what is needed. Because of the improvements, layout making is said to be at least twice as effective as it used to be. Repetitive manual tasks have been reduced.

It was also emphasized that speed itself is not enough as it can lead to errors. Rather it would be better to focus on effectiveness that should be viewed as combination of speed and quality.

4.1.4 Greatest Challenges in solution layout making

Many different challenges were mentioned that impact layout making negatively. Common challenges included space requirements, customer demands, information loss between departments and component creation if suitable one did not exist.

Still, the biggest issue was almost unanimously reported to be lacking information in layout request. Nothing else was deemed to slow down the process more. Because of this, it was stated that usually it is better to somehow finish a layout rather than use too much time on thinking and trying to perfect an incomplete idea. It was said to be pointless to try and make a complete solution as a first version since there will updates to a request almost every time.

Regarding accuracy, it was seen that the solution layouts cannot be made less accurately. The transition to project phase from last solution layout version should be as smooth as possible to avoid any major hazards which can be costly in time and money. With project layouts, challenges included overly tight time schedules or the layout itself to be too heavy to allow reasonably working with it.

4.1.5 3D layout properties

A great number of ideas was received regarding what kind of properties a 3D solution layout program should and should not have. Behind these different views there was a lot of experience and impressions people had for the subject.

A lot of feedback was received that was essentially for or against 3D solution layout design. In an effort to highlight the pros and cons of 3D solution layout design, most of these answers are listed in Table 2. below.

Table 2. The pros and cons of 3D proposal layout design

Pros	Cons
Much more selling than 2D	Takes much more time than 2D
Offers more visually	Hall layouts and machine models usually are received in 2D format
Easier to understand for people not familiar with technical drawings	Risk of sending forbidden material increases
Simulation properties	For FMS not as accurate as with 2D
Reach checks can be done in 3D with robotics	Competing would suffer as layout changes would take longer
Load places can be evaluated better	3D offers visually less with FMS's as they are quite rectangular
Allows automating certain design features and data collection	Using geometrically correct components in not feasible
Quick layout creation with existing components	A lot of change in proposal layouts between revisions

Other positive remarks included that regarding the visual side the load places can be better evaluated in project phase as well. Chance for making mistakes is reduced as there is no need to check different views against one another as they are automatically correct when the model is correct. 2D requires more careful approach because geometrical mistakes are easier to make leading to problems that must be fixed later. With 3D there is no chance for conflicting views. Sometimes, when working with complicated systems, 2D may not be enough to accurately represent dimensions and design features.

On the negative side it is good to emphasize that the biggest concern was regarding time. Many interviewees were questioning that how the equivalent amount of solution layouts could be made in 3D with the same resources. Lastly it was mentioned that it is good to make a new layout at project stage even if the old proposal layout would be suitable. The point was that there can often be some mistakes in the proposal layouts and therefore it is good to make a new version just to check the design for any mistakes.

The consensus seemed to be that the program needs flexible editing to allow quick sketching and checking component relations. This would need to be done with millimetre accuracy. For making and modifying components some CAD properties were requested and the program should be based in a form of component library. Searching older layouts through Aton compliance or some other way of archiving would be also needed.

All automation properties were seen as good qualities, but component cloning and python scripts were especially requested as a must have quality. These would be useful when creating simulations.

Regarding visual traits it was stated that a suitable program would need to able to handle every layout change and the result should not turn visually worse when case is progressing. This means switching from 3D back to 2D drawings with complicated systems should be avoided. Sectional views would be useful as they allow creating better 2D views from the 3D layout as 2D drawings are still needed for annotations and third-party use. The end results made with the program should be exportable to standard file format such as DXF/DWG and STEP.

An important notion was that project and proposal layouts cannot be compared directly as they are designed for different purposes. With projects, there is much more need for accuracy and time demands are not usually problematic since the amounts of project layouts are miniscule compared to proposal. At project stage the layout must be 100 % executable.

When project layouts moved into 3D the creation time increased but that translated into better quality of projects. When comparing layouts in proposal stage against project layouts it was discovered that with MLS there is much less change between project vs. proposal layouts than with robotics. This seems to indicate that the MLS layout process produces more complete layouts.

4.1.6 Is Moving to 3D MLS layouts realistic?

Some interviewees believed that moving to 3D MLS layout creation is realistic if a suitable program is found. Suitable in this case would mean lighter than conventional CAD. The notion that 3D would be more inaccurate was not shared as it was pointed out that most CAD programs are indeed in 3D. The accuracy of older models used were rather questioned instead. Technology was not seen as the main issue but the negative attitude towards 3D design. In order to make the change happen the whole team would have to support it and work towards it.

Many opposing arguments stated that the process is working well at the moment and the end result is good. This is an important notion as the process should not be turned into a worse one.

Along with the statement of inaccuracy the biggest challenge was seen to be the time that is needed to make a 3D layout as it was stated to take 2-3 times longer than in 2D. Sketching in 3D was said to be too time consuming and that it would be more efficient to first sketch the layout using 2D software and after that make it in 3D. Simple 3D layout configurations were wanted in a library to allow reuse as making them every time would be inefficient.

It was deemed hard to say if machine tool makers would be sending their machine model in 3D more eagerly in the future as they would be visually more valuable in a layout. If the rack building could be solved, other components could be placed relatively easy and quick making 3D layouts more viable solution when using only current resources available.

Development phase is needed, where components are designed with care from the beginning. Design should not be just individuals developing models alone. First step in development would be to determine wanted accuracy. Then make new racking components with that agreed accuracy. It should be decided together with the whole team what sort of automation is needed. This would probably mean that a couple of months would be needed to make only the new racking component.

4.1.7 Developing layout making process

The MLS side of layout making is deemed to be currently working well and the problems faced seem to be similar than before relating mostly to requests. For 3D MLS layout requests, it was stated that there is need for a clear protocol. As a proposal the sales could either find the layout from library or a new one could be created with only certain terms. This protocol should be clear and enforced between proposal and layout teams.

As most of solution layout work was seen as a waste, it should be decided how much time is spent on a single case. Then after the amount has been used, it just needs to be stated what information has been used and was available during the offer phase.

With Visual it takes a long time to create MLS layouts as the components have not been optimized yet for this purpose. The perspective used with 3D MLS should be different than in 2D as many repetitive tasks could be automated. It would be hard to say how much time would be spent on a layout if this was the case. The annotations should be made more fluent in Visual. PNP connections could be used so that component cannot be attached in the wrong position.

It was clearly stated that systematic development is needed in Visual rather than individual work. More people should be involved in planning a working library. The MLS side should be gradually moved towards 3D solutions. It should be discussed together with the whole layout team what needs and requirements for a 3D layout building model are. After these are set, the execution methods can be decided. An important thing is approaching the subject with realistic attitude to not annihilate creativity at the very start.

4.2 Model development

As discovered in Chapter 3, the 3D development for solution layouts should be focused on Visual. Interview results suggest this too. In addition, according to interviews the first step in development should be establishing the demands and expectations by discussed with everyone using the model or directly involved with the end results. After establishing what the use cases for the model are, the requirements need to be set and agreed upon. Wanted automation level, needed parameters and preliminary UI design are also to be decided. Implementation should be well designed to allow reasonable designing speed, accuracy, and flexibility.

As stated before the development will be focused on a 3D model that allows the creations of simple FMS ONE MD and FMS ONE MDR systems. The systems can be one- or double-sided. Use-cases for the model are creating proposal layouts directly from a new request and based on old 2D versions. The model will need to be flexible to allow complex design which means an unexperienced user could create a non-working layout. Therefore the model will be used only by layout designers since layout making requires a lot of experience and knowledge.

The model development was started with component modelling. After most geometries and features had been modelled, the script writing was started in order to create automated functionality. Component testing was also an important part of the development, and it is revealed as well.

4.2.1 Python API

Visual Components supports the use of Python API. A Python Script allows writing a script for manipulating commands, components, and the application using Python (stackless, version 2.7) [29].

Python is an open-source programming language that is easy to learn and use whether the user is a beginner or an experienced programmer. Documentation for standard library with tutorials and guides are available online. There are also thousands of third-party modules hosted by The Python package Index (PyPI) which allow even greater possibilities. [30]

Python API will be relied on heavily on the development as most of the automation if not all will be a product of scripts. They can be used for modifying existing systems and UI as well as creating properties, buttons, components and accessing files. Most used structures will likely end up being conditional statements like if/else.

There are several useful methods that can applied to access Visual components. Getting the handle to a vcComponent object is done using getApplication() method. A typical way to access the owner component of the python script is by using getComponent(). Accessing existing behaviours in the component by name can be done with findBehaviour() method. Another useful method is getProperty() which is used for accessing existing properties. [29]

4.2.2 Modelling tools in Visual

Visual has a Modelling view that contains all the tools needed for modelling new and existing components. These different features are depicted in Figure 4. In Component Graph Panel (1) is located component properties, node tree and behaviours. The node feature tree (2) contains all features needed to create the node. Feature properties window (3) can used for viewing and editing parameters. Any messages or values can be printed to Output window (4). In the middle of the modelling view is the 3D world. Here a component can be seen, and its feature selected (5). This feature can be moved and oriented using the manipulator (6). On the command ribbon there are buttons for adding Features (7), accessing Tools (8), adding Behaviours (9) and Properties (10). [29]

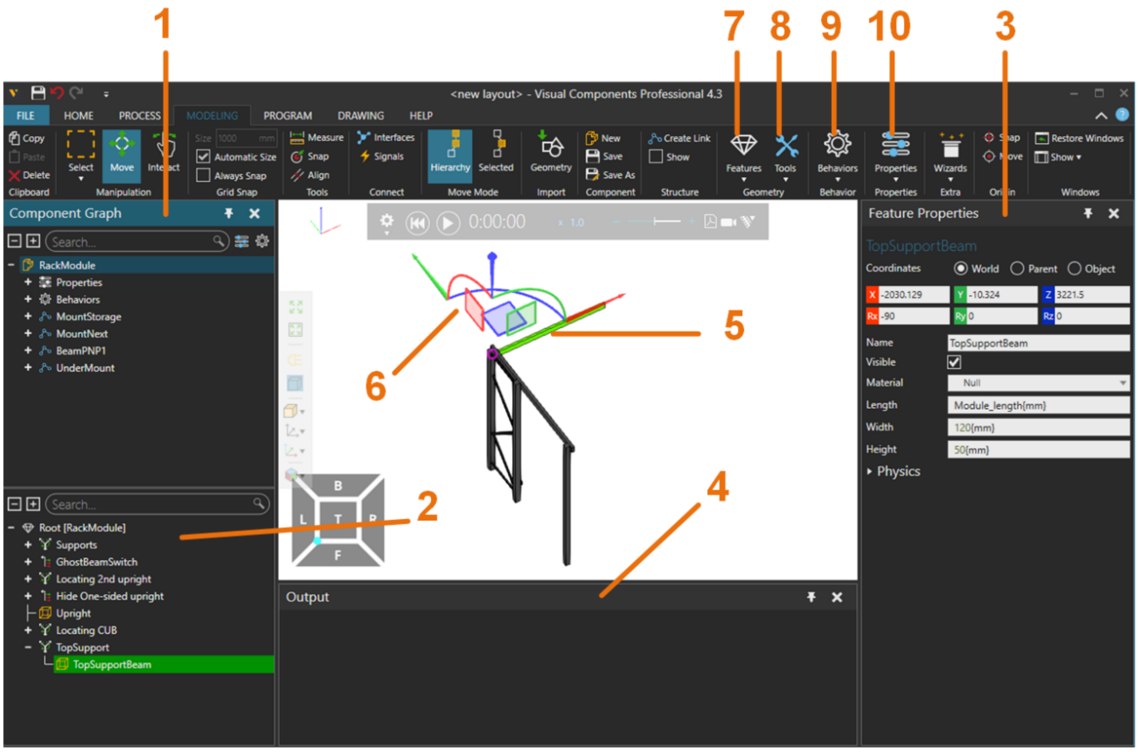

Figure 4. *The modelling view from Visual Components*

Properties are global variables in a component. They are contained in the component root node. Properties are shown in the Properties panel if they are set as visible. [29]

Most common property types needed for MLS model are Integer, Real, Boolean, Button and String. Integers are used as common property values for different dimensions. Sometimes Real type property is needed for calculations. Boolean type allows simple True/False statements. Strings are useful for making dropdown menus with names. Buttons can be connected to Python scripts to initiate a function.

Features are the visual representations of a component. Features are contained in nodes and can be formed into hierarchical trees to inherit values and perform actions. Usually, features are used to contain, group, and edit geometry. Some types of features are also used for showing information or to act as reference points in a component. Different functions can be used to write an expression. Expressions can be used with component properties for making features parametric. These can be type conversions, logical operations, and calculations, among others. [29]

In this adaptation Box and Clone features are used for creating geometries. Frame is used for reference points and Transform mostly for moving geometries using different expressions. Switch requires a choice to be made for turning different features on or off.

Tools are the most useful for manipulating imported geometries. They can be used for simplifying features, editing colours, and dissecting or combining features.

Behaviours are used for performing tasks in a component. They are contained in nodes but may be referenced and connected to other behaviours in the same component. Behaviours can also be utilized for connecting to other components. [29]

There are lots of options in behaviours to use but most useful ones for this application are One to one Interface and Python scripts. One to one Interface type allows connecting components physically or remotely with matching interfaces.

4.2.3 Component modelling

Initially the component modelling was started by utilizing components made previously for earlier model (Version 1.a)). The base values for components were decided together with two other designers that had made previous 3D layout models. The technical possibilities and solutions for implementing requirements set for development phase were discussed to form a basis. After a couple of meetings, the basis was set, and first component was created together.

This component was the EndModule that is located at both ends of racking to provide support and to allow service for the system. The end module main property that would need to be changed in almost every layout was module length which is determined by two factors: the system type and load size. The EndModule was set to be the base component in the layout as crane and rack components would be connected to it. It would also contain different components related to crane aisle. Connections or PNP point were created in both sides of racking for connecting rack modules.

Next components made was crane. An earlier component was used for this also as it seemed to contain most properties and functions needed. The geometry used was directly exported from Aton PDM as a SolidWorks assembly. This would guarantee that the geometry would look correct and save considerable time as modelling it from scratch in Visual would have taken a lot of time with no benefits. Only downside was that the geometry contained a lot of features which can make the component heavy to use. These features could of course be simplified by import options or modelling tools in Visual. The crane was designed as a component that would hold all system default values in its

Python script. These values could then be used to set parameters for the whole system. The only feature for the crane itself would be changing height. An UpdateSystem -button was designed to be a part of crane component and pressing it would update system parameters according to values set in crane component. These values would contain defaults for EndModule width, LowestBeam height, Forkspacer height, Module depth and Crane aisle width.

Last and most complex component to be made was the RackModule. It would consist of 2 uprights, a variable number of beams and the support structure. The beams are carrying loads and their height fluctuates depending on weight supported among other things. On top of beam forkspacers are located that lift the pallet upwards to allow load handling. Forkspacer heights vary depending on system type, pallet type and handling type. Usually there are also cutting fluid collectors integrated under each load, but these were left out for now as they were thought to over complicate the design and hinder rack building.

Soon after creating the RackModule it became obvious that the component should be distributed further into more parts that would be better managed separately. This would also allow more flexible rack building as a big problem with the old model was its the static nature. It was decided that each level would be an individual component that was split into beams and load. The beam component consisted of two beams and forkspacers. The number of loads was set to be chosen between 1-5. After Value change the load places would update. The load component would consist of pallet and load. All parameters were set to be customizable allowing the user to change both pallet and load sizes as well as shape. Loads would be connected with PNP points which also allowed passing data between components.

The beam would be able to read load data and re-distribute the places evenly on the beam. Similarly, PNP points were also created for connecting beam component into RackModule. Number of beams was set to be chosen between 1-8. After connecting the beam component, it would absorb the RackModule width value and adjust to new width. Each beam height could be customized independent from each other in the UI. Now that needed components were created the relationships between components can be seen in Figure 5.

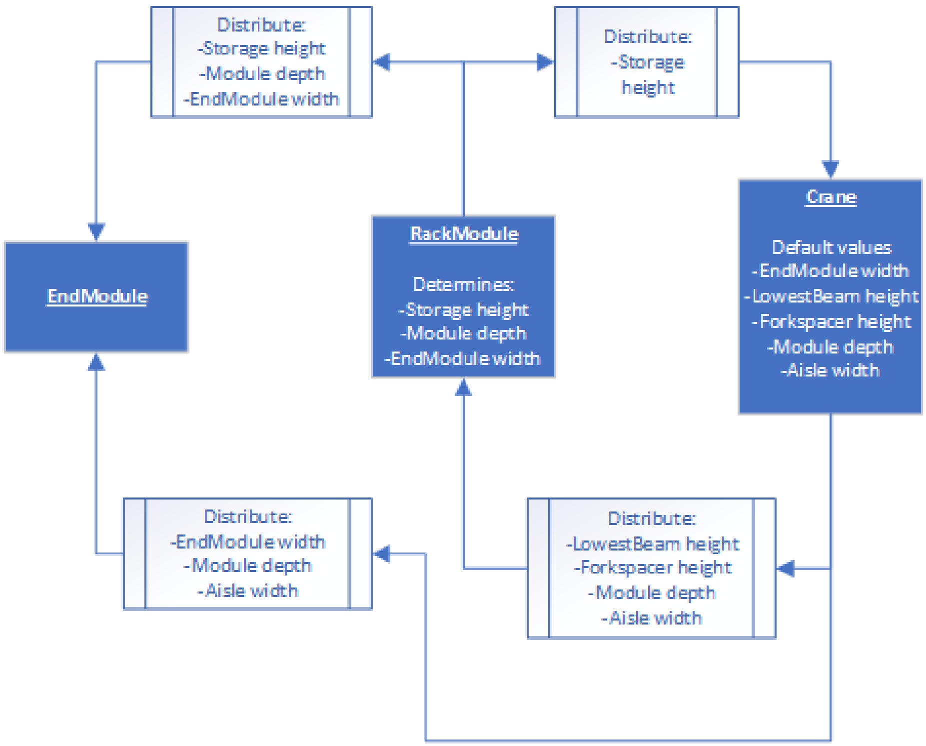

Figure 5. *Initial component relations*

After first round of testing the model a couple things were noticed that should be changed to make system creation more efficient. Having the System update -button in the crane component seemed out of place as that would be the only function in the whole component. Also having system default values to be bound into crane models was not viewed as the best solution as that would mean any updates to crane specifications would mean that each component should be updated separately.

This is why all default values were instead transferred into RackModule's script. In the script a list was created for each system type with the default values. These values could then be utilized with indexes after picking the system type. The storage height value was set to update instead when the RackModule was connected to EndModule. Update System length feature was created into EndModule to move the right end next to last RackModule end thus updating the whole system length.

A main challenge was proven to be the double-sided version of the racking as both EndModule and RackModule had issues when tested. For the EndModule it became clear that the way it was made did not allow customization of both racking sides independently. In the most basic systems this would not be an issue because the system sides would be identical for most parts. Unfortunately, these cases are nowadays rare and almost in every case there is need for customizing EndModule widths independent from each other. This is caused by having asymmetrical RackModule distribution on different sides.

This issue was fixed by basically re-creating the component structure so that the different racking sides could be controlled by a different width property.

Next step was making the RackModule suitable for double-sided system creation. The original idea was to simply hide features unique to one-sided system and then mirror the whole module in relation to racking centreline. Mirroring was eventually deemed to be too complex of a solution as a much simpler method was found. This way the only feature in RackModule that would need to change was the placement for a support beam that would simply flip sides from one side of uprights to another. As the RackModule was turned 180° it could now be placed on the other side of system.

Next challenge was figuring out a convenient way to add equipment into side that has racking and pallet places. Obviously, a machine or station cannot exist in the same space as load places so these load places would need to be removed or moved. Manually doing this would often require changing multiple modules and loads places individually but luckily this could be automated. First a Space reservation component was created to allow using existing machines, stations, and other components. A component could be placed to the space reservation PNP point and the space parameters could then be modified to match the needed space around a component. For ease-of-use multiple configurations were made for commonly used components that could be selected from a dropdown menu in the UI. When the Space reservation was connected to the module via PNP, the RackModule would read the height and width parameters and adjust the module width and beams accordingly.

Safety netting was last feature that was added to EndModule. Safety nets are usually located on all sides of the Racking. The distance from uprights varies based on load size and load handling. This is why properties were created to allow changing the distance on both racking sides. The updated component relationships are displayed in Figure 6 below.

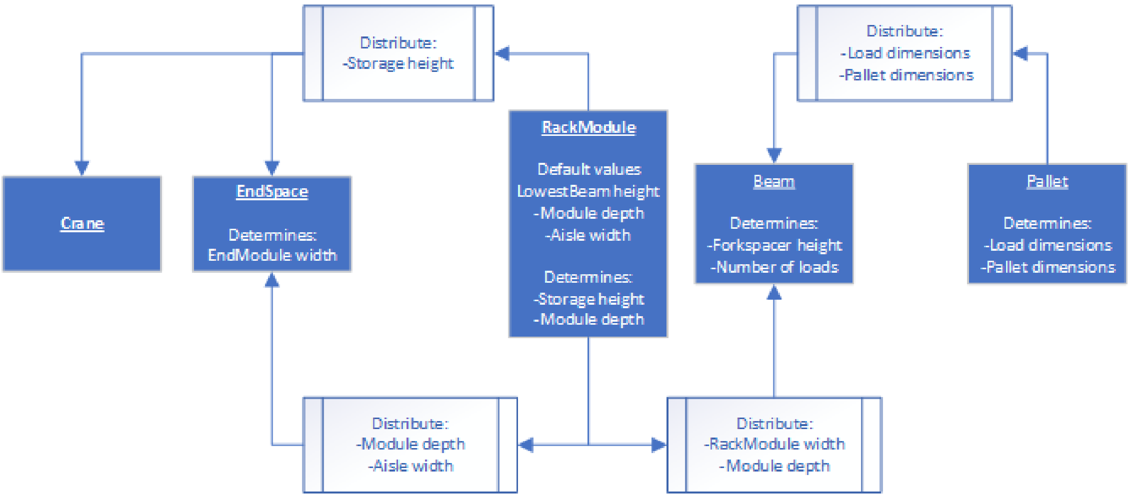

Figure 6. *Final component relations*

All created components can be seen in Figure 7. View taken from Visual environment. All components are listed in numerical order: Load (1), Beam (2), RackModule (3), EndSpace (EndModule was renamed so that the name cannot be confused with RackModule) (4), Space reservation (5), Adaptive DMC-MD (6) and Adaptive DMC-SSR (7). Most geometries look simple in this view as they are built using mostly block features.

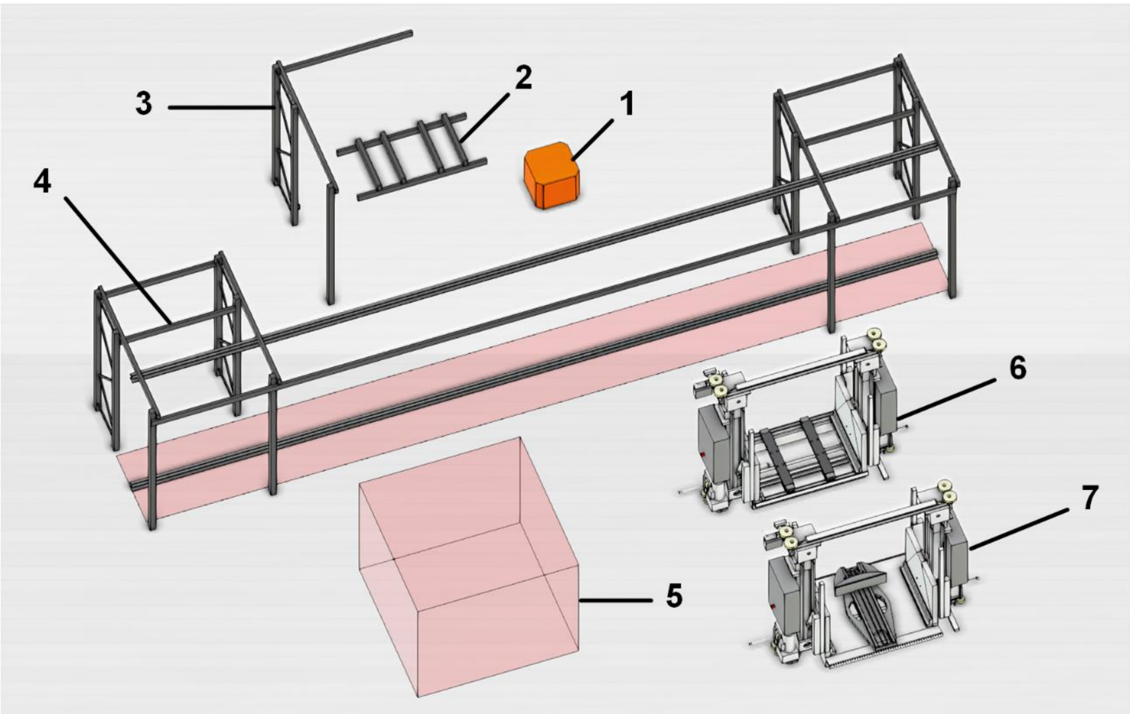

Figure 7. *All created components*

4.2.4 Python Scripts

All components created for the model have a Python script as behaviour with the exception of stacker cranes. Scripts will be most likely added to these components as well at some point as they would allow further development for simulation purposes.

The code structure has been made so that it will be easy to understand later when changes are made. Of course, the code has been commented and all functions or variables have been descriptively named. The code has naturally not been fully optimized yet and does contain some repetitiveness, but these can be improved upon later. At the moment it was seen more important that the code is easily readable and understandable.

Pallet component script is the simplest as it only has one function to adjust pallet dimensions for a Euro material pallet. EndSpace script includes three functions. ModuleConnect is used for getting property values from RackModule and updating the EndModule accordingly. UpdateLengthButton function which storage side is connected and creates a node list of all child components. Then this node list will be ran through a loop and the length of each node or RackModule in this case are combined. After calculations, the total system length can be updated. UpdateCrane function currently only updates the crane height based on height property originally received from RackModule.

Beam component script has multiple functions. ReadPallet will check if a pallet is connected and then absorb pallet properties using PNP connections. RemovePallets will check which pallet places are occupied and delete them based on value selected in the UI. AddPallets checks if a pallet is connected and adds pallets again according to value gotten from the UI. ConnectModule checks if the beam is connected to RackModule and updates beam length and module depth based on RackModule values. ReadPallet checks if pallet is connected and uses load parameters to determine needed space reservation for a single place. This space reservation together with LoadGap-property allow calculating how many places can be fit on a beam.

Space reservation component script contains a list structure where the most common station types have their default dimensions contained. From this list the setup for each type can be accessed using indexes. The SetupChange function allows picking a setup from UI which then corresponds to certain list index updating Space reservation component dimensions. There is also a SwapPlaces function allowing switching station places in double station setups.

RackModule is the most complex of the developed components, so the code ended up being the longest as well. The script has a similar list structure as space reservation containing default values for each system type. ChangeSystemType will update the system base values using the SystemData list-structure when a different type is selected in the UI. ReadBeam function is used for determining next beam height based on previous one. It considers beam height and all features added on top of a beam. Spacereservation allows attaching the Space reservation component to storage side of the system. The module will then update its properties to make enough room for this reservation both in height and in width. LengthChange is used for updated all beam lengths when the property is changed. GiveConstraints is needed for giving a variable constrains and step values. CloneButton clones a single RackModule and connects it to the original one. GhostBeam function shows a transparent beam above an existing beam to showcase where the next beam placement is. CopyBeams can be used for cloning beams for Autofill option.

4.2.5 Testing the model

Most of the testing was done constantly during development. Whenever an issue was noted, actions were immediately taken to fix the problem. This worked quite well as it prevented any larger pile ups and back tracing. Usually, any problems were minor issues that were also quite easy to fix when the bug was located. Luckily, Visual shows in the output the locations of the error which makes tracing easier. During component modelling the biggest and most time-consuming problems were typos in the property names. Any changes to the names would also mean that the name would need to be updated into every expression and script where it was being used.

Other issues noted was that using old components as basis was at first easier but ended up being a burden at the end. Most components where in the end created from scratch as the original structure would not allow the component transformations as they were needed. The old components also contained quite a few bugs and flaws that had to be corrected to ensure that the model worked properly.

5. RESULTS

Research results are presented in this chapter. Most results are from Development Phase but there are also some other points received from the interviews. Future development plans are also presented.

5.1 Development Phase

As a result, from the Development Phase, a working model for creating simple 3D MLS layouts was achieved. The goals set were met and exceeded even.

Main challenge during the development was the lack of experience in modelling components with Visual from authors side and the lack of experience about MLS systems for the other designers. In short, they knew how things could be made but did not exactly know what they were trying to make. Therefore, a lot of time was used in trying to keep both sides up to date and to enforce learning the viewpoints of different sides. Naturally, there was also some disagreement amongst co-workers as the other side was used to working with 3D and the other with 2D. As described in earlier chapters the approach with 3D was quite different to 2D. Issue was to recognize when something made with either solution was good solution for this model and not just the designer’s own preference. Deciding on design features was still achieved usually quite easy as the people involved were rational and after presenting good arguments a consensus was reached.

The workload was distributed in the following way. In the beginning the first component models were made together. After this the workload was split between the author and a colleague so that the formerly mentioned made most of the component modelling and the latter focused mainly on Python scripts.

5.1.1 Using the model

Using the model is started by loading a template containing components from Figure 6. excluding cranes. In addition, the template includes formerly created electrical components CC1, a universal CC and a DataCollector. The universal CC cabinet contains configurations for most electric cabinets that are used with equipment attached to FMS. The DataCollector component is modelled using a Station commander geometry and it can be used to search and collect all component data in the layout by names.

After the template has been loaded it is time to choose if the system is one- or double sided. System type will also be determined by clicking on the RackModule and choosing the system type from a dropdown menu. Next the correct crane can be dragged from component library and attached into crane aisle by PNP. After checking the load and pallet size the parameters can be fed to load component. Now that load size is correct the load can be attached to beam with PNP. Then judging by system type and load size the correct number of loads per level is chosen and placed. Required beam length is calculated and updated to RackModule. After checking maximum available height, the storage height parameter can also be updated. In case this height is not defined, number of levels is chosen, and height placed in result of this. Levels are added in RackModule by calculating first the distance from a beam to another which is done by adding fork-spacer height, load height and space reservation on top of load together. Beam heights follow 50 mm increments so next beam height is chosen by picking the next available height. In the top level the height reservation is determined by load height and highest handling address of the crane. Now the storage module has been completed and can be attached to end module.

Based on load size and system type end area width is adjusted in the EndSpace. Then the RackModules can be added by using CloneModule button created into RackModule or by copy-pasting the made modules. If there are multiple load sizes or types the RackModule building can be done again with wanted parameters. Of course, an existing module's load parameters can also be edited when changes are needed.

After RackModules are placed equipment can now be assigned to both sides of racking if needed. There are PNP points in every RackModule allowing the attachment of a component. Here the Space reservation component is useful as any component with premade PNP connection can be added into it and dimension parameters of the Space reservation can be edited. When ready, the component can now be connected to racking. Next the component is placed in adequate distance from crane aisle. Electrical cabinets can be placed coincident to netting using Snap or Align tools. Any other components may be placed using forementioned methods or by just dragging them into place. This whole layout model usage has been depicted also in a diagram (Appendix B).

After all other components have been positioned, the layout is ready. An Adaptive FMS ONE MDR system was created with the new layout model and the result can be seen in Figure 8. System safety netting was hidden to showcase different features more clearly.

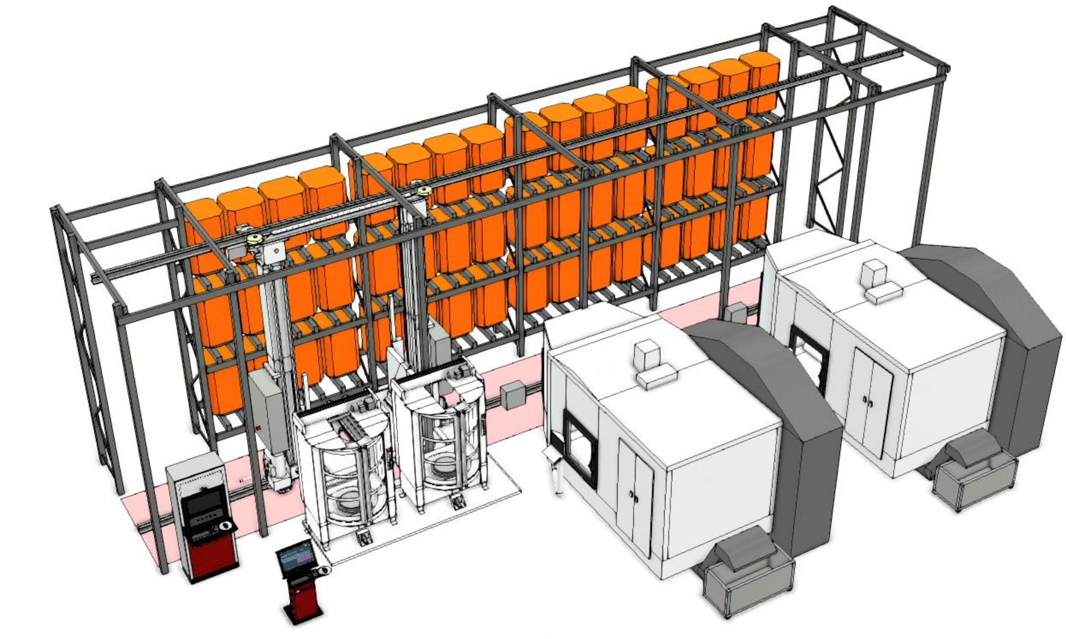

Figure 8. *Adaptive FMS ONE MDR created with the new layout model*

With the new model a different set of deliverable documents were needed. As opposed to the usual PDF and DXF formats something additional was needed to showcase 3D qualities. The files were decided to be a 3D PDF and a PowerPoint that would ultimately replace the 2D PDF. The DXF would undergo some changes as well.

The 3D PDF can be created in Visual easily by simply exporting the layout model. The document allows to view the system without any CAD programs which is good regarding sales use. The file contains a 3D world that can be investigated by panning, zooming, and rotating the viewpoint. Downsides for 3D PDFs are their simplified representation of models and layout size as larger systems tend to be slower to view.

The DXF contains much less information as with 2D layouts because most of this missing information will be displayed in the PowerPoint document. The file would still contain the same top view and sideview of the system with added dimensions.

In the PowerPoint file can be found all the text fields and notations needed. These would include system information such as system type, pallet types and dimensions, load types, dimensions, and weights, and most importantly machine tool make and model. The standard bill of materials would be replaced by explaining all components in the layout in detail by attaching names to components with lines using a picture of the system like Figure 8. The file would also contain any space limitations and load handling information available. The DXF views would also be added together with front and back views of the racking. These will help greatly to showcase load locations and beam heights. In addition, more views can be added if deemed necessary by the layout designer.

5.1.2 Other Features

During Development Phase several goals were set and fulfilled. Other features were developed also as they were seen as useful and reasonable to create. These features include adding materials to the system, the space reservation component, moving upright positions closer to crane aisle, changing EndSpace widths independently, EQ changes, cloning modules etc. One great feature was Rack module Autofill-property. When this option was checked, after connecting the first beam, Python script would calculate how many beams with same loads could be fitted into the height of RackModule and then place them with pre-set space reservations. Overall, all these extra features allow more flexibility in layout design without sacrificing too much on the usability side.

5.2 Development Phase 2

Even though the goals set for the 3D model were achieved there is still many things to improve on. This is why Development Phase 2 will be needed to improve the model and expand the model usability to several other system types. Below in Figure 9. are depicted the 3D model attributes achieved during Development phase. The values are based on authors impressions of the model.

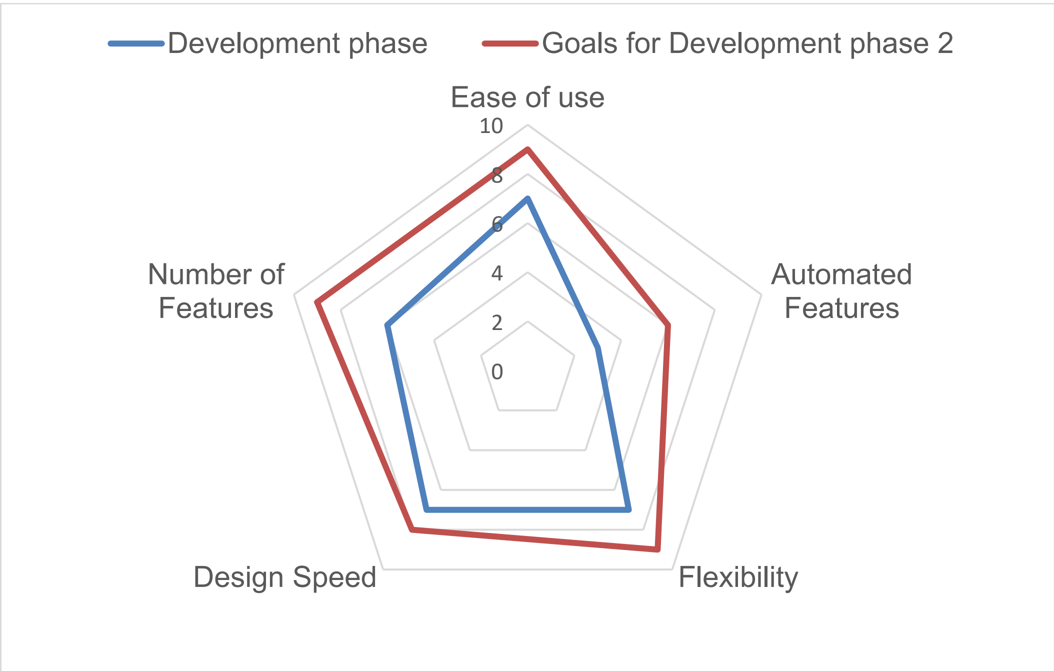

Figure 9. *3D model attributes achieved in Development Phase and the goals set for Development Phase 2*

Attributes such as Ease of use, Flexibility and Design speed are already on good level but can be improved upon. Number of Features and Automation Features are deemed needing most development. The next phase will aim to create more features allowing even more options to create any type of system. An important goal is to improve upon the automation level and trying to minimize the most tedious rack building phases. The goals levels set for each attribute for Development Phase 2 are depicted in Figure 9. as well. The improvements will also take the model flexibility and ease of use to another level while increasing the design speed.

5.2.1 Features to be added

First key feature to be added is the ability to change the EndSpaces from one-sided to double-sided independent from each other. This will allow a more special configuration that is still quite commonly offered. Another would be to allow moving uprights from both sides of the crane aisle independent from each other as well. This will accommodate different handling requirements better as the load may need to be offset from the aisle or the crane to be offset from standard position.

Currently the model does not welcome any grooves to be used with the system. This will need some more attention as especially with heavier loads and systems these are almost everyday issues. Customers may also have lacking height to allow building the system with all the functionalities they need which may again require the system to be placed below floor level. Sometimes this would mean the whole system and all its components but more often only parts of it are in a pit. These parts may be crane, storage racking, stations, or the machine tools.

System selection with current model is limited to only 2 system types, which will need to be expanded on. The key components and changes that are required to make this happen are adding default system parameters to the RackModule script and creating Crane components for each system type. These systems include LD, DSR, XMD and HD. The first three should have most stations and other equipment ready to go but the HD system would definitely need more components. The XMD system would also need some more detail as it currently has three different standard fork setups which all have their own specifications that need to be replicated.

5.2.2 Automation improvements

The autofill property in RackModule needs to be developed so that it would also work from other levels than the lowest one. This would make rack building better as all levels would not need to be the same when using this feature. Off course the copy-paste method would still be better for some situations, but it is always good to have options for different situations.

There are several space reservations that could be automated. These include upper space, netting distance and EndModule widths. Upper space needs to be determined by two variables: highest load height and highest handling position. Netting distance can be automated using minimum distance from loads and setting the distance to work in 50 mm increments similar to system height. The EndModule widths need to be determined by last load addresses as well as system type.

Naturally, most of these space reservations should be measured once the layout is done to ensure correct values. Still, it is important to keep in mind that the automation cannot become a limiting factor to layout building and there may be some cases where it either cannot be implemented or it is more convenient to make a certain feature manually.

5.3 Future development ideas

A lot of information was received during interviews and meetings which did not really fit onto other sections without feeling out of place. Since it would be a shame to lose this information, these ideas are presented on this chapter.

Since nowadays layout team is making all solution layouts, it was contemplated that could the salesperson make sketches with a layout configurator as an example. This could help sales get simple concepts done faster than currently and possibly get layout requests more defined from the start. Problems with this kind of tool would be finding a suitable lightweight tool that is simple and easy to use. Other issues would be usage of the tool since the layout request template already offers similar sketching function which is rarely used.

As evident from the interview data, the low usage of layout request template is seen problematic as it would often clarify request, save time and effort. It would be good to get sales to use layout request template as it has been a problem a long time. One way to enforce the usage of the layout template would be to only create layout when a correctly filled template is used. This could create some tension between departments so this would not be an advisable solution. Another way to approach the issue would be to look at the tool: why is it not being used and how it could be improved. The main problem seems to be time used filling the template.

Offer layout designers could also make project layouts and project people offer layouts to level the workload. Problem would be that there would not be enough specializing to one subject. There could also be an issue on how to direct the work resource intelligently. Allocating too many resources to either side at a certain time could decrease response time with sudden requests.

To make more accurate and realistic solution layouts, the communication between client could be done using 3D STEP files which they could modify and send back. This would be the equivalent to the current situation where solution layouts are sent in DXF format and sometimes customers make corrections and sketches based on our layout. Problems with the proposed direction would be enforcing that no unintended material is sent as 3D models allow greater exploitation of existing designs. Another issue would be extra effort needed to make another document in the proposal phase where time management is essential.

As a more generic statement it was mentioned multiple times that communication issues should be handled better between sales. This would include systematic use of email, calls and other ways of communicating. The main thing would be somehow having relevant conversations documented and the information to be passed to right people. Unfortunately, this is hard to enforce since relevancy is a subjective matter and because simple human errors always occur.

6. CONCLUSION

In this chapter the conclusion of the research is presented. Answers are given to each research question and the study methods are evaluated. The weaknesses and strengths of the results are discussed. Lastly the future aspirations will be revealed.

6.1 Research questions and methodology

First research question was regarding how 3D solution layouts are currently designed with different design software. Different models and past development were discovered. A comprehensive review of current methods was achieved through documentation and discussions.

It was set as a goal to try the automation principle for the 3D layout design. Automating layout generation was discovered to be restrictive and, in most cases, either not useful or needed. Because of this the automation was directed into feature level to help in certain repetitive aspects of solution layout design.

Accuracy needed in the proposal layouts was said to be similar than currently used in 2D layout making. The space reservations and racking should match exactly the drawings made as of now to ensure smooth transition into projects. Model library was deemed to need updating. Components for cranes and missing stations should be made or updated to be usable with the new model.

Regarding model libraries the machine model library is currently the most lacking because of disorganized naming and since many machine 3D models are not available. When a correct model is not available, a 2D footprint can be used. The model library file structure is clear, and components needed for FMS ONE layouts are in the library.

Last question was about how the proposal layout could be used in project stage. This was discovered very early on to be impractical to do as the way project layouts are made differs too much when comparing to proposal layout making. The rack building would need to be done in SolidWorks to ensure the process working also at project state. As stated in the earlier development, SolidWorks does not allow quick enough sketching to fulfill the requirements set for proposal layout environment.

However, during interviews it was said that project layout making would be easier if there were proper racking views made to determine load placings. This is something that can be provided with the new 3D model and helps when storage prices are requested.

Approach seemed to work well, and methodology was appropriate for this application. Analysing current methods provided a good basis for implementation. Interviews were well received by co-workers and answers gotten brought out different views regarding research subject. Off course sometimes it can be hard to objectively compare the answers since there are differences between interviewee backgrounds and specializations.

Model development was essential to discover if Visual could be suitable candidate as a 3D solution layout software. With the Development Phase a working model was developed for creating simple MLS layouts. The features made to the model exceeded set goals and allow for more complex creations already than was originally planned. Model UI achieved a much more user-friendly form than the previous models. Flexibility and quick sketching ability have been improved a lot compared to the older models.

6.2 Weaknesses and strengths of the results

Greatest weaknesses regarding results are the lack of user experience and usage from the new model. It would be great to have some empirical evidence comparing the 3D model against 2D. Unfortunately achieving such statistics would require significant time to compile. Things to compare would include at least the following:

1. Percentage of new cases where the 3D model can be applied. As the offering moves constantly into more complex systems, the simple FMS ONE type layouts are made less frequently. This would imply that the model usage will be quite low because there just are not many cases for it.
2. Accuracy. It would be important to review which method will result in fewer mistakes in the layouts. It would also be interesting to see if one or the other would make less critical mistakes that may prove to be an issue at project stage.
3. Lastly it would be most interesting to find out how the use of 3D solution layouts will reflect on sales: Would the offer/sold ratio improve, could a system be sold with less layout and offer revisions, and how would the customer experience be affected. With every aspect considered, the main question to be discovered is: Are 3D solution layouts a better tool for selling Automation systems?

Strengths of the results are that the process and results are repeatable using the same approach and resources. The interviews allowed accessing some valuable information about designer opinions that are not normally collected in any manner. This provided a good basis to the model development together with information about previous models. The development results show that layout generation is feasible in 3D for proposal use with comparable design time. It was also proven that some features and repetitive tasks can be automated or improved by automation.

6.3 Future work

In practical terms the development and further implementation of the 3D layout model will be continued. Documentation and training will be arranged to allow a new user to utilize the model efficiently. 3D MLS layouts will be provided together with 2D ones until the model and the whole sales process is refined enough to support only using 3D.

VR can be currently used to display the 3D solution layouts with Visual. This can provide a deeper understanding of the system operation making it more tempting as a layout design instrument. There is also the possibility of running simulations while using the VR environment. Visual also has a tool for making the VR world interactive by adding operating buttons. However, the reality is that the VR side is still currently mostly useful as a marketing tool as very few customers have VR technology available.

As always, it is hard to predict what different technologies and software the future may hold but it feels safe to say that the newer generations will aspire to improve design in every which way they can. Therefore, it seems safe to assume that layout design will be no different. This is why constant improvement will be the key to stay competitive and better yet to try and stay ahead of competition, especially in economically challenging times.

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APPENDIX A: INTERVIEW QUESTIONS

1. How many years have you been working at Fastems?
2. Has there been changes in layout requests during this time?
3. Has the time-schedule for requests been realistic?
4. What programs have you used for making layouts?
5. Which of them served the purpose best in your opinion and why?
6. How has layout making been improved in the past?
7. Has layout making process gotten more effective due to improvements?
8. What is the greatest obstacle or challenge when creating a layout?
9. What are the pros and cons of 3D layout design according to your own experience?
10. What are the ‘must have’ properties for a 3D layout program and what would be ‘nice to have’?
11. Do you see moving into 3D offer layout generation realistic in next few years? Argument for or against?
12. How would you develop layout making process?

APPENDIX B: LAYOUT MODEL USAGE