Using digital tools to virtually plan and control a production

A case study on how digital tools can help production planning and control

Master's thesis in Production Engineering

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Abstract

Due to the growing industrial competition and constant rapid development that industries face today, manufacturers need to keep up with the technological innovations implemented in production. These technical innovations consist mostly of digitized tools that enable better production control so that more advanced products can be created based on customer requirements and needs. A digital tool that many companies choose to use is Virtual Twin, which creates a digital representation of a physical system where users can observe a manufacturing site without physically being there. However, there are developments within Virtual Twin that can increase the value for the user and this thesis proposes a framework for manufacturers on how the Virtual Twin can increase value by integrating with a new digital tool, namely the Real-Time Location System (RTLS). Through a literature review, interviews, and a case study, this thesis concludes that there are many advantages in integrating an RTLS and a Virtual Twin to create more value for users, however, this integration also brings some challenges.

Another area where digital tools are used is within visual planning in the manufacturing industries. Visual planning is a concept in manufacturing where the user has the opportunity to use digital tools and strategies to visually plan something, such as a manufacturing order or planning the reconstruction of a production facility to save money and avoid unexpected problems. A digital tool commonly used in visual planning is simulation software. This thesis investigates how simulation can benefit the visual planning of a manufacturing order at Virtual Manufacturing, which is the project's case company. This is done by exploring and using different software, such as IronCad and Visual Components, which build up Virtual Manufacturing's factory and then simulate it depending on the company's orders. By doing so, the results of this thesis can support Virtual Manufacturing's visual planning for future orders, thus avoiding unnecessary costs and unexpected problems.

Keywords: digital tools, virtual twin, visual planning, simulation, real-time location system, manufacturing, industry 4.0, tracking.

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Abbreviations

2D	Two dimensional
3D	Three dimensional
VT	Virtual Twin
DT	Digital Twin
IoT	Internet of Things
RTLS	Real-Time Location System
RQ	Research Question
ERP	Enterprise Resource Planning
CAD	Computer-Aided Design

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1. Introduction

This part of the paper introduces the project and why it is being performed, more in-depth, the background and the problem that is faced, and the different research questions. Also, certain delimitations are presented to further define the project and its research.

1.1 Background

Today's manufacturing industry is constantly improving through the implementation of innovations and technologies, which has led to a new revolutionary industry, namely Industry 4.0. This industry develops production by digitalizing existing work methods and integrating different software with the physical system in production that enables a connection between real objects and people with information-processing/virtual objects [1]. This type of industry is very necessary today because of the environmental problems the world is facing, but also because of changes in customer behavior [1].

This behavior change has led to a greater demand for complexity within the production system because today's customers demand shorter lead times and, at the same time, more customized products [2]. However, a traditional manufacturing system was not designed to be complex and flexible, and therefore companies need to develop their approaches and techniques in production to be able to meet the environmental problems that exist and the demands of the customers [3].

One way to meet customers' demands is to always be able to predict production, by simulating the process, to avoid unexpected problems and costs [4]. Virtual Manufacturing, this project case company, receives several different variations of orders and thus they have problems with this very thing; being able to predict what their manufacturing process will look like after the various orders are completed. Therefore, simulation can be a good digital tool to solve this problem because it makes it possible to visually plan the production by creating a digital mirror of the plant and thus minimize the need for physical testing [4]. For this reason, simulation and visual planning have been very important to the revolutionary Industry 4.0 and will most likely continue to be [5].

Another new technology that has emerged under Industry 4.0 and has received a lot of attention recently in the manufacturing industry is RTLS [6]. This technology enables companies to be able to remotely locate people, equipment, and products in supply chains in real-time, which leads to better production control [7]. This technology requires integration between hardware, which can act as trackers and software that provides real-time location information [8]. RTLS is becoming an increasingly important implementation of Industry 4.0 methods and therefore this project will also investigate how this technology, together with existing software (VT), can optimize production control for companies.

1.2 Description of the case company

Virtual Manufacturing is a Swedish company that provides different services, the primary one being manufacturing specialized industrial carriages, see Figure 1.1. One, or multiple, engineers are sent out to a customer where they discuss the required service, then a solution is presented in the form of a CAD drawing, and then the solution is physically manufactured. This means that there are always new products being manufactured, however, it is not a mass production. In addition, the company provides manufacturing-related consulting services, for example, by helping customers plan out a layout, or 3D scanning a factory and creating a VT [9].

Figure 1.1: One of Virtual Manufacturing's specialized industrial carriage that they provide

The reason why this is relevant is that certain elements of the project are based on the company, for instance, their manufacturing site. The plan is to examine elements such as their manufacturing site, customer orders, and ways of working, and use this in the project. In addition, the results from this project will maybe be applied by the company, meaning that they will use the results for their potential benefit.

1.3 Aim

The project aims to explore a strategy on how to virtually plan out production and its customer orders. This strategy can be divided into two parts, one being related to creating a digital version of a factory where different simulations can be implemented. The goal is to simulate the creation of a customer order, which can then be observed to identify potential bottlenecks, and also virtually plan the allocation of space. The second part is exploring the benefits, possibilities, physical and digital prerequisites for the concept of a RTLS, which is the concept of tracking the location of objects in real-time. The aim is to examine how this system could be used together with a VT to bring more value to the user.

1.4 Objectives and research questions

Being able to digitally build a manufacturing site and then perform certain simulations can bring several benefits. In this case, the objective is to develop a strategy on how to virtually plan a manufacturing order, mainly understanding how much space needs to be allocated. A company like Virtual Manufacturing, which is constantly producing new products with new dimensions, could benefit from having a digital version of its manufacturing site that could be used to evaluate how much space is required for its orders. For example, it could be used as a basis for when deliveries need to be made, and how many batches the order should be divided into. A simulation of the production visualizes the creation of a manufacturing order, allowing the opportunity for the user to observe how the products are created.

In addition, the objective is to explore the benefits, possibilities and prerequisites for installing an RTLS, for instance, which digital conditions are needed, or which physical objects need to be installed. This is connected with visual planning because it allows for the simple location of different objects, which is beneficial. After all, the digital version does not show the real-life location of objects, meaning that if an object is moved in real-life, it will not move in the VT. Therefore, manufacturing companies, such as Virtual Manufacturing, could benefit from having a strategy on how to implement RTLS.

Revolving around these objectives and their potential benefits, the following research questions are created:

Research Question 1 (RQ1): *How could a simulation benefit the visual planning of a manufacturing order at Virtual Manufacturing?*

Research Question 2 (RQ2): *How can RTLS be used together with a VT to create more value for the user?*

1.5 Scope and delimitations

The major restriction for this project is the time, which is around 20 weeks, meaning that the project needs to be designed along that time frame. There is a lot of information regarding the areas that are to be explored (visual planning, simulation and RTLS), meaning that it is necessary to investigate the theory that is relevant to manufacturing. In addition, the research about the RTLS will only be regarding exploring the prerequisites, benefits and possibilities of the RTLS technology, but also how it could be used alongside a VT, meaning that no physical installation will be made.

2. Theoretical Background

In this chapter, various theoretical definitions are presented as well as some technical hardware and software related to the subject of the project. The chapter is divided into two different main sections where the first section is mostly associated with RQ2 and the second main section is associated more with RQ1. In the first main section, the concept of Industry 4.0 and its technologies are presented with a focus on the integration between VT and RTLS. This main section also highlights the hardware and software used to create a VT as well as the hardware and software associated with the project's RTLS analysis. In the second main section, various software associated with virtual planning is presented, which will be used extensively during the project. These softwares are CAD programs and the Visual components simulation program.

2.1 Industry 4.0

Industry 4.0 is a description of what is called the fourth industrial revolution, which is the current and modern technological revolution. This revolution consists of elements like the integration of new technologies, for instance, robotics, artificial intelligence, and the collection and analysis of data at a manufacturing site. This industrial revolution strives to digitalize the production sector, in a sense, upgrading existing manufacturing sites and ensuring that there is a high level of connectivity between physical devices. In addition, the goal is to have a form of centralized data collection system where data can be collected and studied, which then can be used as a basis for making certain decisions. For example, decisions regarding preventive maintenance, or identifying potential bottlenecks that are slowing down the process [10].

Industry 4.0 and its technology will completely transform existing industries and make them more characterized by new technology and equipment, thus, resulting in them becoming more efficient, agile, and sustainable. More efficient, agile, and sustainable in the sense that there is a high level of connectivity between physical devices, data can be analyzed relatively quickly, and decisions could be made faster. In addition, Industry 4.0 supports the expansion of new ideas and models, for instance, the concept of flexible manufacturing, meaning that there are possibilities for mass customization. Flexible industrial robots with interchangeable tools make it simple to switch between different customer orders, especially with technology like sensors, connectivity, and data analysis that allow for fast, and potentially autonomous decisions [11].

Although there are several benefits, there are also multiple challenges mainly connected with workers not having adequate prerequisites to handle this industrial revolution. New technology is being developed rapidly, meaning that there is a need for personnel that can quickly learn, understand, install, and maintain new technology. Also, making sure that the data that is collected and analyzed is well protected and that there is a high level of privacy [12]. However, the benefits heavily outweigh the negative consequences, and these consequences are something that will reduce with time as more industries start adopting new technology.

2.1.1 Internet of things

The IoT can be defined as a network of physical devices that are embedded with software, sensors, and connectivity possibilities, allowing them to collect and exchange data through the Internet [13]. The IoT results in physical objects being able to communicate with centralized data systems, as well as each other. This yields the opportunity to gather and analyze a significant number of data without human intervention [14].

There are several benefits with this technology in many aspects, for instance, making homes smarter and more efficient regarding energy consumption. However, it is the most beneficial in an industrial setting in the sense that it allows for efficient data collection, as well as adequate communication between devices. The data that is collected can be used to optimize production, provide information regarding the status of machines, and improve their overall performance [15].

In summary, the IoT is a significant shift in the way humans operate, making objects more connected with each other, as well as collecting and exchanging data efficiently. In the future, the IoT will develop and become more prevalent as new technology is developed and new objects are connected not only in the industry but in homes and other workplaces [14], [15].

2.1.2 Virtual Twin

The concept of a VT is often mixed with a DT, which is a separate type of model. A DT is a digital portrayal of a real-life system, for instance, a representation of a manufacturing site. The quality that stands out with a DT is that it is connected with its real-life counterpart, meaning that whatever changes occur in the real world occur in the DT, and vice versa [10], [15]. A DT allows engineers and operators to remotely analyze a significant physical system, for example, a manufacturing site, from a working station. This allows users to study data and identify possible errors, which can then be prevented through the DT [16].

In this case, the concept of a VT differs from a DT because there is no connection between a VT and the physical system it represents. Events that occur in the real-life system do not directly affect the system in the VT, and vice versa, meaning that it is not possible to control one system by making changes in the other one. Instead, the goal with the VT is to create a digital representation of a physical system where users can observe a manufacturing site without physically being there [17]. The case company offers this service to its customer, and the result can be compared to a form of mapping system where the user can navigate around the site [18].

2.1.2.1 NavVis 3D Scanning

Creating this form of a VT requires a form of software where the model can be built, and in this case, the relevant software is NavVis 3D scanning methods. NavVis 3D scanning is applied to build a model of a real-life environment, which is performed with the help of a portable machine with multiple cameras and sensors that scan the surrounding area, see Figure 2.1. The user moves around with the device, and the sensors then capture real-time data and establish a form of a point cloud, which is then used to create a 3D version [18].

Figure 2.1: A person standing next to NavVis' 3D scanning equipment

After the scanning is complete and a point cloud is created, the data can be converted into a form of mapping program through the internet, and a user can navigate and observe the scanned area, see Figure 2.2. There are several benefits with this scan, mainly that the user does not need to perform any physical measurements. Instead, accurate sensors and cameras scan the surrounding area and establish a VT. From a manufacturing standpoint, users can observe and navigate the model and identify potential issues [18], [19].

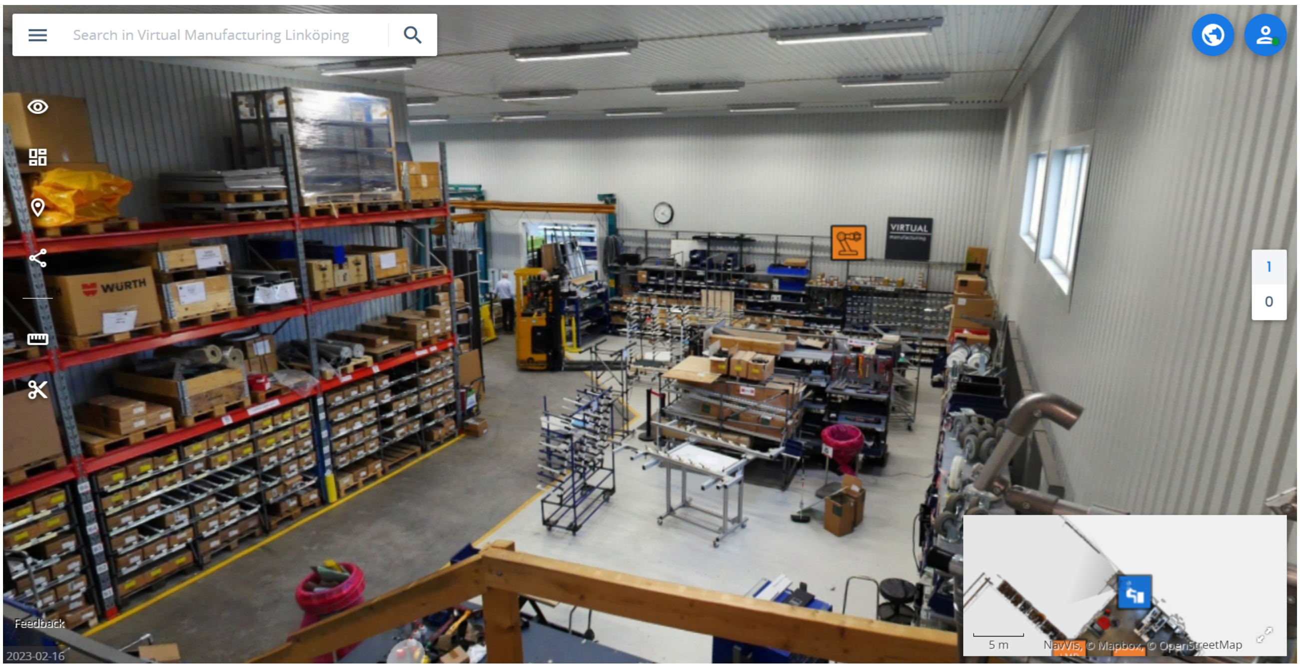

Figure 2.2: An overview of the case company's manufacturing site through their VT

2.1.3 Real-Time Locating Systems

As previously mentioned, RTLS is a technology that is applied to track and understand the precise location of an item, or a person, in real-time. The goal of this technology is to improve overall production control, meaning that there is a clear understanding of where objects, products, and people are located. This type of technology requires between hardware and software, the hardware being trackers and the software being a computer program that manages the tracking. Usually, it is a combination of several aspects, for instance, trackers, sensors, technology, and wireless communication, most commonly, Wi-Fi [20].

The foremost application area for this technology is in the industry and manufacturing, more specifically, with logistics and transportation, thus, ensuring that objects are placed correctly and that products are following the necessary route. Furthermore, it is a beneficial tool regarding inventory and storage because it is common that items disappear, or are not placed in the correct place. This results in time being used to locate the missing item, but if an RTLS was in place, this would not be an issue [20], [21].

Furthermore, the system yields other benefits because it can be integrated with other systems and working methods, as mentioned, sensors, or analytical software. By gathering data and understanding where objects are located, for example, a product in a manufacturing line, it is possible to perform a predictive maintenance analysis, resulting in the workflow being improved [22].

2.1.3.1 Quuppa

RTLS is a technology that has several versions of it, meaning that multiple companies have developed their hardware and software that allows tracking items, or people. One example is the company Quuppa, which is a tracking technology based on a technology called Bluetooth Low Energy (BLE). BLE is independent of Bluetooth, and it is a wireless personal area network (WPAN). The Quuppa system is based on using relatively small battery-driven gadgets which are called Quuppa tags, and they can be placed on physical items or humans [6], [23].

This system is established by strategically placing beacons, or locators, that together cover an intended area, for instance, a manufacturing area. These beacons will then provide data regarding the specific location of the Quuppa tags, which of course are placed in the intended area for tracking [6] [24]. Furthermore, the accuracy of these Quuppa tags is significant in the sense that it provides accuracy up to a couple of centimeters, meaning that it is almost completely accurate [24].

As previously mentioned, RTLS can be applied together with other software, for instance, with predictive maintenance analysis. Regarding Quuppa, the system offers its users an API where the user can connect and integrate the Quuppa system with other technology [22], [23]. The case company plans to use the Quuppa technology at its manufacturing site, acting as a form of demonstration and testing of the technology. In addition, they plan to use the API and integrate the Quuppa system with a RTLS software called Gazpacho to visualize the tracking system [25].

2.2 Visual planning

Visual planning is a concept in manufacturing where the user has the opportunity to use digital tools and strategies to visually plan something [26]. In this project, the goal is to examine how simulation tools and other computer software could benefit this type of visual planning, for instance, digitally building a manufacturing site and then performing simulations in that digital factory.

2.2.1 Computer-Aided Design (CAD)

CAD is the appliance of computer software to draw, create, analyze, and change the design of physical objects. Engineers can use CAD software to establish digital versions of physical items, and it could be performed both in 2D and 3D. It is a tool that is commonly used in several fields, for instance, architecture, or engineering and manufacturing [26], [27].

Furthermore, CAD software yields the possibility to perform several studies, for example, thermal analysis, or strain and stress analysis [26]. However, this project will not consist of these types of analysis because it is not necessary. In this case, the goal is to use CAD software to create relatively simple designs that are compatible with other software, mainly simulation software. The primary CAD software for this project is IronCad because it is the primary software that the case company and its workers use,

2.2.2 Simulation

Regarding manufacturing, engineers often use computer software to build digital models of a manufacturing site, and then perform a simulation of the production lines and different events within that site. Commonly, these models and simulations contain digital versions of equipment, personnel, conveyors, and materials. The goal of these models is to yield a digital representation of a real-life area, where modifications and simulations can be performed [28].

Simulating a production has several benefits, mainly, showcasing how work is performed and at the same time producing shop floor data that can be used in other areas, for instance, preventive maintenance, or finding bottlenecks. By analyzing data and identifying potential issues, new manufacturing strategies can be tested and implemented, thus, resulting in improved efficiency and decreases in cost. For instance, a simulation of a manufacturing site can showcase that a certain manufacturing order can not be completed in time, showcasing that measures need to be taken [28].

Regarding this project, the goal is to explore how simulations could benefit the visual planning of a manufacturing order, which there exists. Being able to simulate a production line in a digitally built manufacturing site allows the user to observe potential issues, for instance, issues related to the allocation of space [28], [29]. It could showcase that there is not enough space to complete a manufacturing order at once, meaning that it must be divided into batches. Testing and learning this information in advance allows for planning and scheduling, thus, preventing issues from occurring before it becomes too costly and difficult to implement solutions [29].

2.2.2.1 Visual Components

Visual Components is a computer software that is used to create a 3D layout of a manufacturing site, production lines, and logistics systems. This allows for a 3D visualization of a factory, allowing for relatively simple planning and testing of new ideas and changes, meaning that existing designs can be optimized. In addition, the design of a digital factory is based on a drag-and-drop function, meaning that changes are, as mentioned, relatively simple to make [30].

More importantly, the software offers the possibility to simulate production, resulting in the user being able to observe the creation of manufacturing orders. In addition, the program provides data regarding production, for instance, when machines are idle, busy, or not working. This yields the opportunity to identify potential bottlenecks before incorporating changes in the real world [31].

Furthermore, the program is designed to be highly compatible with other programs, for example, CAD software, meaning that designs that are made in CAD software could simply be imported. This integration between different computer software is useful in this project because work is performed in different programs, meaning that it is necessary to import work into different software [32].

3. Methods

This chapter presents and explains the methods that are applied in this project, and several methods are applied because there are two different research questions. Overall, it is possible to summarize the methods as the following: exploring computer software, a literature review, and interviews. Exploring computer software and conducting a literature review were performed parallel to each other, as well as from the beginning and towards the end of the project, while the interviews were conducted later on.

3.1 Exploring computer softwares

The first research question relies on exploring how different computer software can be used to visually plan a manufacturing order. The case company offered an array of different programs that fulfill these requirements, for instance, Dassault Systems, and Visual Components. The exploration of these programs was done by finding relevant information on the internet and having meetings with engineers from the case company that knows the software. However, most of the exploration will rely on trial and error, and testing different things.

3.1.1 NavVis 3D Scanning

As previously mentioned, 3D scanning is an aspect that was applied to gather data and build a form of point cloud. The software that was used is NavVis 3D scanning, mainly because the case company regularly uses this software and has a lot of information and experience regarding it. The primary method for learning this program was through a workshop with an engineer from the case company. This workshop highlighted how to use both the hardware and the software, as well as its different benefits and drawbacks.

3.1.2 IronCad

Similarly to the learning process regarding NavVis 3D scanning, the learning process for IronCad was performed in the same way where an engineer from the case company showcased the software. In addition, the workshop presented the compatibility between IronCad and other software, mainly with the 3D manufacturing simulation software Visual Components. Furthermore, the learning process for this software was broader in comparison with the one for NavVis 3D Scanning because the software was more. Therefore, information was gathered through tutorials, video, and reading sessions, and going through the case company's wiki with articles about IronCad.

3.1.3 Visual Components

The method for gathering information and learning about this program was similar to that regarding IronCad. Information was gathered through a workshop with an engineer that regularly uses the program, as well as through tutorials, videos, and reading sessions on the Internet. However, because this was the primary program used to digitally build a manufacturing site and perform simulations, it was necessary to gather as much information and understanding as possible. Therefore, several individual meetings were held with engineers from the case company, as well as with students from the Chalmers University of Technology.

3.1.3.1 Creating a layout

As mentioned, it was necessary to digitally create a manufacturing site where simulations can be performed. In this case, the case company's manufacturing site was chosen because it is relevant to the research question, as well as there being a lot of data and information, for instance, the different dimensions.

Some of the distances and dimensions are documented by the case company, however, there are several that are not, meaning that they were retrieved in some way. This ties back to NavVis 3D scanning equipment in the sense that the manufacturing site was scanned, and then a point cloud was created where the exact dimensions are retrieved. This is deemed more efficient because it eliminates the need to physically measure objects, instead, measurements are gathered through a VT on the internet, see Figure 3.1.

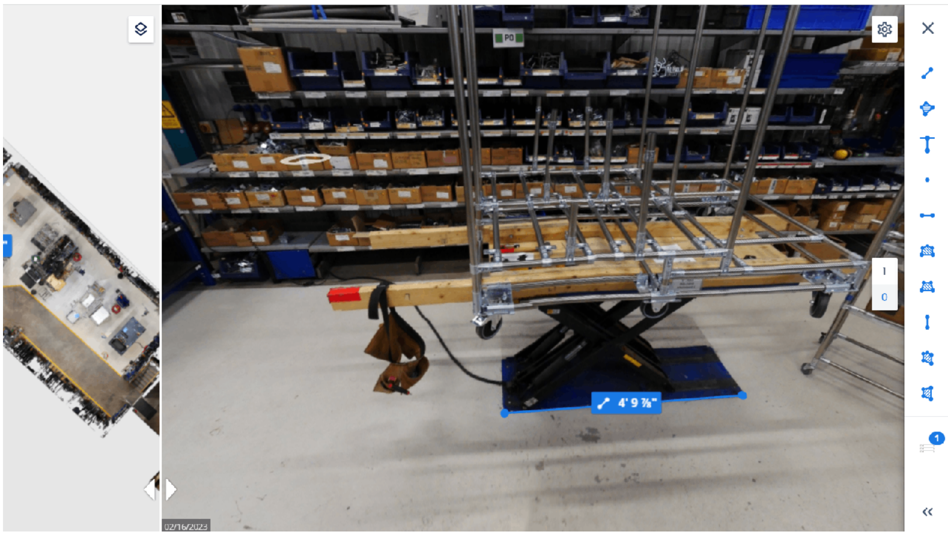

Figure 3.1: An object being measured in the Virtual Twin

With the help of NavVis's 3D model and its dimensions, the model in Visual Component was created using built-in tools, see Figure 3.2. However, some objects were not built in Visual Components because they were too detailed, meaning that other software was used. In this case, IronCad was used to build more detailed objects, and because of the adequate compatibility between the programs, files were easily imported into Visual Components.

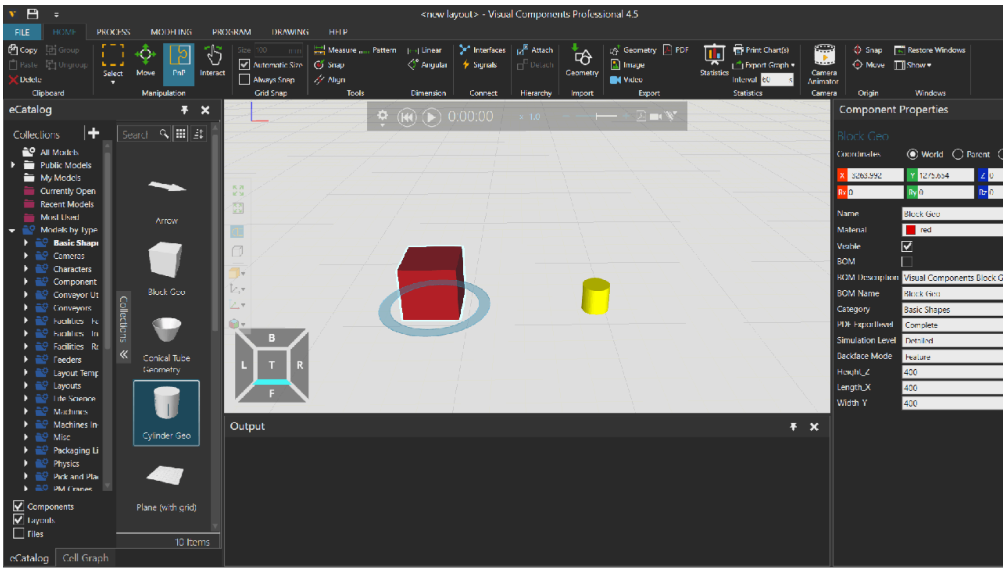

Figure 3.2: Inside view of Visual Components where a couple of objects have been created

This part of the project was relatively straightforward, meaning that there were no significant information searches regarding how to build a digital model. Only a couple of relevant built-in tools were used, and how to use these tools was learned through trial and error, see

Figure 3.3. The only part that required a significant learning session is the work regarding IronCad, mainly because it is a software with relatively a lot of functions, see Figure 3.4.

Figure 3.3: Different built-in tools in Visual Components

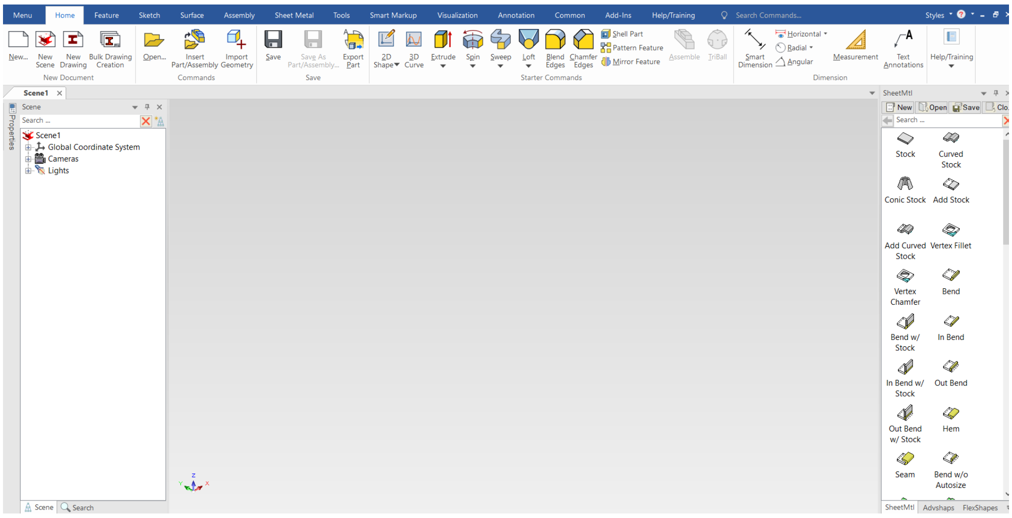

Figure 3.4: Inside view of IronCad

3.1.3.2 Creating a simulation

After the digital model of the manufacturing site was built, the goal was to establish a simulation of a manufacturing order. Through previous experience with the program, there was an understanding that the simulation aspect is relatively difficult and required more learning sessions to fully understand the functions. Therefore, the plan was to watch several online tutorials on how to use the simulation software, for instance, articles and diverse internet forums, but mainly through video tutorials. The reason is that video tutorials offer both visual and audible instructions, which are beneficial because there is an audible explanation connected with a visual representation.

3.1.4 Quuppa

Similarly with the exploration of other computer software, information, and knowledge were gathered by reading articles and watching relevant videos. However, the case company did not offer an in-depth learning session regarding this technology, meaning that there was a lot of emphasis on gathering information on an individual level. Furthermore, there was not any testing of the Quuppa system because it is not relevant to the research questions. Instead, there was only a literature review regarding the benefits the technology brings, how it can be combined with a VT, and potentially how it could be integrated. In addition, there were certain observation sessions of the case company's manufacturing site where potential obstacles and improvements were looked for, primarily infrastructural aspects.

3.1.4.1 Interviews

Significant data was collected through the qualitative method of having exploratory interviews with relevant people, in this case, an engineer from the case company that has a lot of experience working with Quuppa and its tracking system. The interview questions were created in a way that they are connected with relevant topics, for example, the benefits of tracking technology. This allowed for a more adequate structure of the collected data because answers could be divided into different groups, making it simpler to recognize similarities and patterns.

Furthermore, an interview was held with two engineers and one production manager from Volvo Cars in Torslanda. Similarly to the previously mentioned interview, these interview questions were created in the same way where they are connected to relevant topics to the manufacturing industry. These relevant topics were established by reading articles and papers, internal discussions, and external discussions with colleagues.

The interview questions are open-ended, meaning that the answers were supposed to be broad because the goal was to gather as much relevant information as possible from the interviewees. Questions that most likely would produce a yes or no answer, or anything similar to that, were not beneficial for the project. In addition, the interviewees differ from each other because one is an engineer that has significant experience with Quuppa, while the other interviewees are managers that have far less experience, or even no experience, working with tracking systems.

Therefore, the interviews have a different set of questions where the questions for the first part generate answers that yield information regarding Quuppa, while the second part generates answers regarding benefits and challenges that currently exist. The interview questions are found in Chapter 4.3.2. There were discussions regarding whether or not the interview questions are to be tested beforehand by performing a pilot interview, however, it is deemed excessive. Finally, a template for the different interviews was created to make the process more structured, and it is observed in Table 3.1.

Table 3.1: A template for the interviews

Part	Description
Introduction	Before the interview began it was necessary to explain the project and its purpose, as well as the purpose of the interview. Furthermore, it was clarified exactly how the data will be used, and other aspects were clarified as well, for instance, if it was fine to record the audio.
Getting to know the interviewee	Before the interview began, it was beneficial to talk a bit with the interviewee and learn about their role at the company, and in general, create a comfortable environment. Also, this was beneficial when coming up with follow-up questions because unexpected information may be presented.
Prepared interview- and follow up questions	This part consisted of the prepared interview questions.
Follow up questions	This part consisted of follow-up questions that were created during the interview based on information from the interviewees.
Short summary with the interviewee	This part was about closing the interview by summarizing and clarifying the information that was deemed the most important.
Summary without the interviewee	This part was a summary of the interview where the collected data is categorized.

3.2 Literature review

This chapter described how the literature review was conducted, for example, which websites and search engines were used, as well as which keywords and sentences were used to find and retrieve relevant information.

3.2.1 Data collection

A significant proportion of the data was collected by reading relevant articles and papers on the internet, more specifically, through adequate websites. The primary website was Chalmers Library, which was a website hosted by Chalmers University of Technology. This website was adequate because it centralized every article that had been published on the internet, meaning that it was possible to search and identify relevant articles for this project. However, because there was a significant number of articles connected to manufacturing, and most likely the research questions, it was necessary to use adequate keywords to identify relevant articles. Therefore, relevant keywords and sentences were used to find relevant articles, as seen in Table 3.2.

Table 3.2: Keywords and sentences used to identify relevant articles

Keywords	Sentences
“Quuppa”, “tracking”, “Quuppa tracking”, “manufacturing”	“How tracking could benefit manufacturing”, “Quuppa in manufacturing”
“Visual Component”, “Simulation”, “manufacturing”, “Discrete event simulation”	“How Visual Component can be used in manufacturing”, “Simulation and manufacturing”
“IronCad”, “IronCad simulation”, “manufacturing”	“Benefits with IronCad”, “IronCad compatible with other software”
“3D Scanning”, “NavVis”, “manufacturing”	“How 3D scanning benefits manufacturing”, “NavVis and manufacturing”
“Real-Time Locating Systems”, “RTLS”, “manufacturing”	“Real-Time Locating Systems in manufacturing”, “RTLS in manufacturing”
“Virtual Twin”, “Digital Twin”, “Virtual Twin simulation”, “Digital Twin simulation”, “manufacturing”	“Creating a Virtual Twin”, “Creating a Digital Twin”, “Virtual Twin simulation in manufacturing”

“Conduct interview”, “interview questions”	“How to create interview questions”, “How to create interview questions for a qualitative study”

Although several keywords and sentences were presented in Table 3.2, other keywords and sentences were likely used that were not documented in Table 3.2. Mainly, keywords and sentences did not differ relatively much because certain synonyms could be used. In addition, other search engines could be used instead of Chalmers Library, primarily Google’s search engine because it yielded a significant supply of articles and information. Finally, the methods described in this chapter are applied to chapter 3.1. The purpose was to combine the methods described in that chapter with the methods in this chapter to generate as much data with high quality as possible. This was possible by combining internal workshops with knowledgeable engineers with a detailed literature review.

3.3 Data compilation

After data was collected through literature reviews, internal workshops, and interviews, it was necessary to compile the data and ensure that only relevant data was used. This was performed by continuously going through the data and categorizing it into adequate categories. The categories were designed to be relevant to the two research questions, for instance, data regarding RTLS, or data regarding the difficulties of installing a RTLS. This ensured that relevant information was selected but also helped eliminate excessive or irrelevant information, making the presentation of the findings structured and adequate. The different categories to which data was sorted were presented in Table 3.3.

Table 3.3: Description of different categories and which research question they are related to

Category	Research Question (RQ1/RQ2)	Description
NavVis 3D Scanning	RQ1	Data regarding NavVis 3D scanning hardware and software
IronCad	RQ1	Data regarding IronCad and compatibility with other software, as well as benefits

Visual Components & Simulation	RQ1	Data regarding Visual Components and its simulation software, and how it can aid visual planning
VT & DT	RQ1 & RQ2	Data regarding VTs and DTs and which values they bring to manufacturing
RTLS, Quuppa	RQ2	Data regarding RTLS and Quuppa, which is primarily gathered from the interviews and literature study

3.4 Research Approach

This project had several approaches regarding the research, and in-depth, five different dimensions were applied. Some of these dimensions were relatively straightforward, meaning that they were well connected with the approach, aim, and research questions of the project. However, some of the dimensions were a bit more difficult to connect, meaning that they required more explanation and evaluation. The different research dimensions and their respective research approaches could be viewed in Figure 3.5.

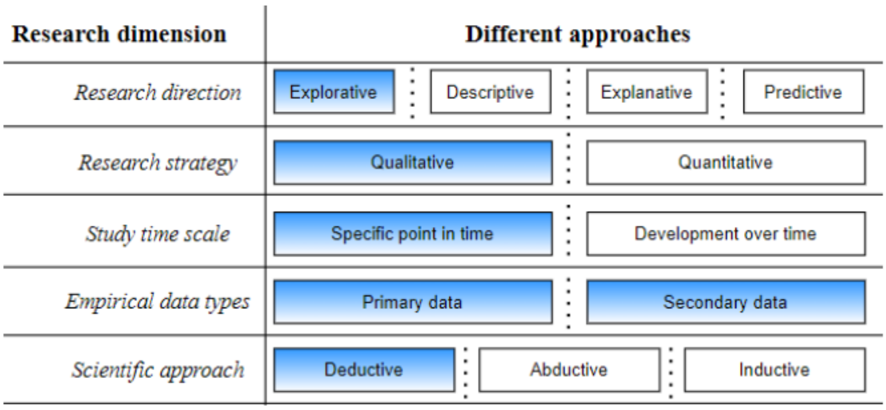

Figure 3.5: A summary of the different research approaches and dimensions

3.4.1 Dimensions

The first research dimension was regarding the direction of the project, and the chosen approach was explorative because it was well connected with the purpose and the research questions for the project. The goal of that paper was to investigate how value could be added to a VT, as well as how simulation and digital tools could aid visual planning in production [33]. It required a form of exploration where different digital tools were tested and applied, and research papers, articles, and previous work were reviewed. Therefore, the approach was explorative rather than descriptive, explanative, or predictive. Furthermore, this type of research went well together with a project that did not have a clear definition of its problem, meaning that there were unknown elements that required exploration [33].

The second research dimension was regarding the strategy for the project, and in this case, a qualitative approach described the project adequately. A qualitative approach was chosen ahead of a quantitative approach because the project did not require a significant collection of data, meaning that there was a lack of quantitative data collection. Qualitative data was collected in various forms, for instance, through literature reviews, profound interviews with relevant people, and workshops with knowledgeable engineers [33].

The third research dimension was about the schedule for the project, and this part was more connected with the first research question regarding how RTLS could add value to a VT [34]. The reason was that there was a form of examination of the current state of the case company, to go along with a qualitative collection of data. The time for development was relatively limited because the duration was set to be around 20 weeks, meaning that there was not a lot of time to dedicate to development. Therefore, the approach for this project was the collection of data at specific points in time rather than there being development over time [34].

The fourth research dimension was regarding the data types, meaning which types of data were to be collected. In this case, both research approaches were relevant for this project because there were multiple ways in which data was to be collected for this project. Information that was collected through interviews was described as primary data, and information that was gathered through literature reviews, workshops, and reading articles was described as secondary data. Both these methods for collecting data were applied in this project; therefore, both approaches were chosen [33], [34].

The final dimension was regarding the scientific approach for the project, and in this case, a deductive approach was selected. A deductive approach entailed that existing research was reviewed to summarize relevant observations and find new information. This applied adequately to the two different research questions because the goal was not to create a new theory; instead, the goal was to explore existing research and connect it with the research questions [33].

3.5 Research layout

The research layout for the project was relatively simple in the sense that it mostly consisted of different ways of collecting data. The data collection for RQ1 consisted of workshops, testing aspects through trial and error, and searching for relevant information on the internet, and the data collection for RQ2 consisted of a literature review and interviews [33]. To ensure that the information was relevant, there were checkups and reviews on the gathered information to ensure that there was no irrelevant information. The number of checkups and reviews, as well as how often they occurred, were not planned, but instead, they were decided through internal discussions. The purpose was to ensure that the project, research questions, and data were correctly aligned with each other [33].

3.6 Research quality

The goal of that project was to explore research questions with potentially beneficial solutions and answers, meaning that it was necessary to conduct a project that was of adequate quality. Therefore, three different aspects were to be considered, which were the following: reliability, replicability and validity, and ethics. Ethics was an important aspect because several interviews were conducted, meaning that it was necessary to tread correctly and be honest and respectful with other people [33].

3.6.1 Reliability

Reliability was an important aspect when researching because adequate reliability ensured that the research was reliable, but also that it could be performed again and yield similar, or the same results. It was possible to divide this category into two sub-categories, which were the following: external reliability and internal reliability. The first one was regarding the fact that the research could be done by a different individual and yield the same results. Internal reliability was a term that was connected with how the representatives in a group interpreted the research and its results, as well as if they deemed the research to be reliable [35].

3.6.2 Replicability and validity

The term replicability was defined as how adequately someone, or a group of individuals, could replicate the research. This entailed the importance of carefully and detailedly describing and documenting the project and its steps, for example, how the interview questions were established, or which websites were used to identify relevant literature [35].

The term validity was described as the integrity and quality of the opinions and conclusions that had been made. Similarly to the term reliability, this category could be divided into two sub-categories, which were external validity and internal validity. External validity was a form of review of the result and if it could potentially be applied in other studies, and internal validity was what the confidence level was regarding if the project had been affected by extraneous variables [35].

3.6.3 Ethics

Ethics was an important aspect of this type of research because several interviews were to be conducted, meaning that the privacy of multiple people needed to be cared for. This aspect could be divided into four sub-categories, which were the following: informing and receiving consent, showcasing respect towards a person's privacy, guaranteeing that no harm would be done, and ensuring that no deception would occur [35]. The engineers and managers who were interviewed were informed in advance that their identities would be kept private, ensuring no harm to their privacy. This commitment would remain unchanged under any circumstances, signifying that no deception was done towards the interviewees.

Furthermore, the interviewees were informed beforehand about the goal of the project, allowing them to learn and understand its objectives. After learning about the project, all intended interviewees willingly accepted to participate, indicating that they likely had no fear of being harmed or deceived. Moreover, the interview questions were designed in a way that avoided putting the interviewees in awkward situations, ensuring they did not have to answer irrelevant questions or ones that could jeopardize their loyalty and position at their workplace. Apart from that, the objective was, to be honest with the interviewees and refrain from attempting to deceive or trick them in any way.

4. Results

This chapter showcases the compiled data that has been collected from the interviews, the literature review, and the internal workshops. The purpose of the result is to present a summary of the findings, which can be used to answer and discuss the research questions.

4.1 RQ1: Simulation and visual planning

In this section, the results from the exploration and the use of the softwares will be presented to answer the first RQ: *How could a simulation benefit the visual planning of a manufacturing order at Virtual Manufacturing?*

4.1.1 NavVis 3D scanning

How to use the hardware and the software regarding NavVis 3D scanning was learned through a workshop with an engineer. The hardware used was the NavVis M6 Scanner, which consists of several parts that are put together, see Figure 4.1. When the hardware is completely put together, the user can then slowly walk around a designated area and the hardware will scan the surroundings using its sensors. A small area was scanned several times during the workshop to learn how to navigate with the hardware, and how to manage the software.

Figure 4.1: NavVis M6 Scanner

After testing and learning how to use the machine, it was transported to the case company's manufacturing site where a complete 3D scan was completed. The 3D scan was then converted into a VT, which had the correct dimensions of the manufacturing site, see Figure 4.2. The VT is accessible through the internet, however, it requires an account to be created on the NavVis website, meaning that only relevant users can observe it. After the VT was created, it was applied to digitally build the manufacturing site.

Figure 4.2: Inside view of the Virtual Twin and the manufacturing site

4.1.2 IronCad

IronCad was applied to create digital representations of real-life objects, however, it was not applied to create every single object at the manufacturing site. The reason is that a lot of the physical objects had already been created before the project started, meaning that it was not necessary to create duplicates. Instead, 15 different digital objects were created using IronCad, which were then marked and documented in an Excel file for other workers at the case company to use if needed, see Figure 4.3. The information that was documented were aspects such as the dimensions, or where the files are located. In addition, internet links from the VT were added to give a visual representation of exactly which digital version has been created.

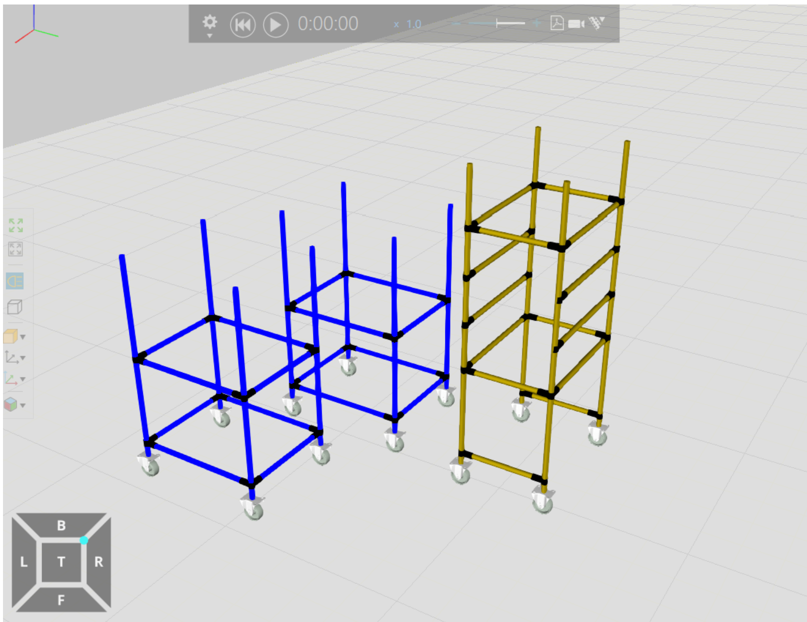

Figure 4.3: Three wagons that have been created using IronCad

4.1.3 Visual Components

This is the primary software that was applied to collect data regarding this research question and examine how it can be connected with visual planning aspects, for instance, a manufacturing order.

4.1.3.1 Creating a layout

The dimensions of the manufacturing site were provided by an engineer from the case company, as well as a simple 2D overview of the site, see Figure 4.4. This information was used together with information from the VT to create the building in Visual Components. After everything was mapped out, the digital files that were created in IronCad were imported into Visual Components and placed in locations that correctly matched the VT. The same thing applied to the files that had been created by other engineers, and everything resulted in a layout that resembled the manufacturing site. This was done relatively fast because the two programs are extremely compatible, and Visual Components is based on a drag-and-drop function, making the process simple.

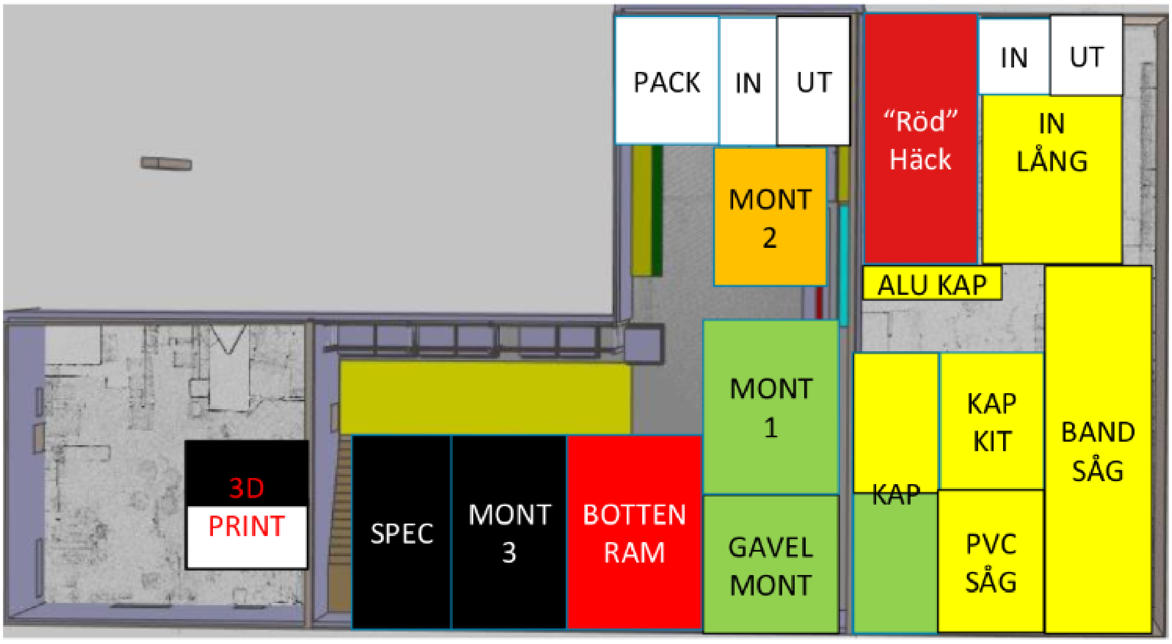

Figure 4.4: Layout of the production site

Furthermore, certain real-life objects were created in Visual Components because the software offers tools that are similar to IronCad, making it simple to design certain items. The user can create and customize the dimensions of standard blocks, meaning that it is possible to create approximate versions of real-life objects from the manufacturing site, see Figure 4.5. In addition, Visual Components offers a multitude of built-in digital representations of real-life objects, for instance, tables, screws, and shelves, which resulted in those items being used to create the layout, see Figure 4.6.

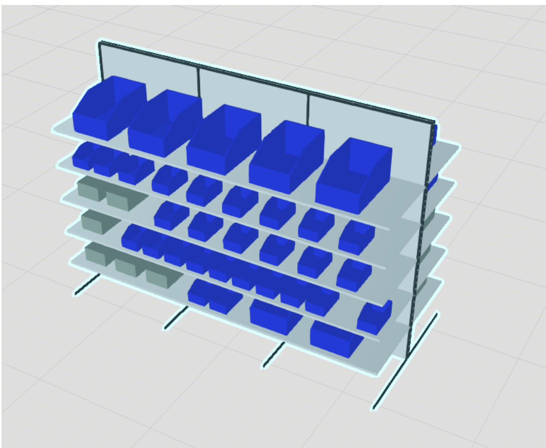

Figure 4.5: A shelf that has been built using Visual Components built-in tools

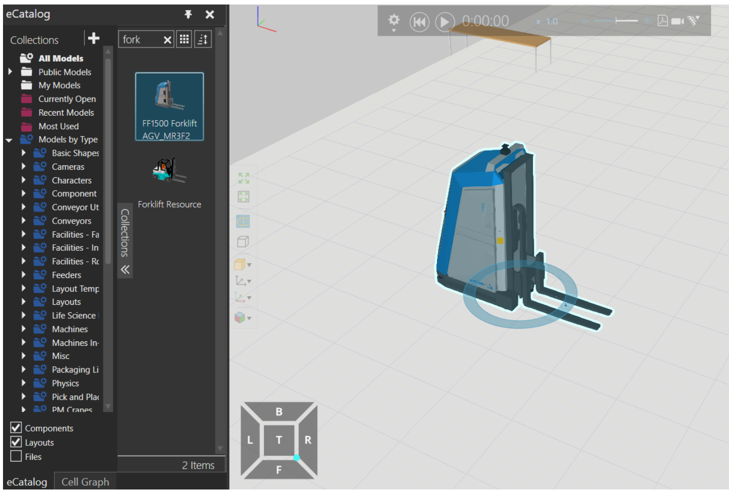

Figure 4.6: A forklift was imported into the model using Visual Component's catalog

The result from this work was an identical digital version of the production site in Visual Components that was labeled "As-Is", see Figures 4.7 and 4.8. The purpose is to showcase what the factory currently looks like, and if future changes are to be made in the factory, then they can be tested in the As-Is-model.

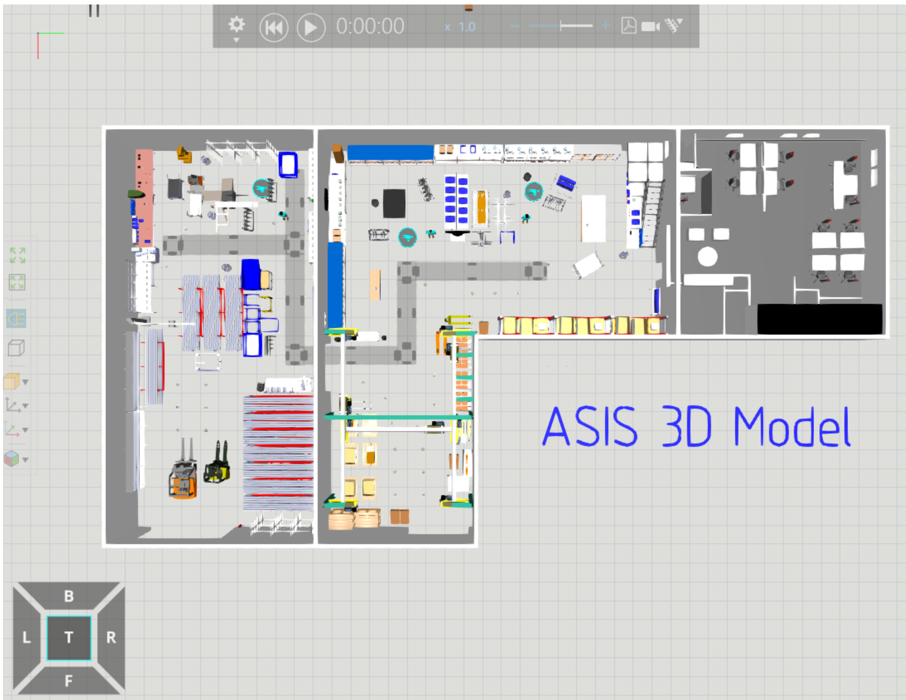

Figure 4.7: An overview of the model

Figure 4.8: Inside view of the As-Is-model

As previously mentioned, certain objects were digitally made by other engineers, but also some objects were found by performing searches on the internet, and those were objects like forklifts, tool boards, and industrial machines, see Figure 4.9.

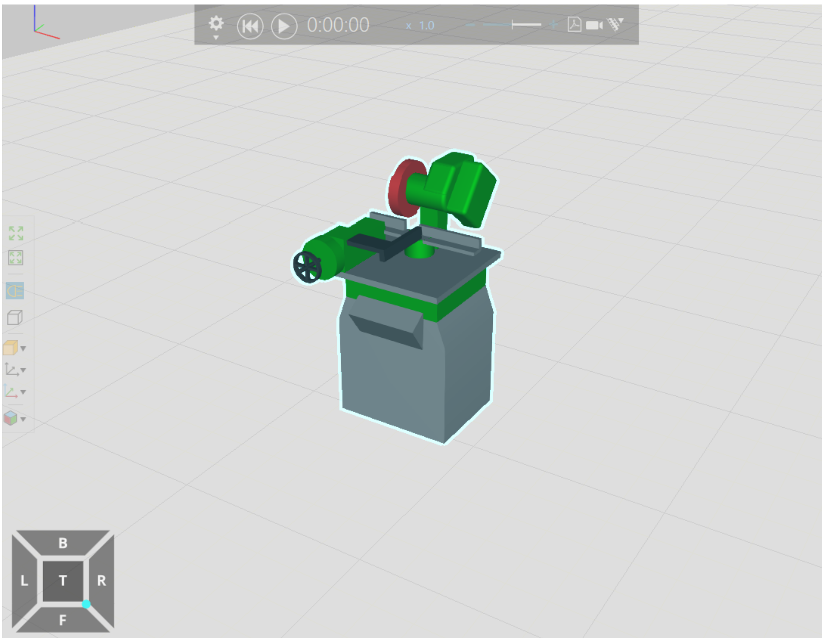

Figure 4.9: An imported industrial machine that has been made by another engineer

4.1.3.2 Simulating a production

The first part regarding the simulation was to follow identified tutorials regarding how to perform simulations in Visual Components. The data that were identified were video tutorials that showcased the fundamentals of how to create a simulation in Visual Components, and the providers for these tutorials were Visual Components through their YouTube channel. The initial simulations were performed in a new file because the digital copy of the production site was not ideal when it came to testing and trying simulations, see Figure 4.10.

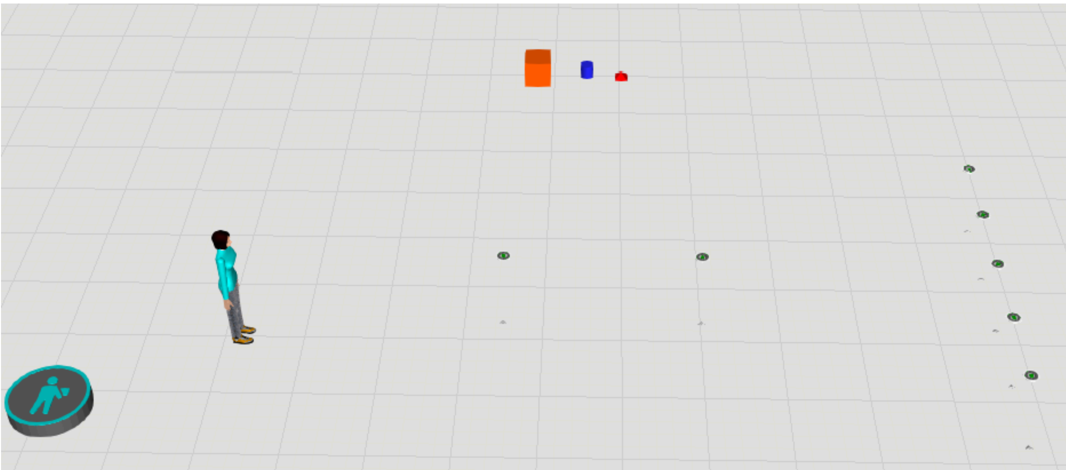

Figure 4.10: A new model made to learn how to perform a simulation

Simple commands and instructions were simulated in this file, for instance, making a human transport a block from one point to another. Certain commands were applied that made the human work, which represented a form of the assembly session, and it was moving parts between several workstations, see Figure 4.11. Furthermore, it was important to find a way for the human to follow a designated path because it was not ideal to have a human that walks through objects. There are two solutions, one being creating a designated path, and the second one being creating a command that stops the human from walking through objects. However, this command does not work when dealing with relatively large models for some unknown reason, and using it results in the program shutting down.

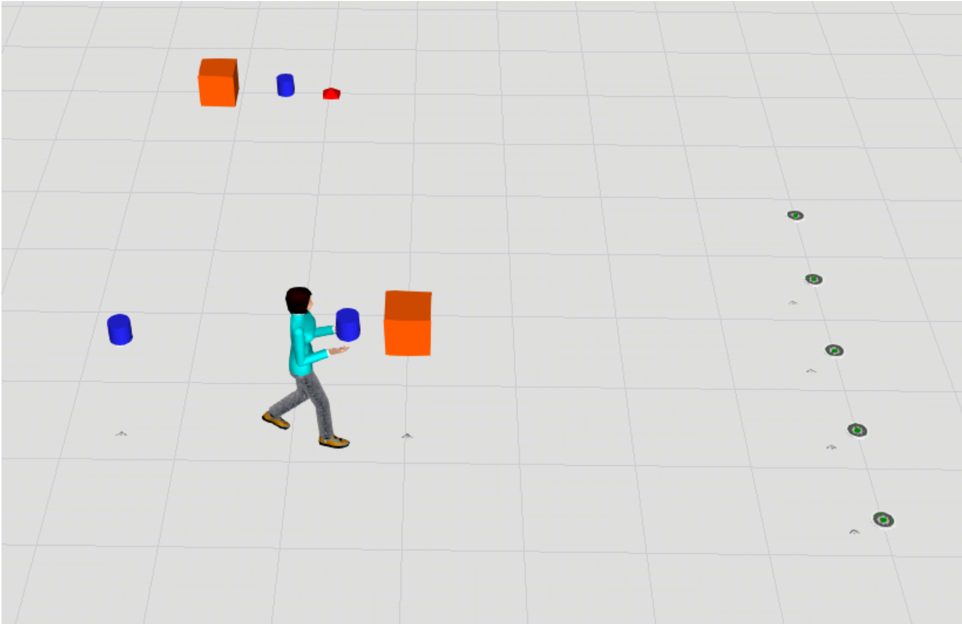

Figure 4.11: A worker moving parts between different stations

Pathways were established, certain ones longer than necessary to see if the human would follow them, and it worked. The result was that the human did not go through objects, but instead followed a designated path, see Figure 4.12. Furthermore, after the pathways were created, it was necessary to explore the assembly tool that exists within the software, mainly because it allows for adequate visualization of an object being created. Different assemblies were created by combining different parts in the software, however, they did not look like a real-life product being assembled, but instead were cubes and cylinders being placed on each other, see Figures 4.13 and 4.14. The reason is that this part was still a learning session, meaning that details were not necessary here

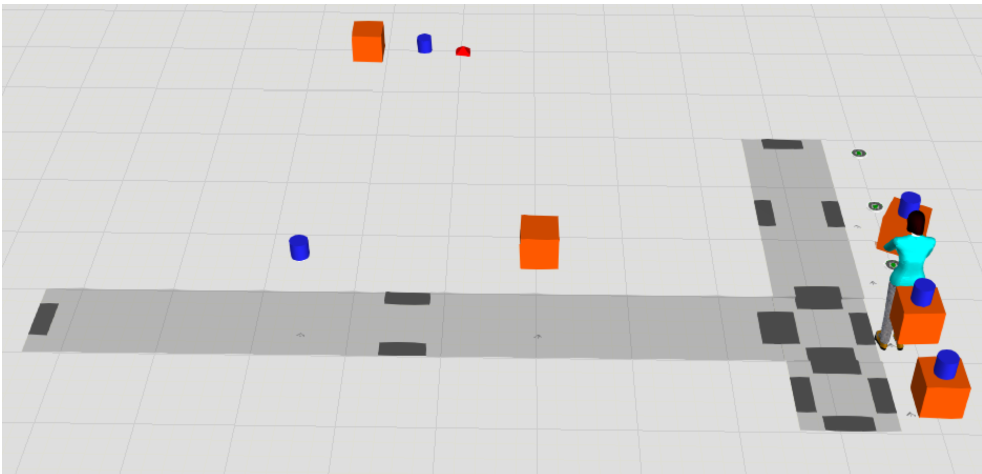

Figure 4.12: A worker is following a standardized path

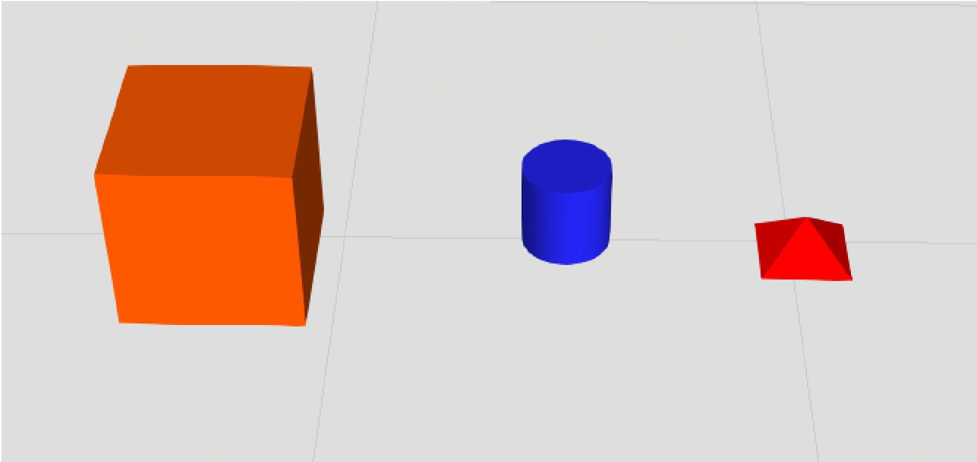

Figure 4.13: Basic shapes that were used during the learning process

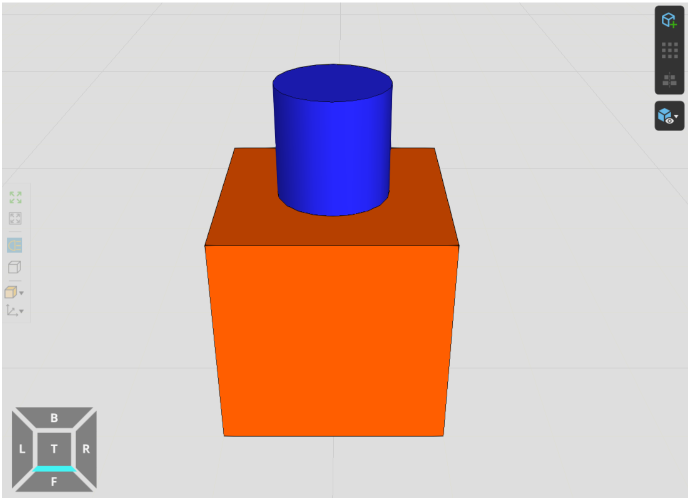

Figure 4.14: An assembly of the different basic shapes

After a lot of testing and creating different files with different simulations, it was time to transfer these methods into the digital version of the production site. However, before creating the official simulation, it was necessary to examine a real-life manufacturing order from one of the case company's customers to ensure that everything was being followed correctly. Here the decision was made to simulate the creation of a product that required multiple human workers, resulting in further testing being made in other files regarding how to perform a simulation that involves multiple workers. The method for having multiple workers did not differ from that of having one worker because it only required adding a worker and giving that worker instructions.

4.1.3.2 Simulating Virtual Manufacturing's production

As previously mentioned, the real-life manufacturing order consisted of multiple workers working alongside each other to create a product, and in this case, 66 products are to be created in a different number of batches. The first step was to simulate work for one worker, and the chosen worker is the one that comes in the earliest, and that person is tasked with cutting and preparing material for workers that come in later. The working instructions for this worker are observed in Table 4.1.

Table 4.1: Tasks and workings instruction for the first worker

Task	Working Instruction
1	Transport material from point A to B
2	Perform work at point B for X amount of minutes
3	Transport material from point B to point C (wagon)
4	Transport wagon from point C to point D
5	Perform work at point F
6	Transport material from point F to point G
7	Transport wagon from point G to point D

The second worker is tasked with assembling the different pipes using tools and fasteners, such as screws and nails. After the second worker has performed the first set of work, the first worker arrives with new material that is used to complete the assembly. Finally, the material is assembled and one product is created, which can then be placed in a designated area. The process is then repeated where new products are created and placed in different locations, depending on where they are instructed to be placed. The working instructions for the second worker can be observed in Table 4.2.

Table 4.2: Tasks and workings instruction for the second worker

Task	Working Instruction
1	Transport material from point D to point E
2	Perform work at point E for X amount of minutes
3	Transport material from point D to point E
4	Perform work at point E for X amount of minutes
5	Transport completed product to designated area (position varies)

Although the simulation was running well, there were issues in the form of humans walking through objects, meaning that it was necessary to implement pathways. Pathways were simply put in the correct places, and then they were connected, resulting in the human workers following the designated path and not walking through objects. In addition, it is important to note that this simulation differs from the simulations performed in other files because regular blocks are not used, but instead, digital objects that represent real-life objects at the manufacturing site, for instance, wagons, see Figure 4.3. Also, the product that is to be created in real-life is used instead of regular shapes like blocks and cones, see Figure 4.15.

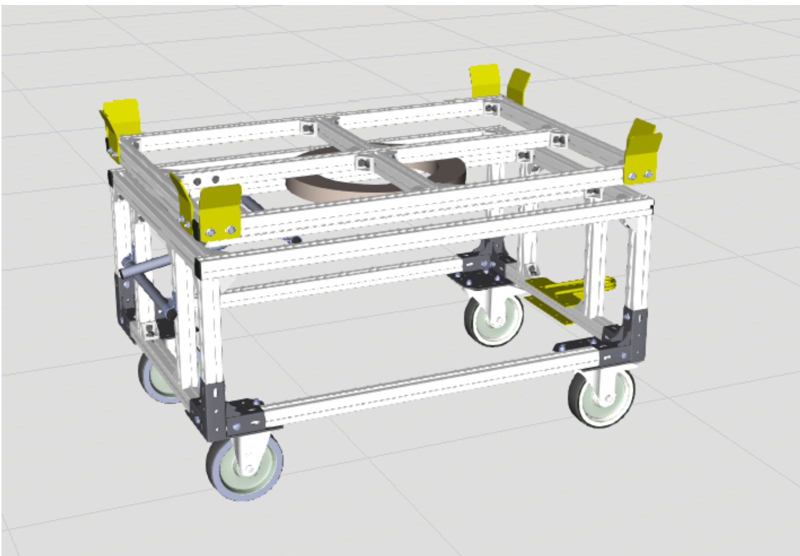

Figure 4.15: The product that is to be produced 66 times

The result after running the simulation multiple times was that the manufacturing site had a limited space where around 40 products could be created before transport was required. The method of stacking the products on top of each other was implemented in the simulation, as well as in real life because they had a shape that allowed for simple stacking. After the preliminary maximum number of products is created, they are to be transported to the customer with the help of a truck.

4.1.3.3 Template for simulation

Because the simulation aspect was relatively difficult to learn, as well as describing using words and a couple of figures, the decision was made to create a form of a template. The template showcases how a simulation of a simple production line can be created, meaning that simple objects like blocks and cylinders are used to represent objects in industry, objects such as industrial wagons, pipes, products, and tools. The template is relatively long, meaning that it is not ideal to have the whole template as an appendix. Instead, it has been uploaded on the file hosting website MediaFire where the template can be downloaded as a PDF-file. The link is found in Appendix A.

4.2 RQ2: Adding value with RTLS

In this section, the results from the literature study and interviews will be presented to answer the second RQ: *How can RTLS be used together with a VT to create more value for the user?*

4.2.1 Literature review

To answer RQ2, literature within RTLS needed to be collected. This literature highlights important parts of RTLS such as its benefits, challenges, future developments, and existing RTLS software from different companies. In addition, this section also highlights VT and its current benefits and opportunities

4.2.1.1 Benefits of RTLS in the manufacturing industry

Fabio Belloni is the co-founder of Quuppa, which is the technology Virtual Manufacturing uses with their RTLS software Gazpacho, and this person mentions that RTLS can significantly improve production efficiency. The reason is that real-time data can be processed efficiently, combined with accurate locations of equipment, tools, vehicles, and personnel being provided [36]. It is further mentioned that three different advantages of

RTLS enable increased efficiency in manufacturing. One advantage is that an RTLS can track components and tools, eliminating waste of time. One study mentions that a company can reduce the number of steps required by 20 percent by implementing an RTLS in production [37]. This is by simplifying the search for objects that are used and moved frequently, for example, pallets in a manufacturing facility.

Another major benefit of RTLS and its device tracking is that asset management is improved [38]. This is by being able to track the location and movements of the assets in the entire supply chain in real-time, thus allowing analyzing potential economic gains from the improved asset use. The management and control of assets in a warehouse can also be improved with the help of an RTLS, as the system provides the ability to achieve and maintain the inventory automatically with 99.9 percent accuracy without having to perform unnecessary inventory checks that can take hours or sometimes days [37].

In addition, RTLS can improve safety in manufacturing by being able to closely monitor the location of personnel and thereby improve the management of emergency preparedness and evacuation procedures [38]. Security within the manufacturing zone is also enhanced as an RTLS can help prevent unauthorized access to restricted areas by providing real-time alerts and notifications when individuals enter restricted zones [38]. The safety of personnel is a high priority in many manufacturing industries and in this way, RTLS also becomes significant in security for companies [39]. However, not only increased safety is a positive consequence of personnel tracking, but also productivity in manufacturing can increase as data from personnel work methods can be analyzed and thus improved [37].

Finally, RTLS can also be used to optimize manufacturing and automation processes. This is by identifying bottlenecks, optimizing workflows, and streamlining operations using real-time location data [40]. Constantly knowing the real-time location data of people and assets, optimizations can be performed on factory layouts and workflows to bring out maximum efficiency in manufacturing [41]. In addition, it is possible to integrate this type of system with other enterprise networks, for instance, with an ERP, resulting in an extensive view of a production process [41].

4.2.1.2 Different RTLS softwares

This section summarizes a literature survey conducted to analyze existing RTLS software and its benefits. Three different RTLS software were investigated and these were Gazpacho, Sewio Networks, and INTRANAV [25], [42], [43]. Below, similarities discovered in all three companies are documented.

There were many different features that these three RTLS software could offer. One of the features enables a real-time visualization tool that gives the customer the ability to review all processors housed in the building. This feature also allows the customer to add buildings to their plans and auto-distribute the anchors, which gives the customer a quick and valuable insight into the process [25], [42], [43].

Another valuable feature that these three RTLS software offers is an application that gathers location data for various objects, which can then be converted into various visual analyses. Such an analysis can, for example, measure how much time is spent in a certain zone. Another analysis also gives the customer the ability to optimize overall fleet effectiveness (OEE) by uncovering idle periods and fixing them. This feature also provides access to heat maps that will help the customer get a clearer picture of production traffic to analyze the cause of delays. Another analysis worth mentioning is the Spaghetti Chart which gives the customer the ability to explore, both in real-time and as a historical replay, the continuous flow to hopefully identify bottlenecks [25], [42], [43].

4.2.1.3 Challenges, conditions, and future developments

Just like any other technology, RTLS technology also has challenges that require certain conditions to be met to have a successful implementation of an RTLS in an organization. One condition, as mentioned in the previous section, is the integration between RTLS and software. For an RTLS to be profitable, it should be able to be integrated with existing systems and technologies within the organization such as the ERP system or other relevant software, such as Gazpacho, for data sharing and process optimization [44]. Companies that use RTLS have these issues when the supplier provides hardware that can only be integrated with their software, meaning that the software and hardwares that the company uses are relatively restricted [45].

Another worthwhile condition, that an installation of RTLS requires, is a good infrastructure. An RTLS program requires the establishment of a suitable infrastructure which means that the deployment of beacons, readers, or sensors throughout the facility must be strategically placed to enable good tracking [44]. An RTLS can lose effectiveness if the IT infrastructure does not have the signal access that an RTLS requires and therefore it is important to ensure that power or ethernet cables are available and properly installed for all RTLS beacons deployed in the facility [45].

Furthermore, there are also future developments within RTLS. A development that is assumed to be very powerful and that can play a big role in future manufacturing industries is the integration between RTLS and DT, that can utilize real-time location data and enable faster and more accurate decision-making predictive analysis [46]. With DT, which creates virtual replicas of physical objects and systems, combined with RTLS, which provides access to real-time location data, organizations can gain good control over their operations. However, this integration requires established edge computing as well as sophisticated AI technology, which can analyze large amounts of data and make predictions about future behavior in the manufacturing industry [46].

Furthermore, handling such a large amount of data means that the Wi-Fi or Bluetooth connection to RTLS will not be sufficient in the future due to capacity, latency and interference [47]. Therefore, the use of 5G should also be installed at an RTLS to develop the data transfer capability and provide a better RTLS accuracy, which many claim is a challenge in the current state of RTLS technology according to a survey [47].

4.2.1.4 Current benefits and opportunities with a Virtual Twin

NavVis' VT offers several benefits and opportunities for their customers, mainly the fact that the customer can have a virtual model of their manufacturing site, or any other site because the service is not only for manufacturing companies. The VT itself offers multiple built-in functions, for instance, the options to digitally measure and label areas, meaning that other users can retrieve stored data, see Figure 4.2. In addition, it results in reduced travel for high-cost employees because they do not have to physically appear at one site, but can instead view it remotely [48].

Furthermore, NavVis' VT could support the planning of changes, meaning that the existing VT can be observed to identify potential improvements. For example, observing where a new, or existing, machine can be placed, thus, ensuring an efficient relocation of objects. This results in certain planning mistakes being eliminated because a lot of aspects can be documented and reviewed [48]. A potential beneficial opportunity for expansion could be that the documented data from the VT can then be tested in different software, for instance, in Visual Components where different layouts are tested [18].

4.2.1.5 RTLS outside the manufacturing industry

RTLS is not only an interesting and beneficial technology for the manufacturing industry, but also it is beneficial for other organizations, for instance, the healthcare, or the military. Regarding healthcare, RTLS and the Internet of Medical Things (IoMT) are applied to improve the efficiency of hospitals, mainly IoMT. The reason for this is that RTLS is relatively new in healthcare, and IoMT has been applied for a relatively long time where internet-based medical technology, hardware, and software are connected. IoMT has always been used to store and use relevant data, but the goal of implementing RTLS is to be able to efficiently track workers, patients, and objects, which is data that can then be potentially studied [49].

More in-depth, hospitals often experience equipment being lost or misplaced, and some of this equipment are high-value items, meaning that a relatively large part of the budget would be used to replace these items. Texas Health Presbyterian Dallas Hospital (TH) has implemented RTLS where high-value items are being tracked, and it has resulted in an annual saving of $288,477 because there is no need to purchase or rent high-value items [50]. Furthermore, the technology was beneficial because it helped the workers immediately identify patients that were regularly moving around, but also patients that were going through different locations for different treatments. In addition, it helped keep track of where workers were located at all times, especially during times when TH was dealing with a shortage in personnel, thus, resulting in time being saved [50].

Regarding the military aspect, RTLS has been implemented in the U.S. military to constantly keep track of vehicles and equipment. It is estimated that this has reduced wasted personnel hours by 87% because the need to physically search for a vehicle has been eliminated. It is estimated that around 23,000 vehicles were tagged and tracked through a system, allowing for instant identification of their location [51]. There was some criticism towards this system because it was deemed a bit expensive, and potentially confusing because there are a lot of physical objects being tracked, however, it is not feasible for personnel to memorize the locations of multiple standardized vehicles that both look the same and constantly move around. Instead, they are marked and tracked, resulting in there always being knowledge about where they are located, and if they are being used by someone [51].

4.3.2 Interviews

As previously mentioned, the interviews were divided into two parts where one interview was with an engineer with significant knowledge regarding RTLS, and the second part consists of multiple interviews with engineers and managers at Volvo Cars. In addition, the interviews were designed to gather data regarding RQ2, meaning that RQ1 was not that relevant for this section.

Furthermore, chapter 4.3.3.2 presents three different interviews that were done with two engineers and one production manager. The three interviewees gave similar answers to some questions, meaning that certain answers will not be presented in this chapter because they are deemed excessive. Instead, the results from the three interviews are put together and can be described as one interview consisting of only answers that differ from each other.

Finally, the results are not direct quotes from the interviewees, but instead, they are paraphrases from the four interviews. The reason is that the interviews did not produce answers that were adequate for the written language, making it simpler to paraphrase the answers and make them as clear as possible. It is important to note that the answers were not fundamentally altered, but instead, they were documented in the way they were interpreted.

4.3.2.1 Interview from Virtual Manufacturing

How does Quuppa work, and which benefits can be seen in industries by implementing this technology?

Quuppa is a technology that is heavily dependent on the infrastructure of the area where it is to be installed, making it relatively demanding in comparison with other technology. The technology requires locators to be installed on the ceiling where they can receive BLE signals from small tracking tags, which are placed on objects that are to be tracked. In addition, the technology requires ethernet cables that are connected to a mainframe, and this can create an economic issue if a significant length of ethernet cables is required.

Normally, technology that deals with Bluetooth is not relatively accurate because the dimensions are usually off by a meter or two, however, Quuppa differs from other technology and gives a far more accurate position. The reason is that it triangulates the signal, resulting in improved precision where it may be off by one or two decimeters, which is far better than being off by one or two meters. In summary, it allows for precise tracking of material and equipment, which can be used in different areas, for instance, keeping track of items, or analyzing movement patterns.

At Virtual Manufacturing, Quuppa is integrated with a RTLS system called Gazpacho. What are the benefits with this software?

Quuppa is a technology that can be integrated with a lot of different RTLS systems, and Virtual Manufacturing has chosen Gazpacho because it aligns well with existing working methods and knowledge at the company. In addition, it is not possible to combine Quuppa with NavVis's software because they are not compatible with each other. Instead, data can be exported from NavVis, which could then potentially be imported into other software. Gazpacho works in a way where tracking data is imported into the software, and then a 2D map is projected with the location of the different objects that are being tracked.

There are several benefits with this form of RTLS, for instance, tracking becoming a form of GPS that can guide workers inside. Furthermore, it can also help create different zones, which can be used to trigger certain commands, for instance, if arrived material is supposed to be at that designated area, then a signal is sent that confirms that the process is going well. Another benefit is that movement patterns can be analyzed where deviations and unnecessary movements can be identified, for instance, if an AGV is not following a standardized path.

Do you believe that RTLS can benefit other types of industries, or is it only beneficial for industries similar to that of Virtual Manufacturing?

RTLS benefits several industries, not only smaller manufacturing sites like that of Virtual Manufacturing. RTLS heavily benefits larger industries because there are a lot of things happening at once, mainly a lot of material being transported around on the shop floor and to different production lines. Because there is a lot of material and equipment being transported, it is beneficial to always know where important things are located.

Furthermore, RTLS would heavily benefit industries where large products are being manufactured, for instance, products like airplanes. The reason is that in these cases, the tools and equipment are moved to the workpiece, meaning that there can be a lot of confusion and many objects to keep track of, making an RTLS highly beneficial. In addition, RTLS would benefit logistics companies that have many resources, for instance, a warehouse company, or a postal company.

How significant is RTLS for Industry 4.0, and what does the future hold for this technology? Can the technology be further expanded?

RTLS is a relatively new technology in the sense that not many industries have adapted it, or begun researching on how to adapt it. However, the future looks relatively interesting and bright for this technology, mainly because the current issues are going to be relatively eliminated. The current issues are that different systems are not compatible with each other, meaning that a lot of technical issues arrive when trying to apply different software, or working with a new partner or customer.

It is not feasible that companies are developing this type of technology that is not compatible with each other. Instead, the future of this technology is heading towards a higher degree of compatibility between different software and hardware, making partnerships and work more efficient. There is not one specific system, or technology, that is going to solve existing issues, but instead, there is a need to work together to solve existing issues and bring significant benefits.

How does your customer use the VT, and what are the benefits? Do the customers appreciate this service? What developments are possible with the current VT?

The customers that purchase the service of having a VT of their manufacturing site appreciate the technology. They like the fact that they can showcase their manufacturing site remotely and that the navigation system is simple but extremely effective. Right now it is believed that they are underestimating NavVis' VT and the possibilities with it, mainly that they are not taking full advantage of the existing options within the software. The VT offers a lot of functionality, for instance, being able to export a selected part of the model, however, the customer does not fully know how to do this. Therefore, it could be beneficial to teach them how this is done and what the data can be used for.

Further developments for the VT would be to explore how compatible the software and its data are with other software and potentially hardware. As mentioned, it is possible to export data from the VT, for instance, a selected part of the model, which can then potentially be used in other fields. Right now, that is the primary aspect that can be explored regarding the VT, mainly because the VT itself is not compatible with other software, but instead, it is the existing data that could be compatible with other programs.

4.3.2.2 Interviews from Volvo Cars

How do you keep track of all the materials, products, and equipment in your factory? Is it common that things disappear, or that it takes relatively long to find something?

There is a lot of different material and equipment that is being used in the factory, and the most important palace to keep track of things is in the logistics and storage area. The reason for this is that the manufacturing process is an assembly line, meaning that it is simple to keep track of materials, products, and equipment. The assemblers do not utilize a significant number of tools, and they are constantly carrying the tools, meaning that it is simple for them to keep track of their equipment. Also, the equipment is constantly being used by the workers because it is an assembly line, making it even more difficult to lose a tool. However, sometimes equipment and material are lost, therefore, precautions have been implemented in the form of having spare materials and tools.

Regarding the logistics and storage areas in the factory, materials, and equipment are documented and labeled, and certain software is applied to store this data and keep track of the number of items. But there is no form of tracking system as of right now, meaning that if something is lost, it has to be found. If it is not possible to find missing objects, then some spare materials and tools can be used, and in the worst case scenery orders are placed and new things arrive. Standardized methods are applied to minimize the number of items being lost, for instance, certain Lean methodologies where unnecessary objects are removed, workstations are cleaned and taken care of, and placing tools, equipment, and material in the correct place.

What do you believe would be the benefits of introducing a form of tracking system (RTLS) where material, tools, equipment, etc. can be tracked? What parts of the factory would an RTLS be the most beneficial?

There would be several benefits from introducing an RTLS, mainly in the form of being able to keep track of physical objects through some sort of software. This would eliminate the time it would take to locate missing objects, meaning that there would be a higher level of control in the factory and on the shop floor. It would probably most benefit the logistics and storage areas in the factory because it is where all the different materials are located, as well as them not being part of a flow.

The products that are being manufactured are automobiles on a production line, which are almost impossible to lose track of because it is a relatively large product that is almost constantly on an assembly line. However, materials that are being stored, or prepared for transport, could be lost, making it beneficial to have a relatively precise tracking system.

Other benefits would be in the form of data being gathered through a tracking system, which could bring several benefits if that relevant data is studied correctly. For instance, bottleneck analysis is based on collecting and analyzing data, and tracking data is directly related to the movement of a physical object, or a person. It would be possible to analyze the movement pattern through the tracking data, thus, potentially identifying deviations, for example, standardized paths not being followed.

Do you believe that a VT could help improve the control in the production, especially if the VT is connected with an RTLS?

The concept of a VT, or a DT, is that changes that are made in the production occur in the twin, and vice versa. But the service that is available from the case company would probably not directly benefit the production because it would not be connected with any of the existing software. However, it could bring certain benefits if it is possible to combine the VT with an RTLS, mainly because it would result in a lot of data being gathered, which can then be applied in other areas. As previously mentioned, these areas could be bottleneck analysis by analyzing movement patterns from workers and the material flow or just the fact that tools and materials would be simple to locate.

What do you believe are the current challenges with implementing a tracking system in your factory?

The primary issue is connected with the infrastructure because incorporating a new system, especially a tracking system with locators and trackers, most likely required a certain infrastructure. Right now, these do not exist because implementing such a system has not been a primary task, however, the installation task does not seem that relatively difficult. It would probably require a group of engineers to research and choose a certain tracking system, and then ensure that the necessary installations and testing are done over the summer. The reason for this is that the factory is closed during certain periods during the summer, thus, making the installation simpler because there is no interference from workers or material.

Do you see any benefits for the customer regarding implementing an RTLS with a VT? If so, what are these benefits?

The primary benefits would probably be for the management and the production site because it's there that the technology is directly applied, and as mentioned previously, the produced data would probably be analyzed and applied in different areas. This would result in improvements being made in production, meaning that the customer would indirectly experience certain benefits because things would go well for the company. However, a more direct benefit could be that the customer could potentially visually follow their order, but that is maybe not that necessary. Currently, the customer has the chance to follow their order by getting certain updates, of course, relatively undetailed updates, however, they are deemed adequate.

4.3.3 Exporting and importing data from the Virtual Twin

The interview with the engineer from the case company resulted in relevant opportunities being discussed, thus, further exploration was performed in NavVis' VT. The interesting viewpoint is that it is possible to export data from the VT and convert that data into a format that can then be imported into different software. This was tested, and it is possible to perform this through NavVis VT by marking a designated area in the software, and then just exporting and converting the data into a relevant format. After that, it is possible to export the data in other software, and in this case, it is possible to export data into Visual Components. The data that was imported into Visual Components was the digital representation of a machine, see Figure 4.16. The object in Figure 4.16 is relatively blurry and undetailed because the computer used to export the file from the VT was not adequate, meaning that it would have taken a relatively long time to export that object.

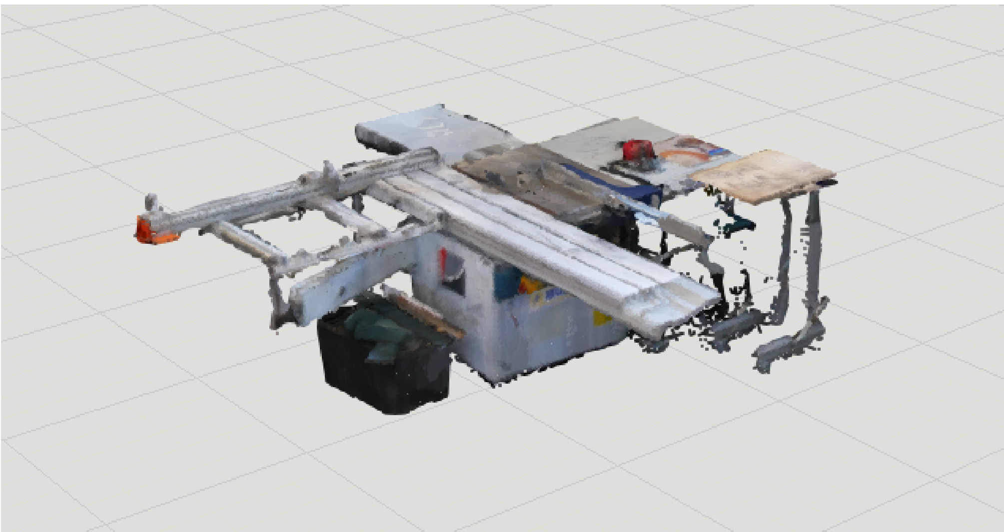

Figure 4.16: Imported object from NavVis' Virtual Twin

5. Discussion

This chapter presents discussions and conclusions based on the results from the literature review, the different workshops, and exploring the different software and hardware.

5.1 Results

This chapter is divided in a sense where the two RQs are separated from each other, and it is necessary to look back at the two RQs to ensure that the discussion is based around them, and they are the following:

Research Question 1 (RQ1): *How could a simulation benefit the visual planning of a manufacturing order at Virtual Manufacturing?*

Research Question 2 (RQ2): *How can RTLS be used together with a VT to create more value for the user?*

5.1.1 RQ1: Visual planning

Several different software were used when exploring the first RQ, software such as IronCad, Visual Components, and NavVis 3D Scanning, which is all software with different strengths and weaknesses. However, it is concluded that the majority of those software are not fundamental to visually plan a manufacturing order, instead, the most relevant software is Visual Components. The reason for this is that Visual Components offer tools that are similar to that of IronCad, mainly that it is possible to digitally design a real-life object. IronCad offers the possibility to create a more detailed version, however, it is deemed excessive in this project because the goal is not to build a highly detailed manufacturing site, but instead, to explore the possibilities to visually plan a customer order.

Regarding NavVis 3D scanning, it is concluded that it is a beneficial software that could be explored further, however, the parts that were applied for this project were not relevant for this RQ. The reason is that NavVis' VT was just used a couple of times, but it was not necessary to digitally build the manufacturing site. Instead, the more relevant findings were discovered from the interview with the engineer from the case company, and those findings are regarding the data that can be exported from the VT, but more on that later. Excluding this aspect, the software was not that relevant for the first RQ, instead, it is more relevant for the second RQ regarding which values can be added to the case company's VT. More discussions and conclusions regarding this software are presented further in this chapter.

5.1.1.1 Visual Components

As previously mentioned, Visual Components is a highly flexible software because it allows for simple importation of files from other software, but it also offers built-in tools that are similar to that of other software, in this case, IronCad. The fact that it is possible to digitally build real-life objects within the software eliminates the need to work between different programs. It is possible to just use these tools and digitally build a manufacturing site to visually plan a custom order, and the reason is that the digital site would have all the correct dimensions. Having the correct dimensions would offer the possibility to import a digital version of a product, and then test out what the most optimal places to place them would be. This is simply due to Visual Component's built-in drag-and-drop function, making it possible to test out different placements, and then choose the most optimal.

Although it is possible to visually plan an order without applying the simulation aspect, the simulation of a customer order does offer several benefits and interesting viewpoints. The simulation of an order showcases exactly how a product is constructed, what the process would look like in terms of observing the laborer's work, and how they would interact with each other. This is beneficial because it would be a relative replica of reality, meaning that it would be possible to identify potential errors, for example, distances being too long between stations, or a workstation needing more work tasks to even out the workload.

Furthermore, the simulation aspect offers the possibility to observe each product being placed in a designated area, as well as the possibility to see products being stacked on top of each other if the shape allows for it. This visual representation makes the visual planning simpler because the user can observe a human worker walk along a standardized path and store a product, as well as observe if there are any issues with storing that product. For example, there is a lack of space in the designated area, or the standardized path not being feasible.

5.1.1.2 Simulating a production of 66 products

The simulation aspect was applied to a real-life manufacturing order where 66 products needed to be produced. Setting up a simulation in the digital version of the case company's manufacturing site was relatively difficult, mainly because it required multiple workers, and it became a bit tedious in terms of making everything run smoothly. However, after every step was implemented correctly, it was possible to observe multiple workers simultaneously manufacture a real-life order and place it in a designated area, observe Figure 5.1.

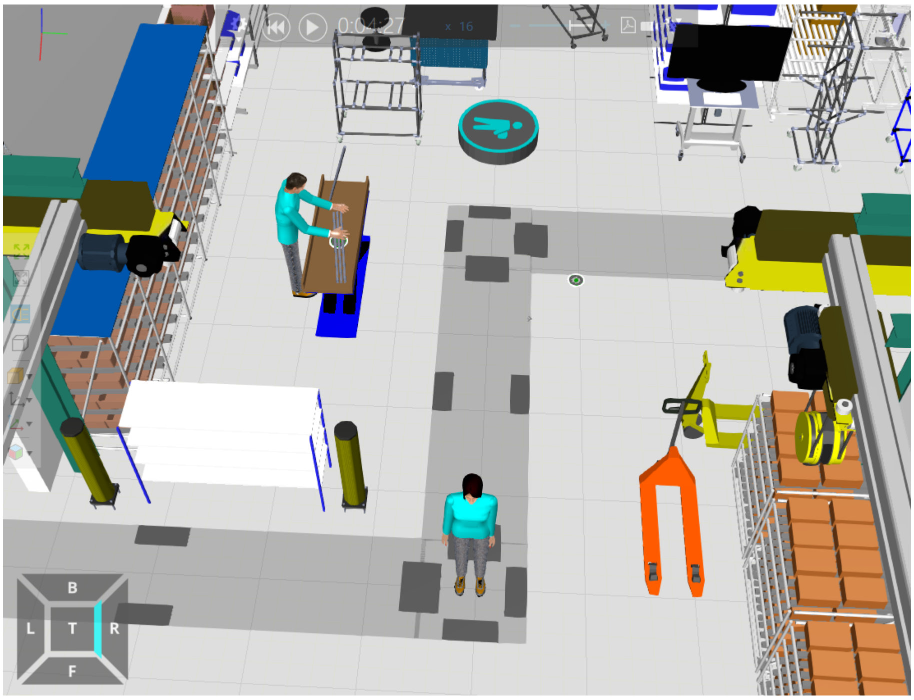

Figure 5.1: Two workers working together to manufacture a product

Before the customer order was to be manufactured, it was visually planned in Visual Components. The result was that different storage locations were tested to see which one was the most optimal regarding the allocation of space, but also regarding transporting the products out of the workshop and loading them into a truck. The results from which positions were chosen can be observed in Figure 5.2. This was beneficial because it showcased existing issues at the manufacturing site, for example, that more space could be created by removing unnecessary inventory, but also by stacking and storing objects in different locations.

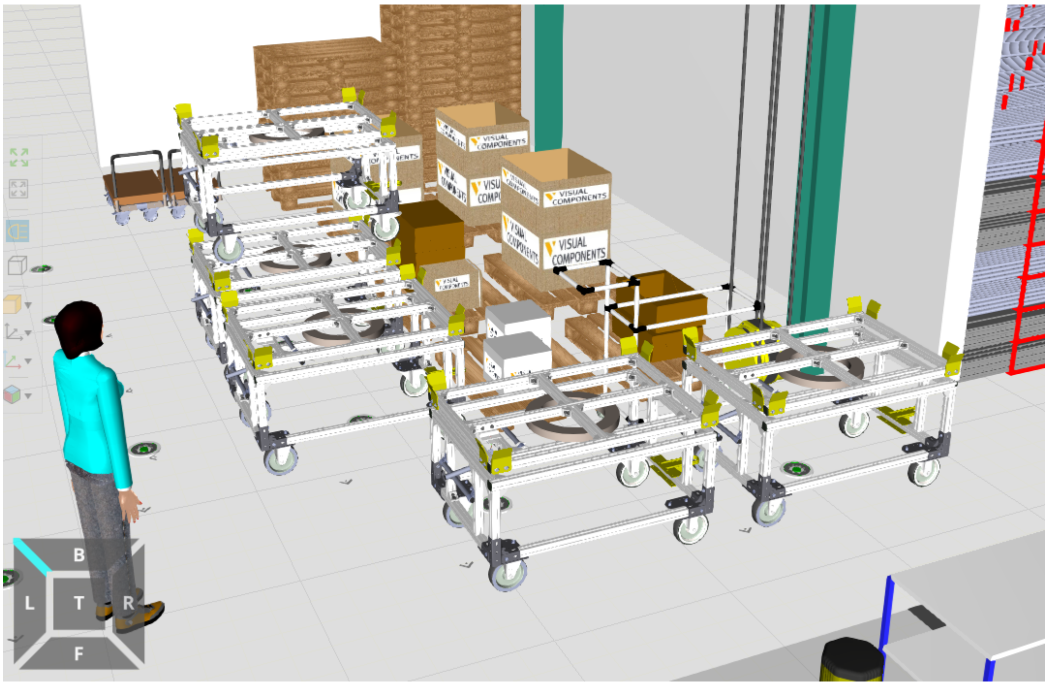

Figure 5.2: Products being placed at designated areas in the factory

Regarding the simulation, it did not showcase any issues in terms of bottlenecks that slowed down the manufacturing process, mainly because the process is relatively simple. There are no industrial machines used to assemble the products, only when the material is being prepared, meaning that the chance for breakdowns is relatively non-existing, and even if the machines do break down, there is a backup of material. The only potential issue that was identified was that the worker that prepares material, in the beginning, could be ahead of the assembler, meaning that they could be standing there without a work task. However, this is only in the simulation, meaning that in real life the worker would probably perform a work task that is unrelated to the assembly process, for example, cleaning the workshop, or performing administrative work in the office upstairs.

5.1.1.3 NavVis 3D Scanning

It was learned from the interview with the engineer from the case company that it is possible to export selected parts from the VT. After this information was obtained, further investigations were made regarding the VT, and those showed that it is possible to select a part of the VT and export it to a format that can then be imported into Visual Components, see Figure 5.3. This is an interesting viewpoint because it could eliminate the need to digitally create a production site through CAD software, or in this case, through Visual

Components. Instead, the whole model from the VT can be imported into Visual Components.

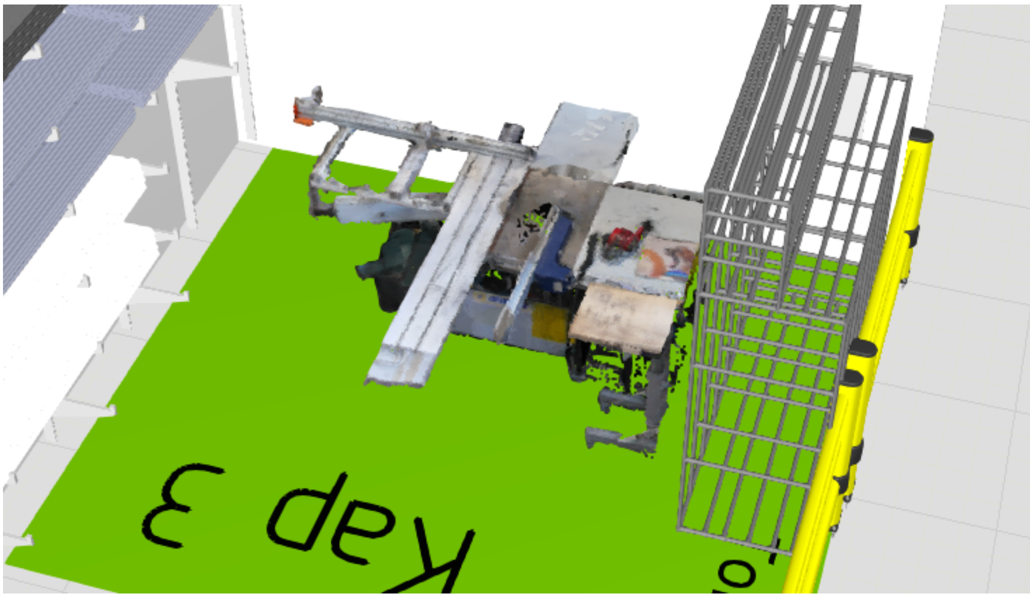

Figure 5.3: Imported object from NavVis' Virtual Twin

However, there are certain drawbacks to this, mainly that it takes a relatively long time to export smaller sections, meaning that it would take a long time to export a whole model. A significant amount of computer power is used to make this work, which is not ideal if a user is working with a computer that is not suited for this work, for example, a laptop during travel. Instead, it is deemed more beneficial to export a smaller part of the model, for instance, a machine that has a lot of details. Another drawback is that if a whole model is exported, then it is not possible to move around individual objects like shelves or forklifts because they have all been saved as one file. These options can be viewed as something extra, meaning that they are not deemed fundamental for the visual planning of a customer order.

5.1.2 RQ2: Adding value to a Virtual Twin

The literature study regarding RQ2 resulted in a lot of different useful information, primarily regarding RTLS and how it is currently applied in manufacturing, but also in other fields, such as in healthcare, or the military. Regarding healthcare, RTLS was applied in an American hospital to keep track of high-value equipment that relatively regularly disappeared. This resulted in a lot of annual savings because the hospital did not need to invest in new equipment, thus, the budget was allocated towards other areas. Furthermore, RTLS was applied to keep track of patients that were going through different treatments in different departments, mainly to ensure that they could be quickly found by a healthcare worker. Similar reasons and results regarding RTLS exist within the military in the sense that high-value equipment and vehicles were tracked, primarily equipment and vehicles that existed in copious amounts.

The reasons and results of applying RTLS within healthcare and the military translate to manufacturing as well. The location of equipment and products is known at all times, thus, eliminating the time required to search for these objects. Furthermore, manufacturing companies can use data from RTLS to observe how their products and workers are moving, meaning that it is possible to perform a form of bottleneck analysis. For instance, creating a standardized path by eliminating unnecessary objects and blockages, thus, eliminating the number of steps a worker needs to take. In addition, it would be possible to improve safety conditions by creating a connection between trackers and restricted and dangerous areas, meaning that a signal is triggered when a worker, or an object, enters a certain area.

5.1.2.1 A suitable system

As mentioned in the result, there are multiple interesting tracking systems with different benefits and drawbacks. In this case, the most familiar and comfortable one is Quuppa, mainly because it is the system that the case company uses to track its equipment. It is also deemed to be highly beneficial because it offers such high precision when working with BLE. From the first interview, it was gathered that working with BLE does not offer a relatively high precision because it could be off by a couple of meters. However, this is not the case with Quuppa because the technology offers high precision with the tracking being off with a couple of decimeters. This is beneficial when the objects that are being tracked are relatively small, for instance, certain equipment, or if there is a lot of different equipment bunched together, thus, making it difficult to identify the right object.

Although Quuppa has several benefits, mainly the relatively high accuracy, it does have several drawbacks. The first interviewee mentioned that it required a specific type of infrastructure where locators need to be installed on the ceiling, combined with a lot of cables being installed in places that do not disturb movement, for instance, on the wall. This requires a lot of planning and work, especially if the site is relatively large, for example, a production site that mass-produces large products, such as vehicles. Furthermore, it could be argued that the Quuppa technology, or any tracking technology, could be abundant when dealing with an assembly line. The reason is that tracking products and materials on an assembly line is simple, and it is almost impossible to lose anything. In addition, assemblers often have low-value tools that do not require to be tracked.

However, just because Quuppa may not bring multiple benefits regarding tracking equipment and products on an assembly line, does not mean that it is not beneficial at this type of production site. It was gathered from the second set of interviews that this technology would be best suited in the different logistics departments, mainly because it is where all the materials are located, as well as them not being part of a flow. Also, it would eliminate the need to install Quuppa throughout the manufacturing site, but instead, it could be installed in the most important areas, in this case, storage areas where there is a lot of movement of workers, vehicles like forklifts, and materials.

5.1.2.2 Suitable compatibility between systems

It is important to note that Quuppa collects data from different trackers, which then have to be used together with a different system. This could be a challenge in the sense that existing technology at a company may not be that compatible, thus, resulting in the company needing to make changes and use different technology. There are several different systems, for instance, Sewio Networks, INTRANAV, and Gazpacho. In this case, the most familiar and comfortable system is Gazpacho, primarily because it is the system that the case company has used to import data from their Quuppa system. Although Gazpacho is highly compatible with Quuppa and its data, it does not offer a relatively modern visualization because it is 2D-based.

There is no major issue with having a 2D-based system, especially if the tracking area is relatively small as it is with the case company’s manufacturing site. However, when dealing with larger storage areas, such as the logistics department that Volvo Cars use, then it is not suitable to have a 2D system because it does not showcase a third dimension. For instance, if an area has a relatively high ceiling then the 2D-based system will not showcase where on the Z-axis an object is located, thus, resulting in time being wasted on searching several shelves. However, this does not mean that the system is not beneficial in manufacturing. The 2D-based system is highly beneficial in keeping track of workers because they are always on the ground level, as well as equipment and vehicles that are not stored in high places. Data could be used to analyze movements and optimize the paths that the workers take, as well as the paths that forklifts or AGVs use.

However, developments are being made in this area, primarily improving the integration between a 3D-based model and an RTLS, the 3D version being a form of VT, or DT, that can utilize real-time location data. The DT that was mentioned in the results is relatively advanced and requires powerful computers, mainly because the goal of that system is to quickly analyze data and have automated decision-making regarding predictive maintenance. In addition, this system would require a fast network, meaning that systems such as Bluetooth and Wi-Fi would not be suitable. However, value can still be added to a VT without implementing predictive analytics, automated decision-making, or the installation of 5G. Instead, value can be added by having high compatibility between existing systems, and a 3D-based RTLS.

5.1.2.3 Virtual Manufacturing's Virtual Twin

Virtual Manufacturing uses NavVis' 3D scanning technology to gather data and upload it on the Internet, where a VT is created that offers the possibility to navigate around. The navigation system and the appearance of the VT are comparable to Google Earth, see Figure 5.4. Although there are several benefits of the VT, primarily that an area can be viewed and navigated remotely, thus, yielding the opportunity to identify potential improvements, it was deemed relatively limited. However, it was learned through the first interview that it is possible to export data from the VT, which can then be imported into different software, for instance, Visual Components. This increased the possibilities of adding value to this technology in the sense that it could be used together with other software to create value for a user.

Figure 5.4: An overview of the case company's manufacturing site through their VT

This would bring value in the sense that the case company could increase the utilization level of their existing technology, in this case, NavVis' 3D scanning technology and its VT. Virtual Manufacturing would not decrease their use of this technology, but instead, export data from it that can then be imported into other software. However, changes in ways of working would be required, primarily finding software that is compatible with multiple software, as well as offering 3D-based visualization. This raises the question: *is it not possible to combine Quuppa with NavVis' VT?* The answer to this question is that it is not possible to combine the two systems, primarily because the VT is not that advanced in terms of there being possibilities to import and use real-time data.

The most suitable option would be to combine the characteristics of the different software. The most beneficial of NavVis' software is that it offers a 3D visualization of a scanned area, which is comparable to Google Earth's navigation and visualization. However, the program does not offer the possibility to import real-life data, in this case, data regarding objects being tracked. With Gazpacho's system, it is beneficial because it is highly compatible with other software, such as Quuppa, however, it does not yield a 3D visualization of a site, thus eliminating a third dimension that is necessary when dealing with large sites.

5.2 Future research

This segment presents potential improvements regarding future research, primarily presenting mistakes that were made during this project and what type of issues they may have caused for the answers to both the research questions.

5.2.1 Recommendations

One of the mistakes made in this project was the fact that certain software was already preselected through internal conversations. Internal discussions were held before the project began regarding which research should be conducted, and what type of software could be used to identify the answers to that research. The premature decision was made to study Visual Components because both the authors have previously worked with that software, thus, the thought process was that it would be simpler to learn and conduct the research.

There are no issues with Visual Components, instead, it is deemed a great software because of its user-friendly interface, navigation, compatibility, simulation, and ability to digitally build objects. However, prematurely selecting which program should be used to conduct the research may have resulted in mistakes being made, for instance, not using more suitable software. Virtual Manufacturing offers an array of different programs that potentially should have been examined more thoroughly before making a decision. Therefore, it is recommended to thoroughly examine different software before making a fundamental decision.

6. Conclusion

This chapter presents the different conclusions that have been drawn from the previous chapter, meaning that it could be viewed as a form of summary.

6.1 Conclusions for RQ1

In summary, it is concluded that Visual Components is a great software for digitally building a real-life manufacturing site and implementing simulations, thus, it being a great tool regarding visual planning. The software offers great compatibility with other software, primarily CAD software, but also offers the possibility to design objects within the software. In addition, its drag-and-drop function allows for simple movement of objects, thus, making it simple to analyze the available space, and if any changes need to be made.

The simulation aspect offers the possibility to identify existing bottlenecks and issues, mainly because the simulation is almost identical to a real-life manufacturing process. These tools were applied to simulate and visually plan a manufacturing order of 66 products. It was possible to manufacture around 20 to 25 products before there was no more space, resulting in a truck being scheduled for delivery to the customer, see Figure 6.1.

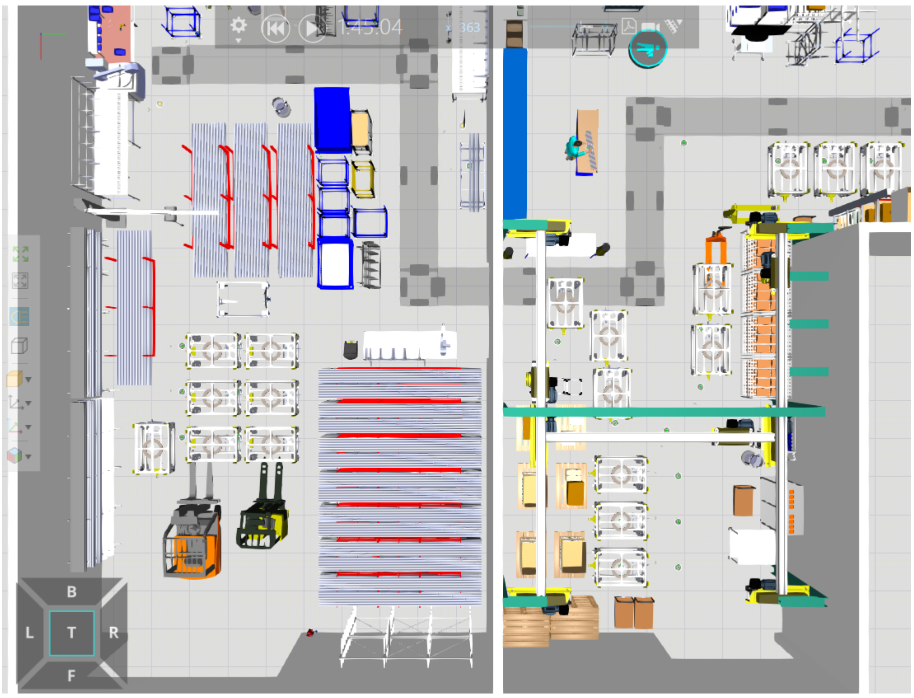

Figure 6.1: An overview of a complete simulation of around 20 products

Despite there being several benefits with Visual Components and its simulation tools, there are drawbacks to the software. The primary issue is that it can be relatively tedious at some moments, meaning that difficult problems can arise, especially when working with simulations. The problems that were encountered during the simulation phase did not have any direct solutions on the Internet, or through Visual Component's YouTube channel. For example, there was a major issue regarding creating a standardized path for human workers where the human kept walking through objects despite there being a designated path. The solution was to change one setting, which is simple to do, but it is something that was not found through the internet, instead, it was found through trial and error.

In summary, the software requires relatively deep knowledge to perform simulations without any errors or tedious issues. This could make companies distance themselves a bit from the software due to its complexity in some instances, however, that can be concluded about other software as well. The possibilities and benefits of Visual Components outweigh the drawbacks, mainly because the drawbacks are the learning progress. An engineer that has learned, and potentially mastered the software, would bring a lot of significant value to a manufacturing company because it would be relatively simple to establish a simulation. In addition, the program is flexible in the sense that when a simulation is established, it is pretty simple to make adjustments to simulate a different customer order.

6.2 Conclusions for RQ2

As of right now, it is difficult to add value to the case company's VT because the software is not that compatible with other programs, meaning that it is not possible to import real-life data into NavVis' VT. Instead, the value is found in fully utilizing the abilities of the VT, which is to export data from it that can then be imported into other software. The exported data is either a smaller selected area, for instance, a machine at a production site, or it could be the whole model.

Regarding RTLS, it would be beneficial to identify an upgrade to the current RTLS used at the case company, Gazpacho. There is nothing wrong with the current system as it offers multiple possibilities for analyzing and improving the movement of workers and equipment. However, having a system that is 3D-based would improve the tracking significantly because it would be as close to reality as possible. Right now, Gazpacho is not suitable for large storage departments because there is no possibility to identify where an object is located on the Z-axis. It could still be applied, but it would be more efficient to have a 3D-based system.

Furthermore, the conclusion is drawn that a 3D-based system needs to be highly compatible with other software. The first interviewee mentioned that one technology will not solve every problem, but every technology working together would. Having a system where it is possible to import data, for instance, data from NavVis' VT in the form of a whole production site, would result in significant value being added to the existing working methods at Virtual Manufacturing. It would not only fully utilize the VT, but also be highly accurate in terms of the location of objects because Quuppa offers great precision in comparison with other tracking software.

In summary, the conclusion is drawn that manufacturing companies should implement RTLS into their manufacturing process because it would increase the control of production. Especially if the RTLS is compatible with existing software, in this case, Quuppa and NavVis' VT.

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Appendix

Appendix A: Link to template for basic simulation in Visual Components

https://www.mediafire.com/folder/jtt321bal5glt/Template

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