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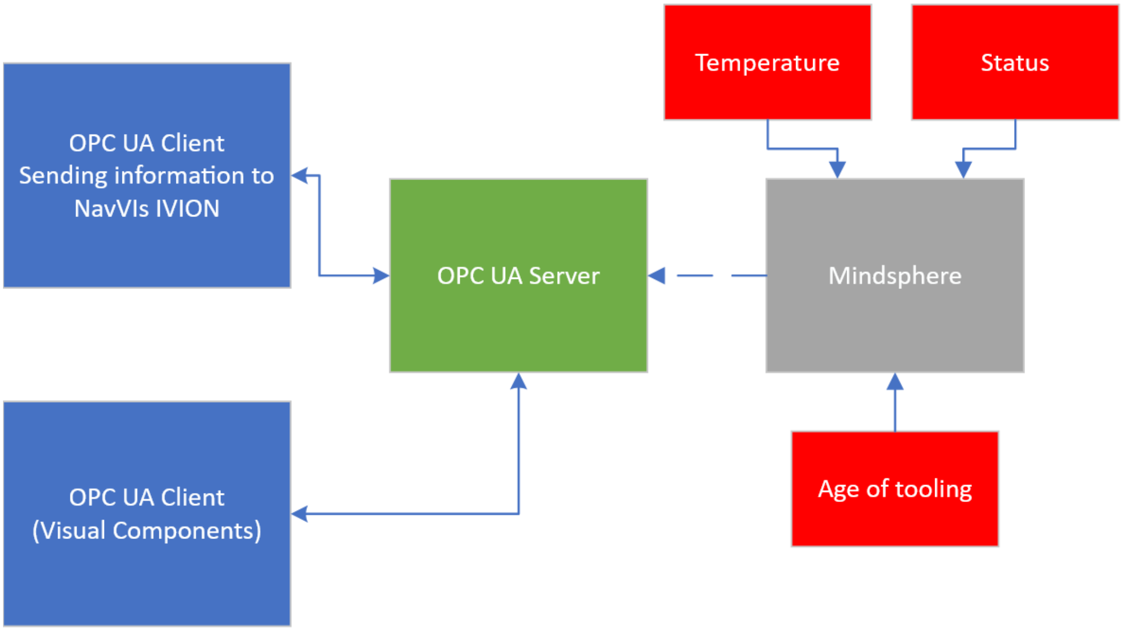

Process Design and Evaluation of a Digital Shadow

Master's thesis in Production Engineering

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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

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Cover: Example of IoT system with sensors and infrastructure to visualize data

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Abstract

Digital shadows and Digital Twins are fundamental to the concept of Industry 4.0. They allow for in-depth analysis of operations, which in turn leads to more streamlined businesses. In this project, a Digital Shadow will be designed and accompanied by two different types of visualizations. The Digital Shadow will be based on a manufacturing company, Bror Tonsjö AB, located north of Gothenburg, Sweden.
In summary, the project consisted of creating visualizations and implementing real-time data. The visualizations were either designed by using 3D-models or point cloud technology. When the visualization was completed, a server was hosted through Python and OPC UA for the purpose of creating the variables to be used in the Digital Shadow. The visualizations were connected to a server that hosted the variables and controlled the behavior of the layout. Finally, feedback was gathered through qualitative interviews to evaluate the process design and how the Digital Shadow could be improved in relation to the predetermined research questions.
The result of this project shows that Digital Shadows hold many use cases and could streamline many types of industries. A Digital Shadow is very versatile and could be designed to suit everything from manufacturing industries to grocery stores. The versatility extends into internal business sectors as well, since a Digital Shadow could be equally useful for a manager or a logistics worker, depending on the design and accessibility. Due to the different methods of integrating this technology, it is possible to tailor the complexity of the Digital Shadow to suit unique situations and find value.

Keywords: Digital Shadow, Digital Twin, OPC UA, Industry 4.0, IoT, Visualization, Points of interest, Connectivity, Digitalization, Real-time data, Point clouds.

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Secondly, we are thankful for the help we have received from Chalmers University of Technology. Our university supervisor Jon Bokrantz deserves a special thanks for his dedication to helping us by reviewing our thesis and guiding us in the right direction. Jon's advice on structuring of the thesis and potentially valuable content to cover has increased the quality of the report. We also want to say thank you to our examiner, Anders Skoogh, for organizing the thesis in terms of administrative work and providing us with a supervisor.

Emir Bekric, Gothenburg, June 2022
John Sandström, Gothenburg, June 2022

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis, listed in alphabetical order:

API	Application Program Interface
CPS	Cyber-Physical System
DM	Digital Model
DS	Digital Shadow
DT	Digital Twin
IoT	Internet of Things
OEE	Overall Equipment Effectiveness
OPC UA	Open Platform Communications Unified Architecture
PLM	Product Life cycle Management
PoI	Point of Interest
REST	Representational State Transfer

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1
Introduction

This chapter presents the background of the project followed by the aim and purpose of the thesis. The chapter also includes limitations and the research questions of the project.

1.1 Background

Digital shadows (DS) and Digital twins (DT) are a big part of the fourth industrial revolution (Negri et al., 2017). The possibility to map process and product flows in a production system allows for testing different solutions without interfering with the state of the production. Connecting the information mapping with the current state allows efficient decision making while simultaneously providing an easy-to-view visualization of the production processes. In an industrial setting, this implies capturing the state of the production (as 2D-drawings often are outdated and misleading) and modeling the resources and flows. The potential of DS and DT creates an opportunity to improve financial results, as well as impacting social and environmental factors. In addition, customer satisfaction can be increased by elevating the quality of products that are being processed. The project will be based around Virtual Manufacturing's mapping platform "Virtual Twin".

Bror Tonsjö AB is one of Virtual Manufacturing's customers, they have already connected a majority of their machines to a set of digital systems that monitors what happens at any given time. Virtual manufacturing has already made a scan of the factory that consists of 360 degree images and point clouds which makes it possible to measure the physical dimensions of machines and similar. However, some parts of the factory have had their layouts changed recently and therefore the scan is not fully accurate. Bror Tonsjö AB would also like to be able to view information about the machines' conditions and status through their Digital Twin platform.

Manufacturing industry as we know it today has undergone several revolutions. The first revolution came with the introduction of steam power and ability to use machines in production in the middle of the 18th century (Herrmann et al., 2020). In the end of the 19th century the introduction of electricity in production and a renewed way of structuring the labor resulted in the second industrial revolution taking place (Oztemel & Gursev, 2020). The third industrial revolution occurred in the second half of the 20th century when robotics and computers made it possible to automate parts of the production. Thereby, some potentially dangerous tasks and jobs were removed and it was also possible to increase the productivity even more (Herrmann et al., 2020; Oztemel & Gursev, 2020; Xu et al., 2018). An illustration of the industrial revolutions can be seen below 1.1.

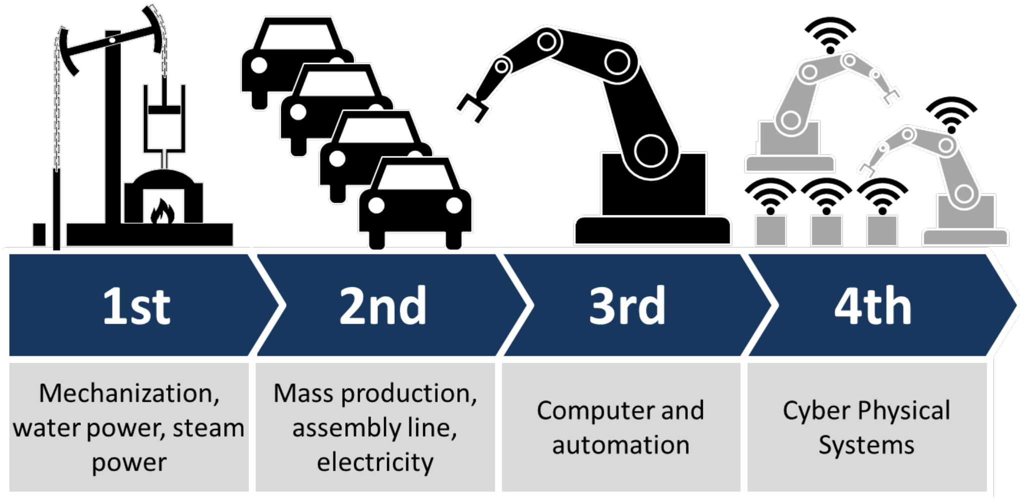

Figure 1.1: The four industrial revolutions, illustration from Roser (2022)

Industry 4.0 was first presented in 2011 in Germany as Industrie 4.0 (Xu et al., 2018) and was planned to be the fourth industrial revolution. Opposed to the three first industrial revolutions Industry 4.0 was forecasted in advance which makes it possible for the industry and the academia to influence what the fourth industrial revolution will be. It also makes a difference since the research regarding the first three industrial revolutions has only been made by observing it afterwards. This time it will be possible to observe and perform research while the change is happening (Herrmann et al., 2020). It is also possible for academia and industry to influence the fourth industrial revolution and affect how it will change the paradigms of manufacturing. While the third industrial revolution made robots and automation common in the factories, the fourth industrial revolution will change the way information is handled. For example, one of the main changes will be the ability for machines to communicate with each other autonomously (Oztemel & Gursev, 2020). However, Industry 4.0 is still as much in the future as something concurrent. Actual implementations of Industry 4.0 are limited and most research on the topic are from small-scale implementations (Bajic et al., 2021).

The concept of digital twins originates from the area of Product Life Cycle Management (PLM) and production systems were not part of the concept from the start (Grieves, 2015). Even though the term *Digital Twin* was not used from the beginning, most of the the authors to the articles used in the literature study in this thesis agree that the concept was first proposed in 2003 by Grieves in a course relating to PLM (Kritzinger et al., 2018; Tao, Zhang, et al., 2019; Uhlenkamp et al., 2019). From the start (before 2012) the concept did not get the attention it got later, one reason is probably that the technology required (IoT, sensor technologies and computing power for example) was not ready to support Digital Twins (Pronost et al., 2021; Tao, Zhang, et al., 2019) at the time. In 2012 NASA (Glaessgen & Stargel, 2012) published a report that brought the concept into the limelight again. The report mainly focused on the possibility to use Digital Twins as a method to monitor the health of critical components, but part of the report was also the definition of Digital Twins that is most common in literature today (Tao, Qi, et al., 2019)

1.2 Aim

Virtual Manufacturing has an objective of expanding their DT platform. The purpose of their DT is to create clear visualization and combine it with data implementation. Virtual Manufacturing themselves mention benefits in regard to safety, marketing and communication. In collaboration with Bror Tonsjö AB, the companies want to evaluate how real-time data can be used in their DT platform for the benefit of both businesses. In the case of Bror Tonsjö AB, the DT will be used to develop the production, while Virtual Manufacturing want to investigate if real-time data is a concept that can be marketed in their platform.

The project will set out to create a 3D-layout of an industrial complex which will provide the basis for a visualization of the factory. The 3D-layout must then be connected in real-time with the physical resources to provide information on their usage and movements. In this case some information might be already accessible from the IT-systems of the company, therefore this project is based on a scenario where ongoing efforts to digitalize the production are already initiated.

The aim of the project is to investigate and start implementing a digital shadow solution for manufacturing companies, in this case specifically at Bror Tonsjö AB. The first part of the project will be to finalize a visual model of the factory using a pre-made scan of the factory and CAD-modeling. Furthermore, the project will investigate what information would be beneficial to be presented in the digital twin. In parallel to this work, literature studies will be performed to understand how other companies use similar technology and what benefits they have seen but also challenges they have met.

The second part of the project is to develop a solution that uses the information from the machines at the factory and presents the relevant information in the Virtual twin platform in a way that fulfills the identified needs for Bror Tonsjö AB. The added functionality should bring value for the company and make the flow of information better. Furthermore, the project aims for the solution to be an example for other companies to show how a DS could be used and what benefits a DS might have in a production context.

1.3 Research questions

Four research questions have been formulated to specify the aim of the project. The project aims to investigate the following questions:

RQ1: How can a DT/DS or virtual PoIs add value for a manufacturing company?
RQ2: How should the information available in the DT/DS be presented to be most useful?

RQ3: Which type of information is necessary to collect to present valuable data in the DT/DS?

It will be important to understand how a DS will be used by the company to be able to include the most important information. Comparisons with other industries that use similar technology (for instance Google Maps) will take place to evaluate advantages and disadvantages of the technology. This would highlight the capabilities of the service across business sectors.

1.4 Limitations

The project will not develop any solutions to allow for the DS platform to make decisions or take actions in the physical factory (such a solution would imply creating a DT rather than a DS). Actions in the physical factory will be required to be performed by human input. The project will be limited to certain software that are convenient to use for both Bror Tonsjö AB and Virtual Manufacturing Sweden AB. Due to the distance from the office of Virtual Manufacturing Sweden AB (where the majority of the project efforts will take place) and the Bror Tonsjö AB industrial complex, the opportunities to visit the actual production will be limited. In addition, with the 3D-layout acting as the basis for the DS, the majority of the work will be focused on the virtual representation of the production rather than implementing direct changes in the actual industry, with focus being on how the virtual platform can benefit Bror Tonsjö AB in their future analyzes of their operations. Furthermore, the availability of real data from the production is limited. The project will instead use simulated data in formats that can be combined with the chosen software.

1.5 Ethics and Sustainability

The results of the project have to be analyzed on grounds of possible ethical- and sustainability-related factors. Suggestions could include personal opinions on surveillance in terms of resource usage, or how the implementation could affect the daily working tasks of current employees. The three fundamentals of sustainability (social, environmental and financial) have to be investigated to find if the project is viable in the long-term. For example it should be analyzed how the additional functionality of the digital twin affects the employees. Are there risks for negative impacts caused by increased surveillance of the production at the factory? Furthermore, questions such as “Is it possible to reduce waste and increase profitability by the use of DS?” should be investigated.

2

Theoretical background

The following chapter will describe the theoretical background regarding DTs and DSs used in the thesis. Since these two concepts share major common points, and the extent of DT-research expanding upon what is available on DSs, the literature is deemed in large parts useful for describing both concepts.

2.1 Industry 4.0

Industry 4.0 is predicted to be the fourth industrial revolution. It is currently ongoing and will continue progressing industrial methods for an unknown period of time. Industry 4.0 is in many ways a vision as much as something tangible and the term is not clearly defined today (Herrmann et al., 2020). Even though the term *Industry 4.0* has been used the last decade and research on the topic has been going on the same amount of time, actual implementations of it is not very common. Furthermore, the term is not clearly defined and depends to some extent on how the researcher views the subject (Bajic et al., 2021). However, Industry 4.0 tries to improve the industry by connecting the physical parts of production (machines etc.) with cyber parts (software etc.). This requires a network connecting these two parts that allows the cyber parts to add value to the production and further understanding of the processes.

However, one part of Industry 4.0 will be the increased use of autonomous communication between machines, technologies like Internet of Things (IoT) will be part of the new industrial revolution (Xu et al., 2018). Today there is no clear definition of Industry 4.0, however, one of the main goals are to decrease the central control of production and move towards a more decentralized approach (Herrmann et al., 2020). One important part of Industry 4.0 according to Herrmann et al. (2020) is the "smart factory" described by Lucke et al. (2008) which will require the flow of information to be fast and reliable. This will also make it possible for the Smart Factory to provide people with the information they need in real time.

2.2 Digital Twins in a production context

Digital twins are one part of the fourth industrial revolution that will to a large degree depend on the previously mentioned networks with machines and computers. According to Tao, Qi, et al. (2019) DTs are a concept that are related to cyber-physical integration. *Cyber-physical systems* (CPS) are a similar term used in relation to cyber-physical integrations often used in scientific literature. The development of DTs and CPSs has been taking place side by side but the most prominent difference today is who are using them. According to Tao, Qi, et al. (2019) DTs are used mainly in industries and in an engineering context while CPS are more often used in a scientific context.

While DTs are used in products, it is for example common to use them in the airplane industry to monitor the need for maintenance of parts, DTs used in production systems often also has a role before the factory is running. When using DTs in a production context the, DT is often used beforehand to perform "Virtual Commissioning" (Negri et al., 2017), a method used to get a better understanding and be able to forecast challenges and issues before the production system is physically built. Virtual Commissioning might thereby help the company to avoid mistakes and letting more of the optimization to take place before the real production is running. The DT can this way help the company to save money and decrease waste before new or changed production lines are used. However, this use of the term *digital twin* can be debated since others states that a DT always should be a representation of something that actually exists (Wright & Davidson, 2020). An alternative term for DTs aiming to evaluate a future system is "Pre-Digital Twin", it can be used to understand risks and challenges with the proposed design (Pronost et al., 2021). Similarly, many researchers states that a DT should allow an automatic flow of data between the physical object and the digital object (Kritzinger et al., 2018), this subject will be discussed more thoroughly later in this section.

DT is a concept that is not defined or used in exactly the same manner by everyone. Most of the applications that claims to be a DT does however consist of physical part, a virtual part and at least connections from the physical part to the virtual part of the twin (Y. K. Liu et al., 2022). The different levels of integration of DTs or similar technologies has resulted in a few different terms to define the level of integration of a specific application. The most common three levels are *Digital Twin*, *Digital Shadow* and *Digital Model* (Kritzinger et al., 2018). However, DT is the level that offers the highest level of integration and Digital Model (DM) is the level with the lowest level of integration (Kritzinger et al., 2018; Pronost et al., 2021).

2.2.1 Digital Model

The DM is in many ways simpler than a DT and does not use any automated exchange of information between the physical and virtual model (visualized in figure 2.1) (Pronost et al., 2021). This means that all the information desired in the DM must be updated and included manually before the model is up-to-date and ready to use. According to Kritzinger et al. (2018) a DM "[...] might include, but are not limited to simulation models of planned factories, mathematical models of new products, or any other models of a physical object, which do not use any form of automatic data integration".

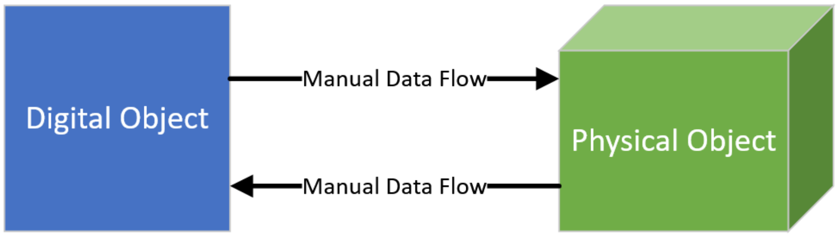

Figure 2.1: Visualization of the concept of Digital Models, adapted from Kritzinger et al. (2018)

2.2.2 Digital Shadow

The DS is different from the DM since there is a flow of information from the real world part of the twin to the virtual part, visualized in figure 2.2. As a result users of the DS will be able to study the virtual system without anyone updating it manually first (Kritzinger et al., 2018). DS is today more frequently used compared to DT (Y. K. Liu et al., 2022). However, the DS might act as one step into further digitalization that might take the users closer to a DT (Bergs et al., 2021). Similarly, Feng et al. (2021) showed that the DS can be a part of the journey to a DT in their demonstration of how to build a DT.

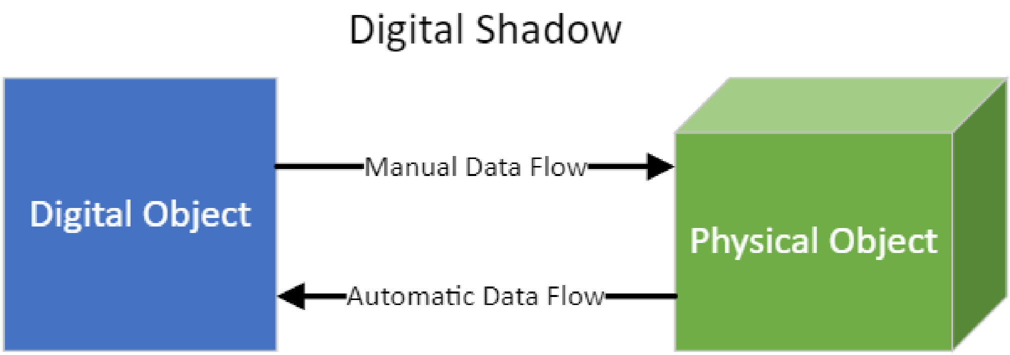

Figure 2.2: Visualization of the concept of Digital Shadows, adapted from Kritzinger et al. (2018)

2.2.3 Digital Twin

According to Kritzinger et al. (2018) a system should only be classified as a DT if there are not only both a digital object and a physical object but also an automated flow of data between them (visualized in figure 2.3). This will also allow the virtual part of the twin to not only run simulations of the system in real time but also control the physical part of the twin. This is made possible by the processing of real time data.

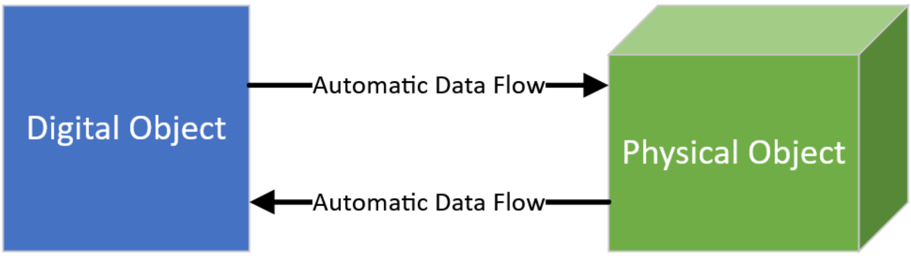

Figure 2.3: Visualization of the concept of Digital Twins, adapted from Kritzinger et al. (2018)

2.3 Benefits and challenges of Digital Twins

In common for all DTs regardless of the level of integration is that the possibilities to record and monitor data regarding the production will increase (Weinand & Rosenberger, 2021). This is data that can for example be used to better predict when maintenance is required. Even though a DT with an automated flow of information in two directions is the most integrated level, the other two levels can be useful in some applications.

There are several benefits of using digital twins, one of them, to visualize information is possible to achieve even with the lower levels of Digital twins. A benefit of the DT (or DS/DM) is the possibility to run different tests on the DT to gain knowledge and understanding of the physical part of the twin (Feng et al., 2021). Even a DS or DM can enable some of these opportunities, visualization and simulation might be possible even in those types of Digital Twins. However, they also have some limitations, for example it will be required that a human is part of the process of moving information from the physical part of the twin to the digital (for a DM). If the outcome of the changes are decided to be used, the changes has to be implemented manually by a human in case a DM or DS are used in contrary to when using a DT.

DTs are highly useful when transitioning to predictive maintenance from less efficient methods of conducting maintenance work (Negri et al., 2017). One of the earliest implementations of DTs for the purpose of maintenance was the collaboration between the National Aeronautics and Space Administration (NASA) and the US Air Force, in which a DT was used to find an estimated life expectancy of their vehicles (Tao, Zhang, et al., 2019). Negri et al. (2017) mentions the benefits a DT brings in terms of maintenance work, which consists of identifying fatigue, cracks and plastic deformation of real-life objects. In addition, a DT makes it possible to accurately forecast long-term performance of processes in hypothetical scenarios. Finally, Negri et al. (2017) specifies that the statistics that come from the implementation of a DT makes it easier for management to take reasonable decisions that are based on objective data when optimizing processes.

The solutions used in Digital Twin applications today varies. J. Liu, 2020 argues that one challenge in the development of DTs are that academia and industry in many cases chooses different software, therefore lacking in standardization. Furthermore, academia tends to choose software that are more general and are possible to use also for DTs while the industry more often chooses propriety software that are specifically intended for DTs.

2.4 Visualization of data

Data visualization is the process of integrating data into classic layout-visualization methods covering processes or factories. There are several different methods for creating a data visualization, some simply provide a complete menu of all the information that is gathered in the factory without physical representation in the digital space, while others combine the data with corresponding 3D-models (J. Liu, 2020). These 3D-models of existing layouts can be reverse engineered quite easily with the help of point cloud technology. For machines or robot cells that do not already have 3D-models, the processes can be designed to the correct dimensions by importing snapshots of the point cloud into CAD-software. Thereafter, the designer may choose the level of detail that is desired in the visualization.

Data visualization is often the first step for organizations that want to increase their technological capabilities (Allen et al., 2021). It could serve as an easier transition into more complex Industry 4.0 concepts, but also as a springboard into large scale digitalization at a relatively low cost. In fact, Allen et al. (2021) argues it is a mandatory step for the integration of Industry 4.0 technology, and therefore also vital for the long-term competitiveness of manufacturing businesses. Large companies have more capital to invest into advanced digital transformation such as large-scale automation and connectivity, meaning smaller business fall behind. To keep up with their larger counterparts, many have turned to visualization and digital analysis. The benefits to be gained from data visualization can be realized with relatively low demands on technical expertise. Implementing it into an organization means there is greater internal transparency in businesses, clearer communication and increased access to factories for a variety of staff including management, engineers and operators.

2.5 Points of Interest

Points of interest (PoI) are representations of real-world objects or businesses in virtual environments (Milias & Psyllidis, 2021). These virtual representations are being used in a multitude of services, some prominent ones include Google Maps, social media such as Twitter and Instagram, and private hotel services such as Airbnb. An example of how PoIs are used in Google maps can be seen in figure

2.4 Other than providing the location of objects, the technology is used to allocate attributes such as type of service (for instance "is the location a cafe, museum or university?") as well as address, phone number, opening hours or other information. Common features include allowing users to review the services offered by the business and provide pictures. The benefits of PoI with extensive descriptions allow for users to gather information on objects beforehand and plan their decision making without having to investigate in person.

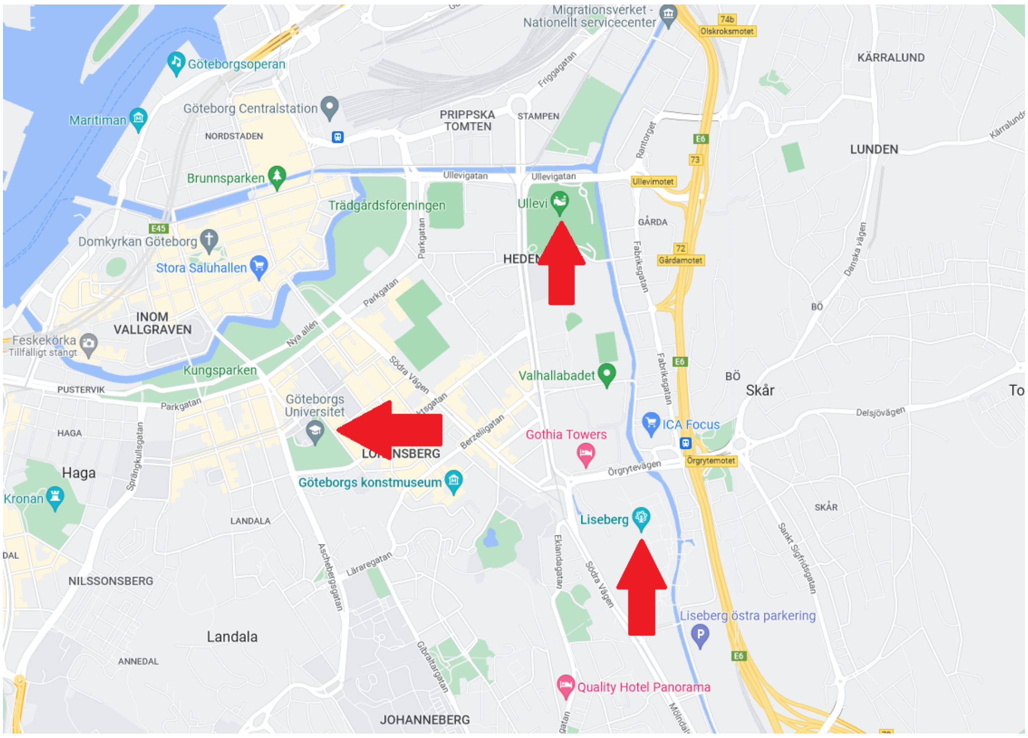

Figure 2.4: Example of PoIs in Google Maps, with three specific PoIs highlighted

The use cases for PoIs are extensive and cover a multitude of business areas, including manufacturing (Li et al., 2021). The technology could be used to help visualize production and store big data for specific machines. This information is in turn valuable for operators and management purposes, such as increasing efficiency by analyzing data related to downtime. Another example is decreasing reaction time by displaying real-time machine problems and therefore enabling allocation of resources depending on the data. In this project PoIs will be used in the NavVis IVION-platform to visualize production-data, see figure 2.5.

Figure 2.5: Example of PoIs in NavVis IVION, the green and red icons are PoIs corresponding to Bror Tonsjö AB's machines.

2.6 Point Clouds

Point cloud technology is a method of capturing a physical object through the help of real-world scanning (Engelmann et al., 2018). Each point consists of coordinate data in the space that has been captured. The accuracy and density of these point clouds generally varies based on sensor and the distance from the sensor at the time of capturing. Therefore, to gain an accurate point cloud of for instance an industrial complex, it is important to closely capture all relevant objects and their surroundings.

This type of technology is useful for creating virtual models of physical objects through CAD software(J. Liu, 2020). It also allows for the designer to easily model the object with an appropriate level of detail of their own choosing, with the most relevant features being captured by the cloud and the choice of which ones to incorporate into the model largely laying with the constructor. This allows for flexibility in terms of chosen level of accuracy and time spent on creating the virtual representations.

2.7 Connectivity

Connectivity and IoT are some of the technologies that are enabling Industry 4.0 (Xu et al., 2018). From the start the technology was used mainly to track objects but today IoT are used in combination with other technologies. Sensors makes it possible to monitor and get more data from the production than ever before. It is also possible to get information regarding the environment and logistics for example.

The data collected by the help of IoT can then be used to optimize the production systems in a factory, it also makes it possible to make improvements in real time (Xu et al., 2018). To make all these sensors possible and feasible, the development of wireless communication during the 21st century has been crucial, it makes it possible to connect a large amount of devices into one network to a much lower cost than before. One of the challenges of Industry 4.0 is that there is no universal standard for communication, but there is a need to be able to use different sources to collect data (Schleipen et al., 2016).

2.7.1 OPC UA

OPC UA (Open Platform Communications Unified Architecture) is a vital component for the purpose of realizing IoT- and Industry 4.0-solutions (OPC-Router, n.d.). It serves as a standardized communication platform that is well-suited for industrial environments as it enables processing of data largely independent of the manufacturers methods of data storage. According to Schleipen et al. (2016) "OPC UA is mostly used in higher automation levels for the purpose of monitoring and control" but it can also add value by providing a standard for communication between different systems. The concept of OPC UA is that the manufacturer collects data through their internal systems and then, after a server is hosted, the communication protocol grants standardized exchange of data. According to Mahnke et al. (2009) "OPC UA will allow systems to make product features available in a standard way, which they can not expose today without the new options provided by OPC UA". This makes the platform a viable way to get IoT to be a solution in production systems.

OPC UA was initially designed by the OPC Foundation as a solution to the previous application, OPC Classic, being too limited in its' implementation(OPC-Router, n.d.). OPC Classic was restricted to Microsoft Windows platforms, while OPC UA is independent and can be accessed regardless of operating system (Andrei et al., 2020). The platform allows this through its' use of the internet protocol suite (TCP/IP) (OPC-Router, n.d.).

OPC UA could be described as consisting of two major elements, the OPC server and the OPC client (Mahnke et al., 2009). The server has the purpose of granting functionality to the client in a standardized OPC manner. The clients on the other hand are used to provide data to the server that the server can expose to other clients, see figure 2.6. Furthermore the server can contain an embedded client that allows the server to communicate with additional servers (Mahnke et al., 2009). Clients in the network can not only be used to provide data, they can also be used to visualize data and also allow the user to change variables if the variable is writable.

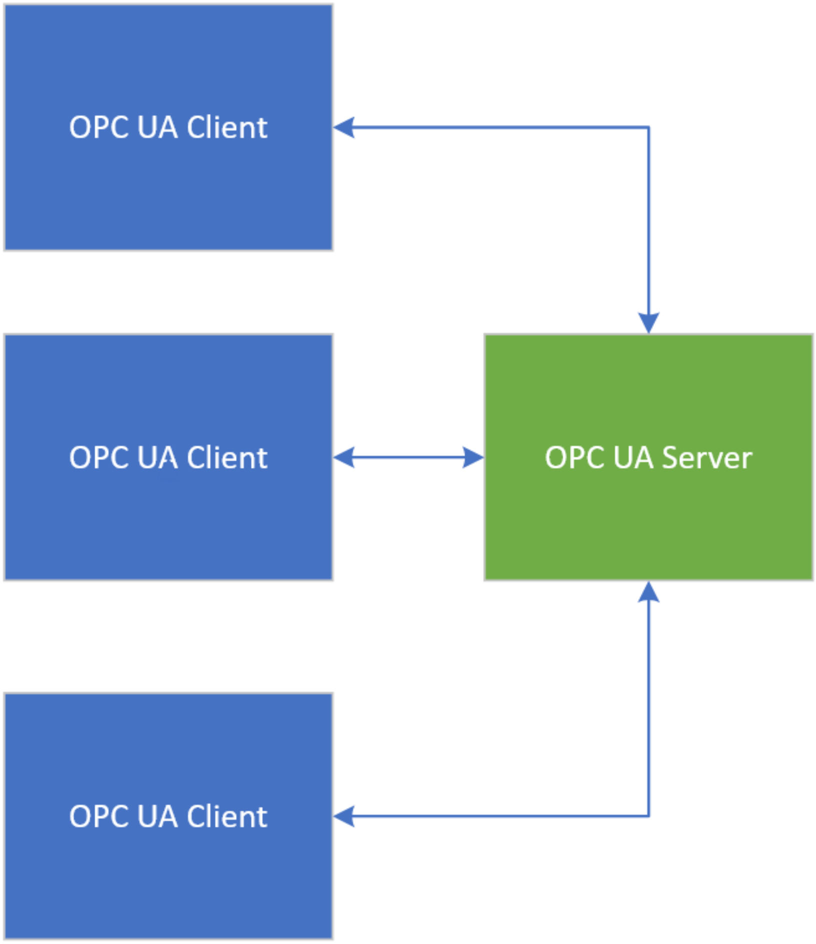

Figure 2.6: Simplified explanation of the relationship between clients and servers in OPC UA. Adapted from Mahnke et al. (2009).

In OPC UA *address spaces* are used to provide a standard way for clients to get access to the objects on the server (Unified Automation, n.d.). The address space consists of a group of OPC UA nodes, the OPC UA Nodes will have a class, the class used to model data is the *variable* NodeClass (Cavalieri & Salafia, 2020). This NodeClass can have the attribute *DataType* which describes another of its attributes *Value* which can be used to store specific data from the production.

Opcua-asyncio is an open source and free to use Python library that allows the user to set up an OPC UA server and client. It is possible to add functionality to make it suit the interest of the user (Github, opcua-asyncio, 2022).

2.7.2 REST-API

REST is an abbreviation of *REpresentational State Transfer* and is a style that is used to make designs for web APIs. Web APIs (*Application Programming Interface*) is a concept used to make it possible to get responses by sending for example

HTTP(S)-requests. The responses and requests can be sent in for example JSON-format. Some of the methods that can be used in requests are described in table 2.1 and can be used to for example access data, posting new or update data (Fredrich, 2022).

Table 2.1: HTTP-methods used in this project (Fredrich, 2022)

Method name	**Function of method**
GET	GET is used to retrieve data
POST	Used to create new data
PUT	Used to update a resource

3

Methodology

This section will describe the different methodologies included in the project.

3.1 Design of Digital Twin

The case study will largely follow Virtual's Gate-Driven Industrialization Process, which is a work method consisting of six gates (four phases). The gates are specified as following:

- **Gate 0 - Definition of Business Case** (Concept Phase). This signifies the background of the project, objectives, aim and planning. These steps are vital to ensure that the project group has an idea of what is important for the project and a general understanding of the business. Initial planning should be conducted to provide an idea of time distribution for specific tasks.
- **Gate 1 - Today's Scenario "As Is"** (Pre-Study Phase). After the background, objectives and planning have been set, it is time to describe the current state of the business in relation to the project. Today's Scenario will be used as a framework upon which suggested improvements and their analysis will be based on.
- **Gate 2 - Future Scenario "To Be"** (Pre-Study Phase). The desired state and impact of the project. The Future Scenario includes understanding the customer needs and requirements in order to deliver an optimal solution. This gate shows the result that is expected following the efforts of the project group.
- **Gate 3 - Process Design** (Pre-Study Phase). In this part, the work to design the Future Scenario is started. The work during gate 3 should result in a process that can be used to complete the project. The process goes in depth to prepare for testing to be started. A close-to-reality solution is created.
- **Gate 4 - Sourcing & Training** (Detailed Planning). When the design is deemed ready, small scale testing is conducted. A prototype of the solution is created, or a workshop could be held with involved employees. This process allows for quick feedback on valuable features or inputs from the end user.
- **Gate 5 - Implementation Ramp-up** (Installation & Standard Operating Procedure). Implementation of the Future Scenario in the actual state of the business. At this stage the solution should be ready and thoroughly tested to ensure major quality issues are avoided. The resulting service or product should be expected to operate without significant errors.
- **Gate 6 - Follow Up, Kaizen** (Installation & Standard Operating Proce-

dure). Analysis of the implementation and result. Reflection into what could be improved and if the implementation went according to plan. This gate connects to the discussion and conclusion part of the final report in the project.

Virtual's Gate-Driven Industrialization Process is designed to work with many different types of projects which means that the description of the different stages may in some cases not be directly applicable in this project. Gate 4 and 5 (Sourcing & Training and Implementation Ramp-up) will not be fully realized in this project, as the final result of this project is not going to be implemented in the actual production, especially not in full-scale. The main reasons for this is the lack of access to the actual production and production data. Nevertheless, the following Gate 6 (Follow Up, Kaizen) will still be used as a method of gathering feedback, improvement potential and ideas for future development. As the result of this research will culminate in a proof-of-concept, it could be further built upon to directly suit customer needs.

3.1.1 Design methodology for Digital Twin

While choosing the design for the Digital Twin, extensive literature search was performed to find the optimal methodology. The search pointed out a few specific methods for creating a Digital Twin:

- **Data-based digital twin** This method is described by Adamenko et al. (2020) and is based on collecting data on a physical object. This is usually done by structuring data according to functionalities or other criteria. The method creates a general view of the physical counterpart and can be used for root-cause analysis and complemented by machine-learning algorithms. An advantage to this method in comparison to others is that it is not as dependent on technical information to be realized.
- **System-based digital twin** Adamenko et al. (2020) goes on to describe another method, the System-based digital twin, which sets the actual physical object in a more central role. Models of machinery need to be created and therefore technical information of these processes is mandatory for accurate representation. The authors go on to describe the need for a "skeleton", which consists of models and data. This type of digital twin is great to use in combination with simulations, and what-if analysis can be applied to find how certain circumstances would impact included processes. While this model is quite complex, it does result in deeper understanding of the physical state.
- **Combination** The final method mentioned by Adamenko et al. (2020) is simply combining both the previously described approaches. While this is time consuming, the method would be comprehensive and advantages from data-based and system-based methodology can be reached. One great strength of combining the two is that the model can work with both collected data and future scenarios in which data has not yet been collected in the physical state.

Constantinescu et al. (2020) describes a methodology which is similar to the combination mentioned earlier. This method consists of four steps:

1. Physical objects such as industrial machines or robotic arms need to be recreated in virtual design software like CAD.
2. Installing sensors that collect desired data on these chosen objects.
3. When data has been collected then analysis, algorithms and simulations can be applied.
4. Actions for optimization described with the help of visualization and documentation with the aid of the digital twin.

The chosen methodology for the duration of the technical DS design will be the combination method mentioned by Adamenko et al. (2020) (which is largely similar to the method described by Constantinescu et al. (2020). The steps of these methods will fit into the third gate "Process Design" of Virtual Manufacturing's work process. A visualization of the overall idea of the project method is illustrated in Figure 3.1.

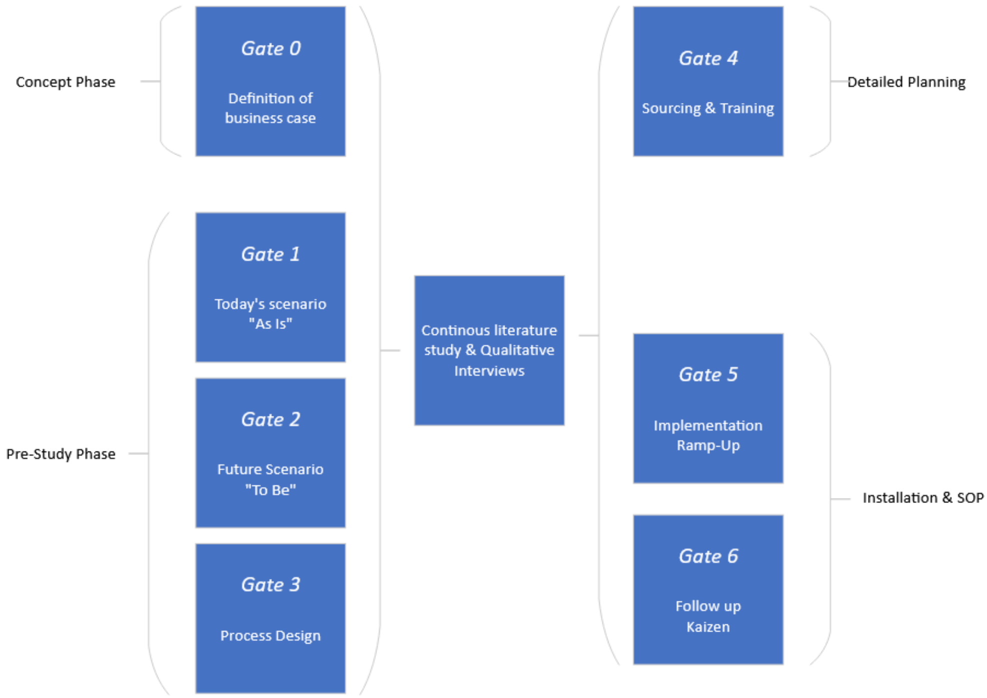

Figure 3.1: Illustration of project work methodology

3.1.2 Today & Future Scenario

Early on in the project, the current state and availability of the current scenario needed to be assessed. This showed that while Bror Tonsjö AB had implemented sensors that collect data into large parts of their production, this data was not integrated into any extended 3D-platform but was purely stored in their IT-systems for information that could be useful for operators and other employees. In addition, while some groundwork had been performed in terms of 3D-visualization (3D-scanning and virtual model of walls and pillars), it needed to be heavily expanded to be useful.

For the future state, the 3D-visualization needed to be fully complemented with all relevant processes, and data had to be integrated into that platform. This would describe, in an easy-to-understand manner, exactly what was going on in the production, even for someone who never visited the factory in person. The data to be visible in the DT should follow customer needs and requirements, as well as additional data that could create value for Bror Tonsjö AB in their decision making.

3.1.3 Process Design

In line with the method mentioned by Constantinescu et al. (2020), the initial step of the process design was to create virtual models of Bror Tonsjö's industrial machines, robots, and other relevant objects. Before getting into the CAD-software, an already completed 3D-scan of the factory was already available in the online mapping platform NavVis IVION. To structure the 3D-scan, points of interest were added for each machine to easily navigate the 3D-scan and add some structure that will be useful for progressing the project.

With all points of interest added, the CAD-modeling could be started. While recreating the factory, accuracy of dimensions was vital for the legitimacy of the virtual factory. Therefore, point cloud technology was used to crop out each machine from NavVis IVION and insert into the CAD software. With the point cloud ready to use, the vast majority of the machines, robots, cranes and others could be designed. A few models could be delivered by suppliers and therefore did not have to be designed. When a machine was designed, it was checked off the machine list and stored for later use. The level of detail was comprehensive, especially in terms of dimensions, but also appearance as this added value to the visualization. Smaller details such as machine elements were deemed unnecessary for the final goal and therefore largely neglected as it would drastically increase time consumed into CAD.

When all CAD-models were completed, the software Visual Components was used to compile the full visualization of the factory. A basic version of the complex already existed, but consisted only of walls and pillars. Objects were added to this basic version to build the 3D-layout. The 3D models were added one by one and put in their correct place with localization guided by the scan available in NavVis IVION. This included the CAD-modeled machinery, but was also complemented by pallets, forklifts and other material handling models that were available in the Visual Components software.

As all the desired objects were added to Visual Components, the 3D visualization was deemed complete. Following this, the real-time data from the sensors needed to be gathered. However, Bror Tonsjö AB could not personally share their data for the purpose of the project because the data custodian was a consultancy firm that implemented the Mindsphere solution for them. The data custodian was contacted to grant permission, and they offered a solution that updates a single data source of one machine every other hour. This was deemed inadequate, as for the sake of the project, a real-time solution was desired. With limited access to the actual data from the production, it was decided that "simulated" production data should be used. This solution was reached by hosting a personal server through Python programming and adding custom variables that symbolize the state of production processes. With the data ready to use, it then had to be connected to the 3D visualization.

The Visual Components software has a built-in connectivity feature that was used to attach the data to the visualization. With the server up and running, only the server address was needed to gain access. Thereafter, specific components were connected to signals from the server. The nature of the signals was chosen to be Boolean due to the streamlined interactions with these signals and the Visual Components software. Boolean signals required little workarounds since a false/true signal could easily be understood by Visual Components to activate certain features. For integer variables such as tool cycle data, a Boolean variable was added to the server that reacted on the value of the integer. When the tool cycle integer surpassed a specific value, the Boolean signal would activate.

Similar connectivity functions were built into the NavVis IVION-platform to build upon the PoI-based system. First APIs were developed in the software Postman to be able to read and write to the PoIs in NavVis IVION. The REST-APIs were built using the documentation provided by the company behind the platform. The next step was to use the export function in Postman to export the REST-APIs to a format adapted for use in a Python environment. When the REST-APIs were developed a Python script expanding on the OPC UA Asyncio library was developed to be able to read data from the OPC UA server and if changes had occurred sending new data to NavVis IVION. The PoIs in NavVis IVION could then be used as a tool to visualize data from the OPC UA server.

3.1.4 Follow Up, Kaizen

For the purpose of following up on results, feedback was gathered through qualitative interviews with Bror Tonsjö AB and Virtual Manufacturing staff. The interviews were of structured nature. It was decided that, prior to demonstrating the results, a few general questions would be asked regarding the interviewees views and definition of a DT/DS. Thereafter, a presentation of the process design would be held, followed by additional questions related to the design itself.

3.2 Research methodology

The work procedure consisted of identifying the customer needs and finding solutions to solve their industrial problems and challenges. A structured research method was followed to document the project and follow optimal working procedures, which added to the standard working procedure of Virtual's Gate-Driven Industrialization Process. The developed solutions needed to be reflected upon and evaluated to realize the benefits and potential shortcomings. When shortcomings were identified, they would be further analyzed to understand their impact and thereafter provide greater suggestions.

The method that was used for this project to gather data mainly consisted of qualitative interviews (with the Bror Tonsjö AB and Virtual Manufacturing staff). These interviews were mainly unstructured, as several meetings with responsible staff took place during the course of the project in which new information was provided to the project group. Structured interviews were arranged as needed for further clarification and feedback. Secondary data analysis also took place, specifically during the Pre-Study Phase, in the form of literature studies.

The literature studies were performed regarding the technology and what benefits and consequences that could follow the implementation of the DT/DS (for instance ethical or technological). The purpose of the literature study was to gain holistic knowledge of this type of technology, the implications any implementation could have in the production, and researching important takeaways from similar projects. The prioritized literature consisted of academic resources and papers.

3.2.1 Qualitative interviews

The qualitative interviews were mainly of unstructured nature. However, some semi-structured and structured interviews were organized. These interviews were held to gain insight into the actual state of the production of Bror Tonsjö, their working procedures in relation to the proposed digitalization of their industrial complex, as well as finding customer needs and requirements when designing the Digital Twin. Unstructured interviews were initially held with Bror Tonsjö simply to gather basic information on their approach and efforts of digitalization. When this was established, semi-structured interviews were conducted to find more specific information (for instance what data is collected? What systems are currently in place?). Structured interviews were used for the purpose of gathering feedback on the final process design.

In order to store the content of the interviews for future analysis and reflection, one of the interviewees was selected to transcribe the answers as they were given. The reason mainly one person was selected to do this was that the quality and flow of the interview would not deteriorate due to taking notes.

For the purpose of analyzing the data in a structured manner, a coding method had to be introduced (Bryman & Bell, 2011). The reason for coding the qualitative interviews was to reduce the influence of preconceptions or personal opinions. There will always be some bias based on personal experience when performing the coding, but the goal is to minimize it and present objective, transparent data. While theory in the field of DTs and DSs was studied beforehand, the coding was introduced with the mindset that previous theory should not affect how information is perceived from the qualitative interviews. Therefore, should the qualitative interviews indicate some exceptions from the theory, it should not be discarded. The chosen coding method consisted of initial transcribing of the interviews safeguarded by audio recordings to fill any gaps of information. These transcriptions were then studied through reviewing the repetition of key concepts, ideas and themes throughout the interviews and organized into lists (Gibbs & Taylor, 2010). After that, the key takeaways were categorized into four sections relevant to the research questions, which were chosen as the following:

- Definiton of DT
- Potential of value-creation
- Use case for technology
- Further development and requested features

The chosen coding method was used for the sake of analyzing the feedback interviews at the end of the process design. While information had been gathered as an iterative process to gain knowledge of the production, their current situation and how to plan the process design, the earlier interviews were mostly unstructured and not transcribed literally. Therefore, to keep the coding accurate, it was decided that coding should be kept to the fully transcribed feedback interviews.

3.2.2 Literature Study

A literature study was conducted to provide secondary data for the purpose of the project. The literature mainly consist of research papers gathered from Chalmers Library services and their available databases such as EBSCOhost and SCOPUS, as these are considered to be highly reliable sources to use for referencing and discussion. While performing the literature study, keywords were chosen and sources documented based on what keyword was used to find specific papers, therefore providing structure to the search. Examples of some keywords used include *Digital Twins*, *IoT implementation*, *Points of Interest*, *Online mapping* and others, for a full list, see Appendix A. In addition, since Industry 4.0 technology is a relatively modern phenomenon and research is ongoing, emphasis was put on the date of the papers and taken into consideration while reading.

The literature study was an ongoing process throughout the project. Initial studies were held to understand the background, business case, definitions and challenges of Industry 4.0 technology. As the thesis was progressing, the literature search could be more focused into specific topics, for instance guided by information that was gathered during the qualitative interviews.

4

Results

4.1 Understanding the case

In the start of the project multiple informal interviews were performed to get an understanding of the case. The stakeholder at the factory was interviewed as well as the stakeholder at Virtual Manufacturing. This initial data collecting provided the project group with knowledge of the current situation of the factory, the expected uses of the DT/DS and the tools available in term of software and infrastructure. These interviews were not transcribed literally as explained in 3.2.1 and therefore not coded, but the main takeaways from the initial interviews were summarized.

4.1.1 Initial interviews with Bror Tonsjö

The conclusions from the first interviews with the CEO at Bror Tonsjö AB were the following:

- Currently Bror Tonsjö AB is already collecting a lot of information regarding the machines' status, such as current status of machines, error codes and tool changes.
- Some of the machines are already connected to a system called Mindsphere which collects and visualizes some of the information on dashboards in the factory.
- The group of people that will use the DT are mixed, the role of the one who uses the DT will depend on why the machine is interesting at the moment. It could for instance depend on machines having stopped or that the tooling should be changed.
- Bror Tonsjö AB would like to visualize all the stops, and desirably why they occur as well. It would be interesting to use signals from Mindsphere show to information in Bror Tonsjö AB's point cloud view (NavVis IVION) according to the management at the factory. In addition, Bror Tonsjö AB thinks it would valuable to identify bottlenecks and analysis based on maintenance statistics.
- In the future Bror Tonsjö AB thinks it would be valuable to use a DT to run simulations and understand the consequences of changes in the production. For example if Bror Tonsjö AB would introduce new machines and products, it would be desirable to preemptively identify the effect on the production and the logistics required (such as for instance number of pallets).

4.1.2 Initial interviews with Virtual Manufacturing

The conclusions from the first interviews with the supervisor at Virtual Manufacturing were:

- A 3D-model of the factory using the already made 3D-scan of the factory would be a good start to the project. The 3D-model should be accompanied by a 2D-layout.
- The supervisor prefers the project to present information in NavVis IVION using PoIs, preferably using data from the factory. In whichever way data is presented, it is desirable that there is some sort of coloring feature that represents changes of machine status.
- Virtual Manufacturing has not used Mindsphere as provider of data before. However, there are ongoing projects with similar systems.

4.2 3D-Visualization

The result of the 3D-Visualization was a combination of several independent efforts through unique software. In sequence, it can be described as initiated by the 3D-scan (which was performed before the project started), continued by creating PoI in NavVis IVION, design of CAD-models and finally recreating the full factory in Visual Components by placing the CAD-models in the accurate position.

Implementing PoI into NavVis IVION resulted in a clear display of machines localization in the factory. Almost every machine that was provided in the list of objects was added to the 3D-scan as a PoI, however there were some minor discrepancies due to the 3D-scan being slightly outdated. This meant some objects did not exist in the virtual scan. Adding PoIs resulted in a functionality similar to Google Maps street view, where it is possible to orient the factory and identify machines, as well as search for specific objects due to the object number being included in the name of the PoI. Furthermore two PoIs were used to show and make both a 2D-drawing and a 3D-model (CAD-model) of the factory available for the user of NavVis IVION, see figure 4.1.

Figure 4.1: 2D and 3D models of the factory can be accessed by these two PoIs in NavVis IVION

The point cloud visualization was, as previously stated, created with the platform NavVis IVION with a prepared 3D-scan of the factory. In NavVis IVION, categories were created for all the specific processes, such as for instance turning or drilling machines. All machines in the factory had been assigned a number by Bror Tonsjö AB, which was printed on each machine in the production. When a machine was selected in the list of objects, the machine was located by finding its' assigned number through navigating the 3D-scan. A PoI was then created for that specific machine, which was then added to the appropriate category. In addition, short descriptions were added to the PoI that clarified any notes that were included in the object list from Bror Tonsjö AB. This process was repeated for all objects, providing a clear overview of all machines in the point cloud, and sorting them all into categories to allow for easy identification and navigation. The purpose of this work was not simply to create a visualization that is to be connected with real-time data, but also to simplify the process of creating the 3D-models.

The first step of creating 3D-models consisted of utilizing the point cloud. When a machine was chosen for design, a cropped out point cloud of that machine was taken and imported into the CAD software. This made it possible to reverse engineer models of machines in correct dimensions, an example of resulting 3D-models using this technique is illustrated in figure 4.2 and 4.3. A layout consisting of walls and supportive pillars of Bror Tonsjö AB's production was already available, to which the 3D-modeled machines were added. For the purpose of finding the correct location for each machine, careful estimation in the NavVis IVION platform was used. The machine's surrounding were identified, as well as their distance to walls, pillars and gates, which was used to determine the placement of the machine in Visual Components. In terms of other objects that were not in the provided object list from Bror Tonsjö AB, such as pallets, shelves and barrels, there were pre-designed models available in the Visual Components software that were used for these details. These types of objects were not designed in CAD by the project group, since the pre-designed models represented their appearance very accurately.

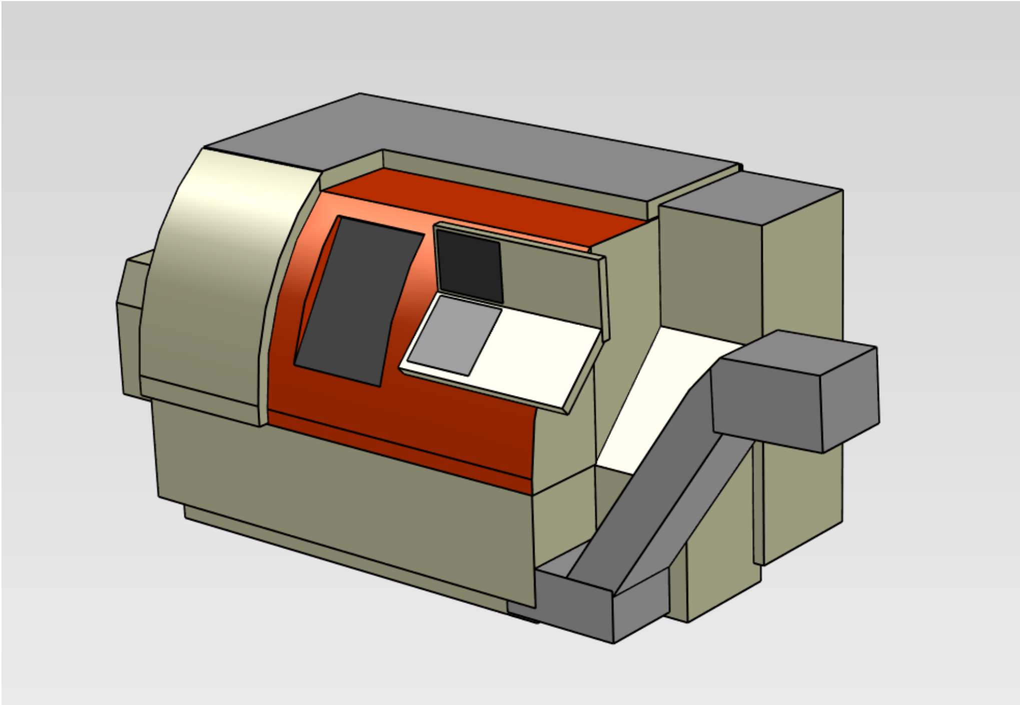

Figure 4.2: First example of machine designed through reverse engineering using point clouds.

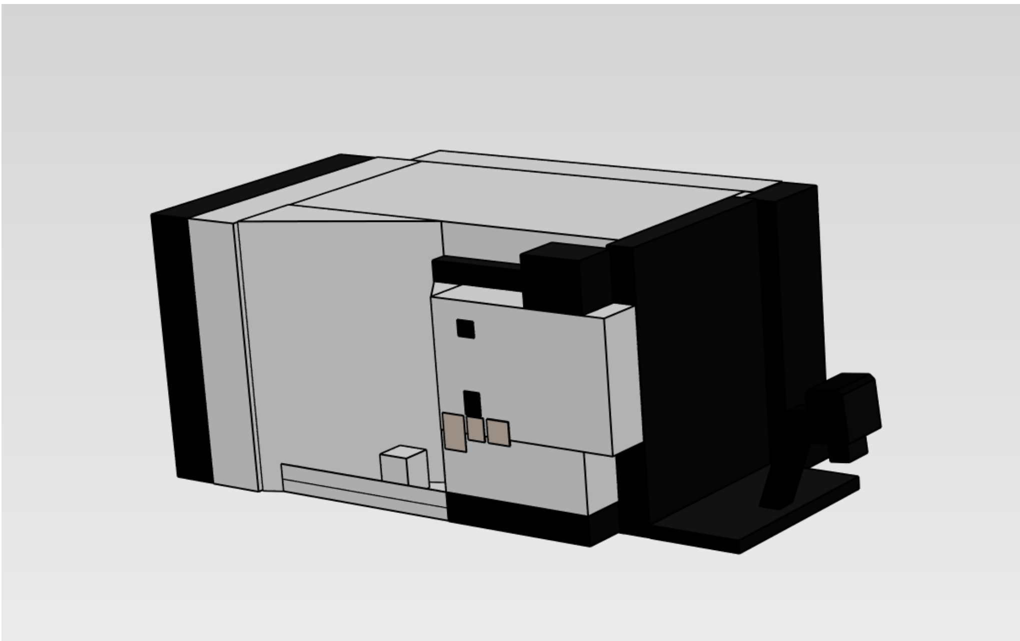

Figure 4.3: Second example of machine designed through reverse engineering using point clouds.

The level of detail in the CAD models were chosen to, if possible to determine from the 3D-scan, accurately represent a machine through their exterior. A trade-off between aesthetics and time invested into 3D-design had to be made, due to the immense work that would have to be invested into CAD to make one-for-one copies of each machine. Simply described, the machine features should be recognizable and easily identified. That being said, minor details that did not provide much value for the purpose of the project (like machine elements, specific buttons on a control panel, etc.) were not added as a balance of time and precision. Objects that take up considerable space in the factory like machines, cranes, fences and logistical items such as pallets are added in order to get a proper idea of the layout and available space. While the full 3D-visualization can not be published due to customer confidentiality, see figure 4.4 for an idea of the layout.

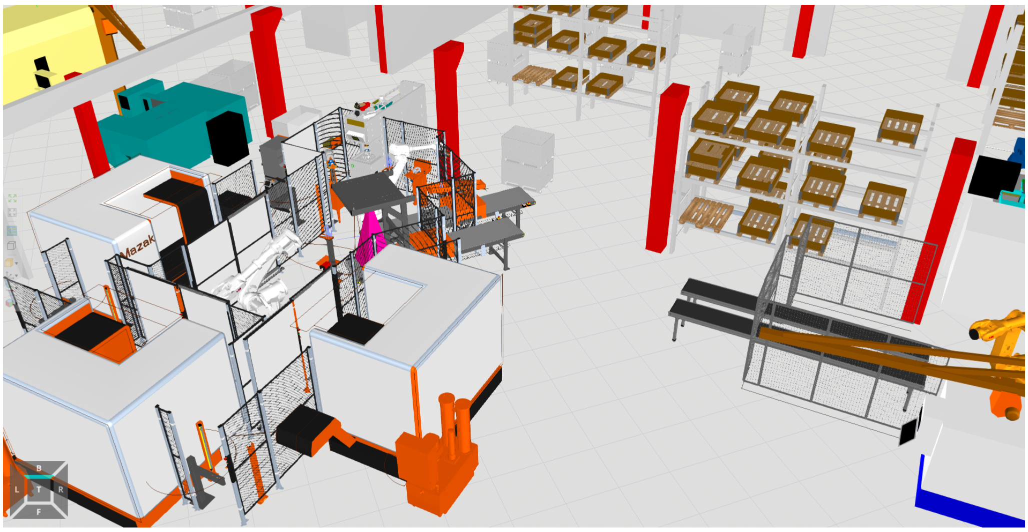

Figure 4.4: Example of enclosed machine cell with robot, accompanied by nearby pallets, shelves and conveyor belts

4.3 Connectivity and Internet of Things

The creation of a 3D-model and introduction of PoIs was the first step of the project. The next step was to connect the visualizations to data regarding the production. However, the real time data was not accessible for this project in any manageable way. Therefore a concept using simulated data using a platform that would be available if the project group had better access to the factory was used. The system used today at the factory have support for the platform OPC UA, therefore the connectivity part of this project took that into consideration and developed a solution using that platform.

4.3.1 OPC UA Server

The first step to accomplish connectivity features was to create an OPC UA server that would simulate machine data. This was made by adapting and using a Python library (OPC UA Asyncio) to create a server and later also a client. The result was an Python script that when running will host a local server with customizable variables. The script that was created for hosting the server set up various typical production data, including active status, temperature and tool cycles. The "active status" was Boolean and depended on the temperature variable, a continuously changing integer in the server. The temperature variable was set to a starting value of 75 that randomly increases or decreases by three points each second. Upon reaching a temperature in excess of 80, the "active status" variable would switch to provide a signal in the visualization. The tool cycle was, like the temperature, also an integer that was connected to a Boolean signal. The tool cycles started at zero and, for purposes of modeling and clarity, increased by one each ten seconds. The final two variables were related to item count and full containers, item count being an integer acting similarly to the tool cycle variable, and a Boolean signal named "Full Container". To see a summary of the variables and their behaviors, see Table 4.1 below. This script, in general, provided a proof-of-concept solution that showed possibilities of implementing real-time data if a production database is available. An excerpt from the Python code used to host the local server are available in appendix B. A flow chart describing how the OPC UA server were used and connected to clients can be seen below in figure 4.5. The figure also shows how the system could have been connected to Mindsphere.

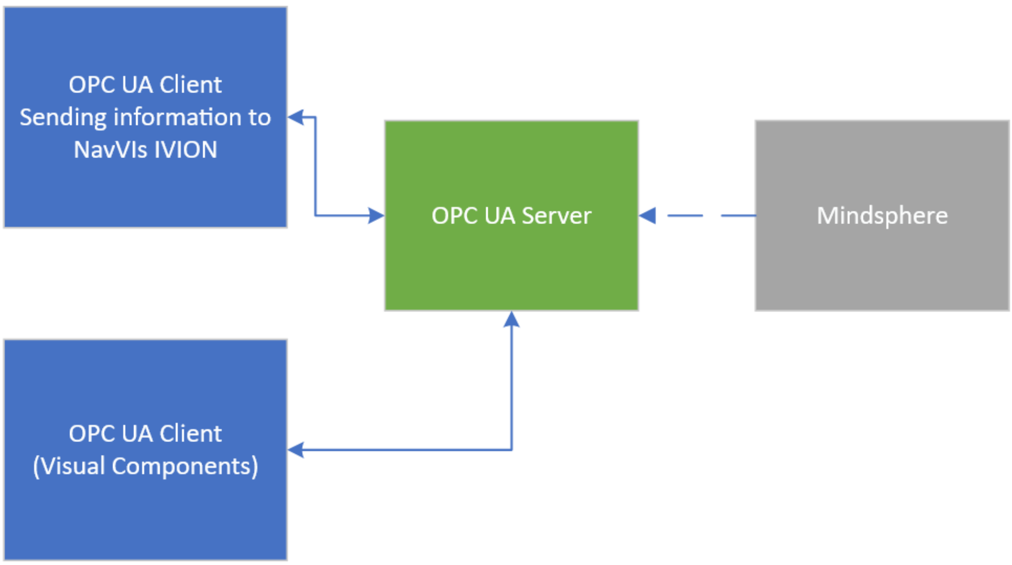

Figure 4.5: A flow chart describing how the OPC UA server were connected to clients and how it could have been connected to Mindsphere.

Table 4.1: Table of all variables used in the server script

Variable	Starting value and behavior	Effect on DT
Active status	Boolean that is dependent on temperature variable	If true, presents a green signal in the DT. If false, presents a red signal and posts an error code warning that temperature levels are overheating.
Temperature	Integer that starts at 75 and randomly increases or decreases by three each second.	Upon exceeding the value 80, the variable will change the Active status Boolean to False.
Tool change	Boolean that is dependent on the tool cycle variable.	If true, presents a yellow signal and posts an error code warning that a tool change is recommended.
Tool cycle	Integer that starts at zero and increases by one each ten seconds.	Upon exceeding the value ten, the variable will change the "tool change" Boolean to true.
Full container	Boolean that is dependent on the item count variable.	If true, presents a red signal and posts an error code warning that containers need to be emptied or replaced.
Item count	Integer that starts at zero and increases by one each ten seconds.	Upon exceeding the value ten, the variable will change the "full container" Boolean to true.

4.3.2 Information to show in Visual Components

The aforementioned server was connected to the 3D visualization created in Visual Components. A pre-designed signal tower in the Visual Components software was chosen to be placed on certain machines to signify their current status in the 3D-visualization. This component was chosen as it suited to the general layout of the factory, it resembles a typical production component consisting of three separately colored lights (red, yellow and green).

The variables in table 4.1 had to be manually added in Visual Components for the software to process them. Each variable was added as a Boolean or integer depending on its' behavior, which was then linked with the corresponding variable in the Python script through Visual Components connectivity features. The Boolean signals were then directly connected to a specific light on the signal tower through Visual Components. Each light was then connected to an appropriate Boolean variable, with "True" signals illuminating the lights on the component. The *Active status* variable was connected to the green signal, while *Tool change* was attached to yellow light and should be interpreted as a recommendation for changing tools rather than emergency maintenance. *Temperature* and *Full Container* were considered more severe for the production, and were therefore connected to the red light. The process of creating and connecting variables in Visual Components was conducted individually for every machine that was selected for real-time data, due to the need of setting unique variables for each machine.

The integer variables were useful for printing error codes in Visual Components output field. A Python script within Visual Components was created for the purpose of managing these error codes. In the script, the tolerated maximum values mentioned in 4.1 were set. Thereafter, the integer variables were compared with the maximum tolerances in if-statements. If the integer variables from the server exceeded the tolerances, error codes would be printed depending on each variable. A few certain error codes were created, examples of which can be seen below:

- *Machine 34 - Change tool!*
- *Machine 34 - Full Container*
- *Machine 33 - Temperature too high!*

To see an illustration of how the error codes are printed into Visual Components output field, please see figures 4.6 and 4.7. The figures also demonstrate the functionality of the signal towers. To see the full Python script that was created for the purpose of controlling the behavior of the error codes, see Appendix C.

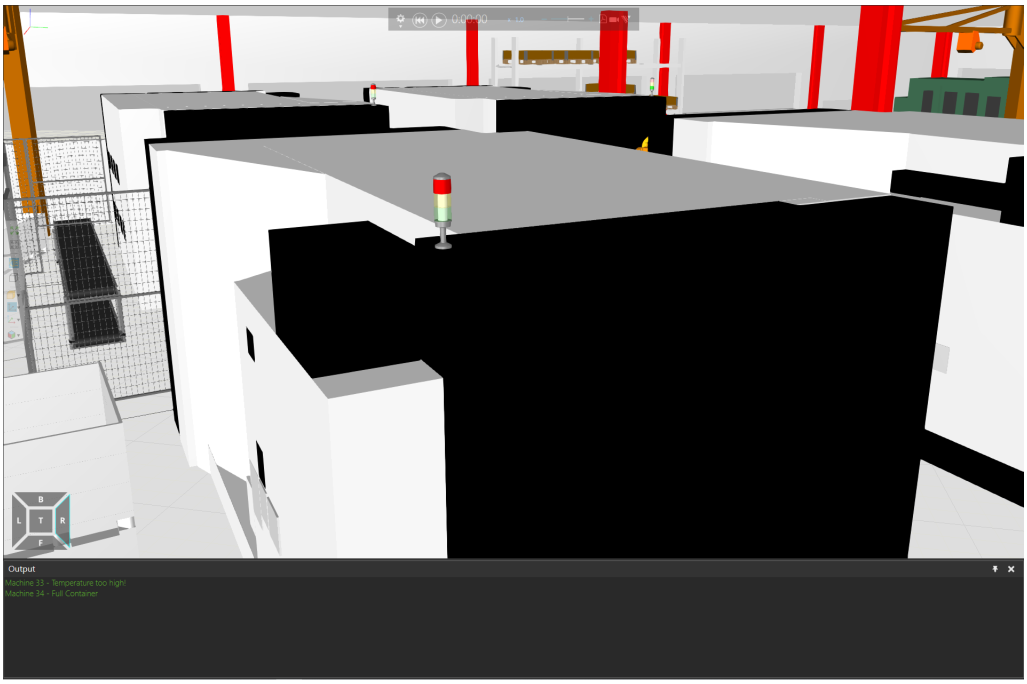

Figure 4.6: Close-up of machine 33 accompanied by several machines with signal towers. The signal tower is showing a red signal because of temperature levels exceeding tolerances.

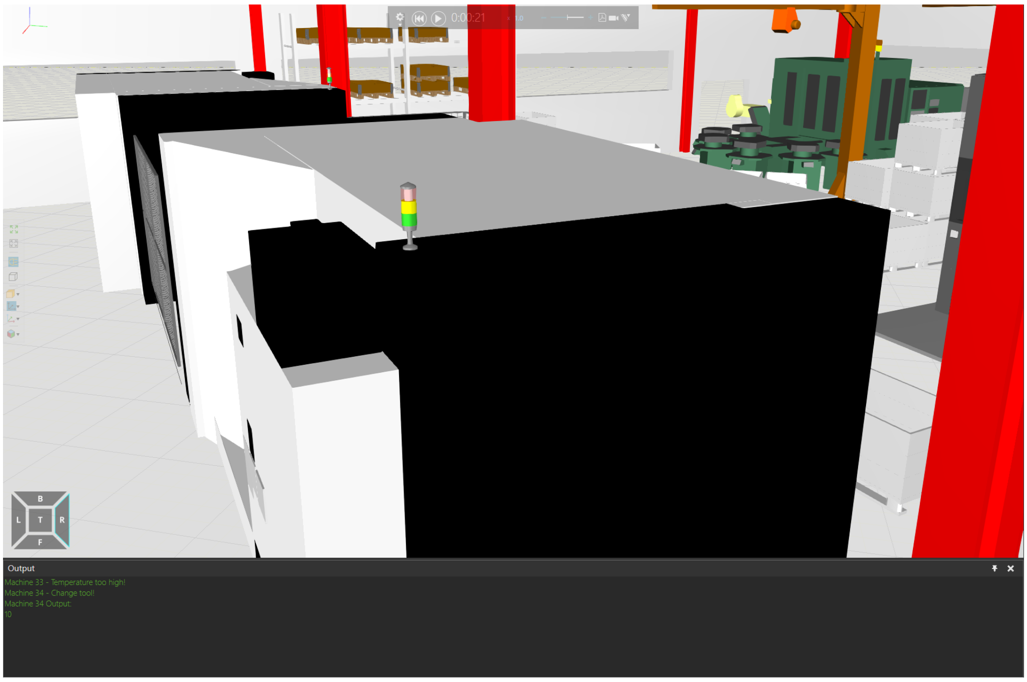

Figure 4.7: Close-up of machine 34 signaling a tool-change is recommended.

4.3.3 Using PoIs in NavVis IVION to visualize information

Connectivity features were added to the PoI in small scale, just like in the Visual Components software. A client for OPC UA was programmed using the previously mentioned OPC UA Asyncio library for Python. The client was first connected to the previously mentioned server. When the client code is running it is constantly checking if the status of any of the machines has changed since the last check. If any changes has occurred the client will update NavVis IVION with new information.

To be able to change the information displayed in NavVis IVION it is necessary to use REST-APIs specifically defined for NavVis IVION, see section 2.7.2. The REST-APIs were first tested and developed in the software Postman. In Postman it is possible to separate the different parts of an HTTP or HTTPS request to be able develop APIs faster. It is also possible to export code in a preferred language and with small changes import it into the context where it should be used. The first step was to ensure that the Python script would have access to read and write the information displayed in NavVis IVION. This was achieved by passing a HTTPS request for an authorization token together with a username and a password. The token (a string of text) was then used to gain access to other functionality within NavVis IVION.

The next step was to download all the information regarding one PoI. Initially Postman was used to gain knowledge of which data the PoIs contains and the format of the data. When passing a GET-request with the ID of a PoI and the authorization token the response is in JSON-format and contains information like the position of PoI, title, description and URL of the icon. When the information regarding one

PoI was downloaded it was possible to manipulate it to later upload it via a PUT-request containing ID of the PoI and the updated data in JSON-format and thereby update the PoI.

When the functionality to update the information of a PoI was accomplished in Postman the next step was to implement the functionality in the OPC UA client to be able to actually read the information provided by the OPC UA server, see section 4.3.1. As previously mentioned it was possible to export the HTTPS-request from Postman and adapt it to a variation of languages. This project used Python and consequently the requests were exported in a format adapted to Python. However, Python requires some library to be able to work with APIs, Postman has the ability to export the APIs into Python-code that are complemented by the requests library which was used in this project for that matter.

The OPC UA client (written in Python) had mainly two functions; reading and interpreting data from the OPC UA server and reading and writing data to NavVis IVION. The first step in this process was to give the machines used different IDs to allow the client to keep track of multiple machines. The next step was check if the status of the machine had changed since the last time the status of the machine was checked (see Appendix D). If the status has changed the program continues to download the information of the specific PoI corresponding to the specific machine. This data will be in JSON-format but to update the information using Python it is converted to the dictionary format to be able to use keywords to update certain features of the PoI. The Python program updates the data in the Python dictionary using the data accessed from the OPC UA server. In this project the status affected the color of the icon connected to the PoI. Furthermore, a status message and error code may be displayed in the description field together with the item count for that machine. When the data are updated it is converted back to JSON-format to be able to use a PUT-request to update the PoI in NavVis IVION (see Appendix E). When this process is executed for one machine the script starts over with the next machine until the program has checked if the status has changed for all the machines. When all the machines are checked the program starts over and reads all the statuses again and updates the PoIs if necessary.

The continuous updates of the PoIs makes it possible to read data regarding from the factory using NavVis IVION according to the figures below (see figures 4.8, 4.9 and 4.10)

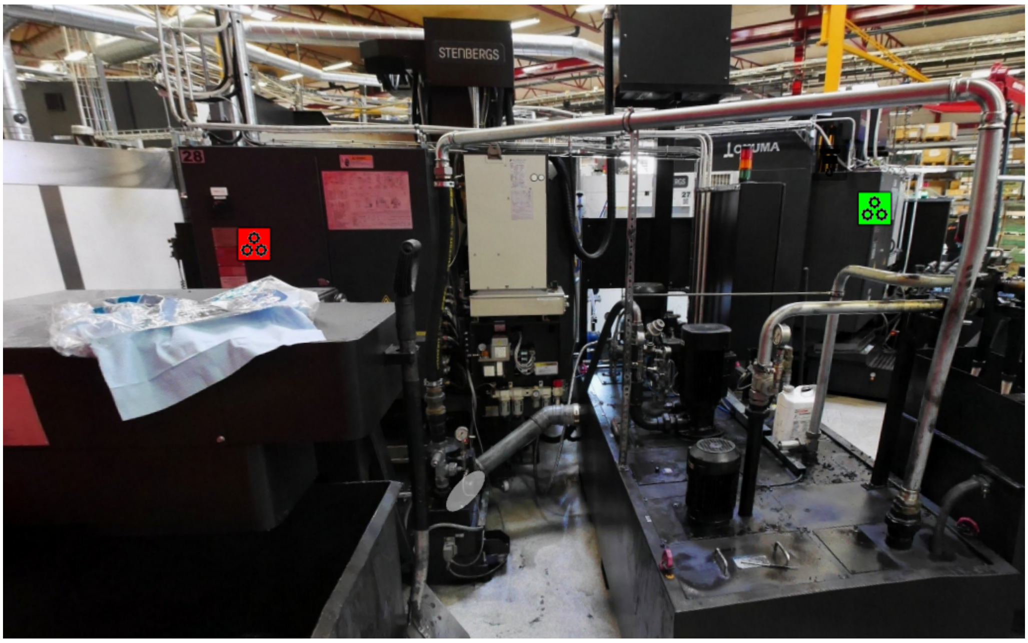

Figure 4.8: PoIs connected to two machines in NavVis IVION visualizing the status of the machine.

Figure 4.9: Overview from NavVis IVION including five PoIs visualizing the status of the machines. In the top left corner additional information for one of the machines is displayed

Figure 4.10: Screenshot from NavVis IVION showing the possibility to visualize the status using PoIs and to show more detailed information in the corresponding information window.

Furthermore, the program contained a list of the PoIs (and their IDs) corresponding to the information available from the server. The script then downloaded all the information the PoIs contained. When the information was downloaded the next step was to update the information using the data accessed from the server. The data was for example status of the machine, items produced since a specific time and a potential error code. When the information were updated it was uploaded again and the information was displayed either as text or as for example the color of the PoI. Thereby the information is easily accessible using a web browser, furthermore it is a way to visualize it to make it easy to understand.

4.4 Follow Up Interviews

In total, seven interviews were held with Virtual Manufacturing & Bror Tonsjö AB staff to gather feedback on the process design. These interviews were structured with questions separated in two phases, before and after demonstrating the process design.

Before the demonstration, some general questions regarding DTs were asked. The purpose of these questions was to establish what idea the interviewee has of a DT beforehand. Thereafter, the demonstration took place, and more specific feedback-related questions were posed. The questions that were used before the demonstration are specified in appendix F. These questions were used to get a general understanding of their opinion and knowledge about DTs.

The next step was to show the demonstration of the DT that was the result of this project. The main parts of the demonstration was firstly to show the 3D-visualizations that were made and what details and features that were included. Secondly, OPC UA were briefly explained followed by an explanation of what had been done in regards of connectivity in the project. This was demonstrated first by showing the work done with Visual Components and the ability to use it to visually show signals in the simulation, see 4.3.2. Furthermore, the ability to show information in NavVis IVION was demonstrated. This demonstration included visual information about the status of a specific group of machines and also certain data (in text) like a potential error code and the amount of products made since a specific time, see 4.3.3.

To identify patterns in the answers, a coding strategy was applied as described in 3.2.1. The main categories that were grouped for the purpose of coding were as previously mentioned:

- Definition of DT
- Potential of value-creation
- Use case for technology
- Further development and requested features

Analyzing the seven feedback-interviews from this perspective implied that:

- A majority of the interviewees (five out of seven) used the keywords *digital representation* to describe a DT. This keyword was then used in combination with *real-time data* in three interviews.
- In three interviews, the value of a DT was partially described as a tool to *test and evaluate* changes before implementation. In addition, *value for communication and data storage* was identified in another three interviews, while other topics such as *logistics*, *maintenance* and *ease of access* were mentioned to a smaller degree. In general, the answers for this topic showed the diversity of benefits that could be gained in a DT, which could depend on the background of the recipient.
- Similar to the previous point, the perception of use cases for the technology was not unanimous. In four cases, the *logistics* and *production technicians* were discussed. *Management tool* was the second most prevalent use case, found in three interviews. Other keywords that were found to a lesser extent include *simulations*, *remote work* and *gaining knowledge*.
- For further development and additional features, *simulations* was requested in two interviews. No clear pattern was identified, as the suggestions for improvement were mostly unique depending on the interviewee. Some other keywords were *adapting to several industries*, *changing displayed information* and *embedding NavVis IVION to expand possibilities*.

The interviews were held with people of different backgrounds and positions, with some being management and LEAN-oriented, while others held more direct experience from production-related work and technological design. The purpose of this was to gather opinions from different perspectives to get a holistic result. To summarize the results, it can be concluded that previous to the demonstration:

- Six out of the seven interviewees defined a DT as a digital representation of the factory (including visualization) that is connected to reality in order to provide a mirror image of production. The remaining interviewee specified a DT as a real-time database (similar to data-based digital twins that were described by Adamenko et al. (2020) and mentioned in 3.1.1), not necessarily needing a visualization but considering it a desirable feature.
- All interviewees could see some value in using this type of technology, but the answers were widespread and mentioned several different use cases. These include: simulations of production for implementing change or streamlining logistics, increasing efficiency of maintenance routines, increasing knowledge of operations, ease of communication and greater access to the factory.
- The general consensus of who would benefit from a DT being implemented was management, production technicians and maintenance workers. However, other uses were mentioned, such as logistics departments keeping track of stock levels and flows, with one interviewee saying that it could probably be useful to anyone in the company depending on what data is being analyzed.
- In terms of what type of business could use a DT, answers were quite mixed. It was concluded that the technology had use cases beyond traditional manufacturing companies, and could possibly extend into for instance grocery stores and health care. When it comes to company size, most interviewees thought large companies with several production sites would be able to find more utility for the DT, with smaller companies not reaping the same benefits due to them likely having a singular factory. The distances between the production plants in larger businesses makes it more valuable to use DTs as access to factories will be more streamlined. In addition, the costs of implementing and maintaining such a system was considered too pricey for smaller businesses due to the need of expanding IT-departments and hiring competent developers. However, others mentioned benefits for smaller companies as well due to potentially reduced costs related to surveillance. Two interviewees specified that it largely depends on the maturity level of the organization in regards to IT-infrastructure and openness to technology in general.
- The value of a 3D-visualization was considered great due to the ability of redesigning layouts. It could reduce costly mistakes occurring from misconceptions of the factory dimensions during the redesign. 3D-layouts could be great for communicating and sharing ideas, especially if the discussion is taking place through web-communication. For production technicians, it is important to recognize the environment when highlighting problems to other workers, which is made easier through 3D-models. On top of that, it could be used for sales due to enabling technical discussion of improvements. It could also be valuable to be able to show the factory without entering it when hiring personnel, or if there are safety reasons to not have people inside the factory.
- Industrial mapping through PoIs were mainly identified as a method of increasing availability of data. It could clarify the status of maintenance and stock levels. It could also be used for storing instructions. Two interviewees thought it was mainly a tool for management to keep track of their production, especially when working in global companies with remote production sites. One

interviewee answered there was not much inherent difference between using scanning and PoIs compared to 3D-models but it largely depended on what information was being portrayed.

The main takeaways from the questions asked after the demonstration, that were focused on the specific process design, can be summarized as the following:

- All interviewees saw value in using real-time data in combination with some sort of visualization tool, either the full 3D-design or using point clouds. Two interviewees separated between the two solutions and mentioned that point clouds in NavVis IVION are more readily available than the 3D-model designed in Visual Components.
- The perception of benefactors of the technology within an organization did not change after the demonstration.
- Choice of valuable data between the options (3D-model and point cloud) was similar, consisting of long-term statistics, production output, OEE (Overall Equipment Effectiveness), maintenance data and logistics. One interviewee mentioned that the two systems complement each other, singling out the 3D-visualization as invaluable for layout-changes as well as future development, but realizing this comes at a higher cost than the point-cloud platform. Another interviewee separated the two solutions, saying that the PoIs could be used to greater effect for "slower" information. Other types of data to be stored in PoIs but excluded in the 3D-model were work instructions and basic information of machines.
- Advice on further development was somewhat mixed. Expanding upon the 3D-model to be a more accurate representation of reality (including simulations, production flow and status of specific batches or products) was the most common suggestion. Others mentioned expanding the data to present other valuable information, while another request was to expand the possibilities in NavVis IVION to accept more common systems of data management.

The answers given during these follow-up interviews provide the basis for evaluation of the process design. This is related to the discussion of the research questions in the following chapter. To see the full structure of the feedback interviews, see Appendix F and G.

5
Discussion

This chapter will discuss the how the project got its results and what they mean. Furthermore, future development and research opportunities. Considerations regarding ethics and sustainability will also be discussed in this chapter.

5.1 Research Questions

In the start of the project, three research questions were specified that should be answered during the course of the project. The specific research question influenced the direction of the project and for example the formulation of the question in the performed interviews.

5.1.1 Values of Digital Twins and Points of Interest

After the literature study, process design and feedback interviews, it can be concluded that the value of DT/DS is extensive and not limited purely to manufacturing companies. As theory was being tested, all interviewees agreed that this type of technology could be a useful tool to improve operations. The implementation of real-time data, whether accompanied by a visualization or not, could be used for statistical purposes, analyzing logistics, improving production flow and realizing modern maintenance routines by transitioning to predictive models. In addition, it could increase knowledge internally of the organization. Due to the flexibility available in the design stage, a DT/DS could be valuable to most businesses and employees in specific businesses. It largely depends on the information that is gathered and how it is portrayed.

The theoretical background of this report has described some of the benefits an implementation of DTs/DSs could potentially bring to an organization, mainly consisting of visualization benefits and testing (Feng et al., 2021; Weinand & Rosenberger, 2021). However, through the feedback interviews, a wide variety of use cases were collected. Therefore, greater value could be realized than previously discussed. Although Weinand and Rosenberger (2021) and Negri et al. (2017) mentioned the role data serves in DTs when improving maintenance and decision making, it should be considered that a DT could influence a business to transition from less efficient maintenance to predictive methods. Implementation of a DT/DS could be the initial step an organization takes to identify shortcomings in their production in order to become more data-oriented in their analysis. As mentioned in the feedback interviews, there is a variety of choices depending on the design priority of the DT/DS to manage data (such as flows or long-term statistics). This groundwork could then lead to future pushes into for instance predictive maintenance.

Virtual PoIs can be used to realize value in different types of businesses, ranging from grocery stores to manufacturing companies. While the value of PoIs is widespread in most industries (Milias & Psyllidis, 2021), scientific research on their specific use for manufacturing companies is limited. Nonetheless, J. Liu (2020) does mention that PoIs can be used for the sake of visualization and data storage, which is also confirmed in the feedback interviews. Point clouds accompanied by PoIs are a viable alternative for organizations that do not recognize the need of creating a 3D-layout but still feel the need of incorporating real-time data. PoIs could also be used for data storage, without implementing real-time features, for instance through providing easy access to manuals, work instructions and long-term data. For businesses outside the manufacturing industry, it could be useful for registering logistical data and, in the case of grocery stores, act as a benchmark for analyzing how quality of products deteriorate depending on shop routines. One example of that is optimal time for restocking fresh goods. The conclusion of the use cases of this technology is that it is a valid alternative to creating a 3D-modeled DT/DS. If a business does not desire the benefits that come along with a simulations software, PoIs require a shorter design process assuming the infrastructure required is already in place.

5.1.2 Presentation of Information

All the interviewees, regardless of previous experience with DTs, considered it valuable to combine real-time data with some sort of visualization, creating a system-based DT. The manner of presenting the information was not quite as uniform, as point clouds were preferred to 3D-modeling by some interviewees. The main benefits of using point clouds solutions such as the NavVis IVION platform is the accessibility, as the entire factory can be observed using a standard web browser, and lower costs related to implementation & maintenance of technology. Furthermore, it is a way to visualize a factory that are easy to understand and does not require any special training to use. Important to consider however, is that using a 3D-simulations software such as Visual Components drastically increases the potential of the DT/DS. The technical limitations of NavVis IVION makes it more complicated to design an advanced system-based DT.

The general theory of designing DTs found in this report were Adamenko et al. (2020), who described three different measures of creating a DT, and the methodology mentioned by Constantinescu et al. (2020). A data-based DT (Adamenko et al., 2020), with little visualization of layout but more focused on the raw data, is one way of presenting information. This solution would not realize any benefits that come with 3D-modeling or point clouds, such as avoiding communication errors or greater accessibility, but could still be used for analytical purposes. The system-based DT, and the final "combination" method, are more similar to the process design of this project and the design proposed by Constantinescu et al. (2020). From that, we can conclude that there is a large variety in system-based DTs that come with their own benefits and drawbacks, which is not specified in the scientific research referred to in this thesis. Point clouds and 3D-models could both be used for a system-based

DT/DS, but are best used in the circumstances that have been described previously as optimal for each unique case.

5.1.3 Required Information

The information to be added in the DT/DS was summarized to production output, OEE, maintenance information, statistics for analytical purposes and logistical flow. For the DT to provide such information the production system has to feed it with data like the present status of the machine, temperatures etc. This will require sensors and networks sending the data to a server with a database to make it possible visualizing the information. The method of visualization is important to consider when presenting data. Using a platform like NavVis IVION is more open, but security of sensitive data needs to be considered due to that accessibility. There is no clear answer to what information has to be included in a DT/DS, it depends on the purpose of the DT/DS. The data needs to be adjusted according to the recipient of the data, which could be everyone from logistical workers to production engineers or managers.

The academic research discussing DTs such as Kritzinger et al. (2018), Weinand and Rosenberger (2021) and Feng et al. (2021) all describe the technology as reliant on data, but do not always go into details what kind of data should be used, other than maintenance data. While efficient maintenance is a great upside to DTs, the flexibility in the design means DTs/DSs can be helpful in a multitude of cases. These cases are illustrated through the varied responses in the feedback interviews. A DT is only limited to whatever the organization decides its use case should be and who should access the DT as a tool.

5.2 Design of Digital Twin/Digital Shadow

The project group involved in the case study from the start realized that it was necessary to limit what would be part of the case study. To develop a fully functional digital twin with automated flows of information in both directions would not be possible with the time and resources available. For example it was determined that it would not be possible to implement functionality that would allow the digital world to influence the physical world. Similarly, some of the stakeholders thought that it would be useful to run simulations in an easy and accessible way based on the data collected by the digital twin. This is something that is reflected in the research questions and their answers but it was not part of the field study or the practical work in the project.

Early in the project the challenges regarding access to relevant data were discovered. In this particular project the challenges were that the relevant data was not handled by the company themselves but by an external company. One consequence of this was that the external company did not have the possibility to share the data in a format easily usable for the project. Furthermore, questions about data security and integrity comes into play, especially when data stored at one location are to be used in a second location. Additional challenges in such setup is that the information has to get through multiple firewalls and the company has to make their production data available over internet, in the best of worlds this will not be an issue but it will mean an increased risk. The solution in this project of hosting the server at the same computer that ran the client is possible to show how it is possible to visualize data. However it will not be a suitable solution in most situation and is something that should be considered when starting a digital twin project.

As mentioned in the theoretical background (chapter 2), one issue of digital twins might be the incompatibility between different systems. In this project OPC UA was used which might make it more versatile since it is an open platform (Mindsphere, the system that is used at Bror Tonsjö AB, has support for OPC UA). However it will always depend on other systems involved. For example in this project Visual Components has support for OPC UA while NavVis IVION do not. Therefore it might always be a risk that specific implementations of digital twins including connectivity demands that specific solutions for the implementation are developed.

5.3 Ethical Considerations and Sustainability

As technology evolves it is important to consider what effects large-scale adoption could have on society in terms of ethics and sustainability (Kiger, 2021). In the past, previous industrial revolutions have resulted in immense evolution of production methods which have raised the ceiling on the possibilities of manufacturing companies. While the industry in itself has benefited, the effect on workers and the environment has suffered. As an example, the first two industrial revolutions resulted in poor living conditions for workers, unsafe labor, and environmental deterioration in terms of high levels of air pollution. Therefore, an analysis of these factors need to be considered when designing DTs/DSs.

DTs/DSs, as mentioned throughout the report, have great potential to streamline production processes. From a sustainability perspective, there is an opportunity to improve both financial and environmental shortcomings. As businesses turn more efficient and increase their OEE, their production related costs will decrease. For instance, with more knowledge available of the organization, employees can use their time more efficient through the increased transparency. Another example is the increased utility of maintenance workers through the implementation of predictive maintenance based on long-term DT/DS data. Not only would this lead to saving financial resources, through streamlining operations there is an opportunity to realize the full value of inherited machines and materials, for instance metal tools. Finding the optimal method of handling these resources imply less waste and in turn greater environmental sustainability.

The concept of DTs and DSs comes with obvious ethical considerations. There is a risk that, if a business decides to implement a DT/DS, the employees might feel the management is introducing excessive amounts of surveillance. This of course could depend on a multitude of factors, including everything from work culture, strength of unions and the extent to which the DT/DS is designed. Management has to take these factors into consideration when implementing a DT/DS solution and find a solution that fits their unique case, or risk consequences to the social sustainability of their operations. This could be especially relevant when trying to design an extensive DT/DS based on point clouds. Since point clouds is a technology that relies on real-world scanning (Engelmann et al., 2018) (J. Liu, 2020), having a fully up-to-date and advanced DT/DS could imply extensive surveillance of the physical part of the twin. This could in turn lead to discomfort among employees, who might feel they are being watched or controlled constantly. One interesting note that was mentioned in a feedback interview, is that the level of acceptance for this could vary strongly in different industries or hierarchies of an organization. While it has to be analyzed on a case-by-case basis, manufacturing industry has more history of large-scale control and surveillance for the sake of increasing productivity.

5.4 Further research

Some features were not included in the final result due to time constraints and other restrictions, but might be desirable in some situations. An accurate simulation of production processes would be desirable as it would extend the visualization and understanding of the production through mapping of production flows. The DS was not connected to actual industry data due to the restrictions on the project, but should that be implemented, there are security concerns that need to be considered due to the large amount of data that is being processed. Some of that data could be sensitive information that should not be leaked. Other than that, more in-depth functions to the DS should be added in the future to verify their effect. One example of that is designing the DS to be fully connected to a factory and analyzing how it would work in practice, including extensive error codes, methods of communication and data storage.

6
Conclusion

This project has studied the process of designing a DS for industrial use. Two different types of visualizations were created, one by using point cloud technology in combination with PoIs and the other through full 3D-modeling of a production site. The visualizations were then connected to real-time data, although no actual production data was included in the design, this was simulated through Python programming to act as a proof-of-concept with the help of a standard communication platform called OPC-UA. The result of the design was then evaluated through qualitative interviews which were used for gathering feedback and analyzing the value and use cases of the technology.

In conclusion, the result shows that DTs/DSs have great potential to streamline and increase knowledge of production systems and processes. The technology could be used for analytical purposes to gain deep knowledge of production-related issues, as well as increase efficiency in terms of maintenance. One example of that is an organization looking to rework their maintenance routines, using data presented and stored in the DT/DS to move towards less wasteful maintenance procedures with accurate predictive methods. The versatility in set-up of the DT/DS (such as choice of data to collect and scale) makes solutions quite flexible for companies in terms of adoption. The accessibility of information potentially spanning across several levels in an organization could make it easier to ascertain what is necessary to rapidly solve real-time problems. Due to the flexibility of the technology, it could be used in various organizations and tailored to their specific needs. Whether accompanied by a full 3D-visualization, point clouds or simply using a data-based DT/DS, the technology could be seen as a helpful tool for most businesses.

In terms of PoI, there is value to be gained and their use case can be extended to include manufacturing. The idea of storing information in a virtual setting is useful for analytical purposes in industry. Displaying data in an easily accessible manner could increase knowledge of organizational procedures and the status of the production. Such transparency would be available to operators as well as management, and increase cohesion in addition to overall understanding of the organization. The use of PoIs should be seen as a valid alternative to full 3D-modeling. If a business does not require an advanced simulations software that can accommodate a real-time DT/DS, considers such solutions too costly to maintain, or simply values accessibility much higher, it could be a viable option. However, it is important to mention the benefits that come with simulations. It could be used to increase the complexity of the DT/DS, including production- and logistical flows, and creating a true twin of a production site where movements of people, production equipment and products are illustrated.

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A

Keywords used in literature search

- Digital twins
- Digital shadow
- Points of interest
- Online mapping
- Online mapping production
- Industrie 4.0 Implementation
- NavVis IVION
- MindSphere
- Industry digitalization
- Iot implementation
- Industry visualization
- Digital twin AND production
- Mindsphere implementation
- Designing digital twin
- Industrial data collection
- Point cloud iot
- Industrial point clouds
- OPC UA
- Connnectivity

B

Excerpt of Server Code OPC UA

```
async with server:

    async def Update_Toolcycles(index):
        global cycle_counter
        global new_val_toolcycle

        cycle_counter[index] += 1 #Counts cycles for the Tool_cycle variable
        if index == 0:
            if cycle_counter[index] > 10:
                new_val_toolcycle[index] = await Toolcycles.get_value() + 1
                await Toolcycles.write_value(new_val_toolcycle[index])
                cycle_counter[index] = 1
            if new_val_toolcycle[index] > 10:
                await Toolchange.write_value(True)
            else:
                await Toolchange.write_value(False)

        elif index == 1:
            if cycle_counter[index] > 10:
                new_val_toolcycle[index] = await Toolcycles2.get_value() + 1
                await Toolcycles2.write_value(new_val_toolcycle[index])
                cycle_counter[index] = 1
            if new_val_toolcycle[index] > 10:
                await Toolchange2.write_value(True)
            else:
                await Toolchange2.write_value(False)



    async def Update_Status(index):
        global Check_Errorcode

        if index == 0:
            temp_check = await Temperature.get_value()
            Check_Errorcode[index] = await Errorcode.read_value()

            if temp_check > 80:
```

```
                await Status.write_value(False)
                await MachineStopped.write_value(True)
                if Check_Errorcode[index] == 0:
                    await Errorcode.write_value(1)
            else:
                await Status.write_value(True)
                await MachineStopped.write_value(False)
                await Item_Count(index)
                await Update_Toolcycles(index)
                await Container_Full(index)
                if Check_Errorcode[index] == 1:
                    await Errorcode.write_value(0)

        elif index == 1:
            temp_check = await Temperature2.get_value()
            Check_Errorcode[index] = await Errorcode2.read_value()

            if temp_check > 80:
                await Status2.write_value(False)
                await MachineStopped2.write_value(True)
                if Check_Errorcode[index] == 0:
                    await Errorcode2.write_value(1)
            else:
                await Status2.write_value(True)
                await MachineStopped2.write_value(False)
                await Item_Count(index)
                await Update_Toolcycles(index)
                await Container_Full(index)
                if Check_Errorcode[index] == 1:
                    await Errorcode2.write_value(0)

[..........]

    async def Update_Temp(index):
        if index == 0:
            new_val = await Temperature.get_value() + random.randint (-3,3)
            await Temperature.write_value(new_val)
        elif index == 1:
            new_val = await Temperature2.get_value() + random.randint (-5,5)
            await Temperature2.write_value(new_val)


    async def Item_Count(index):
        global Item_Count
        global TimeForProduct
        global Time_Present_Product
```

```
        Time_Present_Product[index] += 1
        if Time_Present_Product[index] >= TimeForProduct[index]:
            Item_Count[index] += 1
            Time_Present_Product[index] = 0

        if index == 0:
            await Itemcount.write_value(Item_Count[index])
        elif index == 1:
            await Itemcount2.write_value(Item_Count[index])

[.............]

    async def Cycle_Machines():
        global Number_of_Machines

        i = 0
        while i < Number_of_Machines:
            await Update_Temp(i)
            await Update_Status(i)
            i += 1


    while True:
        await asyncio.sleep(1)
        await Cycle_Machines()
```

C

Visual Components Python Behavior Script

```
from vcScript import *

comp = getComponent()
ToolCycle = comp.findBehaviour("ToolChange1")
ToolChangeNeeded = 10
ItemCount = comp.findBehaviour("Itemcount1")
MaxItemCount = 10
Temperature = comp.findBehaviour("Temperature1")
MaxTemp = 80

ToolCycle2 = comp.findBehaviour("ToolChange2")
ItemCount2 = comp.findBehaviour("Itemcount2")
Temperature2 = comp.findBehaviour("Temperature2")


def OnSignal( signal ):
  pass

def OnRun():
  app = getApplication()
  while app.Simulation.IsRunning:
    if ToolCycle.Value > ToolChangeNeeded:
      print ("Machine 34 - Change tool!")
      print ("Machine 34 Output:")
      print (ItemCount.Value)

    if ItemCount.Value > MaxItemCount:
      print ("Machine 34 - Full Container")
    delay(1)
    if Temperature.Value > MaxTemp:
      print ("Machine 34 - Temperature too high!")

    if ToolCycle2.Value > ToolChangeNeeded:
      print ("Machine 33 - Change tool!")
      print ("Machine 33 Output:")
```

```
    print (ItemCount.Value)

  if ItemCount2.Value > MaxItemCount:
    print ("Machine 33 - Full Container")
  delay(1)
  if Temperature2.Value > MaxTemp:
    print ("Machine 33 - Temperature too high!")
pass
```

D

Client Code to Check Status of Machines

```
async def Check_Status(i):
global oldStatus
global getStatus

if getStatus[i] != oldStatus[i]:
    await Get_POI(i)
    oldStatus[i] = getStatus[i]

async def Read_Status():
    global getStatus
    getStatus[0] = await Status1.read_value()
    getStatus[1] = await Status2.read_value()
    getStatus[2] = await Status3.read_value()
    getStatus[3] = await Status4.read_value()
    getStatus[4] = await Status5.read_value()

    global ErrorCode
    ErrorCode[0] = await ErrorCode1.read_value()
    ErrorCode[1] = await ErrorCode2.read_value()

    global Item_Count
    Item_Count[0] = await ItemCount1.read_value()
    Item_Count[1] = await ItemCount2.read_value()


    async def CyclePoIs():
        global Number_of_PoIs
        await Read_Status()

        i = 0
        while i < Number_of_PoIs:
            await Check_Status(i)
            i += 1
```

E

Client Code to Update PoIs

```
async def Put_POI(Request_JSON,PoiId):

    payload = f"[{Request_JSON}]"
    headers = {
        'X-Authorization': f'{AuthorizationToken}',
        'Content-Type': 'application/json; charset=UTF-8',
        'Accept': 'application/json, application/javascript, text/javascript,
                text/json'
                }

    response = requests.request("PUT", urlnavvispois, headers=headers,
                data=payload)
    print(PoiId)
    print(response.json)

async def Update_POI(response,PoiID): #Manipulate POI
    response_JSON = json.loads(response.content)

    global getStatus
    if getStatus[PoiID] == True:
        response_JSON["icon"] = icongreen
    else:
        response_JSON["icon"] = iconred

    global ErrorCode
    if PoiID < 2:
    global Item_Count
    Item_Count_String = str(Item_Count[PoiID])

    if ErrorCode[PoiID] == 1:
        response_JSON["descriptions"]["en"] = "<p>Machine stopped, temperature
            too high</p>\n\n<p>" + "Item Count: " + f"{Item_Count_String}"
        print(response_JSON)
    else:
        response_JSON["descriptions"]["en"] = "<p>Machine running
                normally</p>\n\n<p>" + "Item Count: " f"{Item_Count_String}"
```

```
    response_JSON = json.dumps(response_JSON)
    await Put_POI(response_JSON,PoiID)

async def Get_POI(PoiID):
    urlnavvispoi = f"{urlnavvispois}"+f"{urlNavvisPoiListNav7[PoiID]}"

    payload={}
    headers = {
        'X-Authorization': f'{AuthorizationToken}',
        'Content-Type': 'application/json; charset=UTF-8',
        'Accept': 'application/json, application/javascript,
            text/javascript, text/json'
}

    response = requests.request("GET", urlnavvispoi, headers=headers,
            data=payload)

    await Update_POI(response,PoiID)
```

F
Questions for interviews, before demonstration

- How do you define a DT?
- What utility do you think a DT provides?
- What general value do you think a DT brings to a business?
- What is the benefit of creating a 3D-visualization?
- How do you think industrial mapping with PoIs can benefit a business?

G
Questions for interviews, after demonstration

- What value would this DT bring to a business?
- What positions/roles would gain from using this DT?
- What features would be desirable?
- What other information should be included?
- What type of business do you think would use such a DT?
- What does this DT accomplish that alternative solutions do not?
- Do you have any suggestions for further development?

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