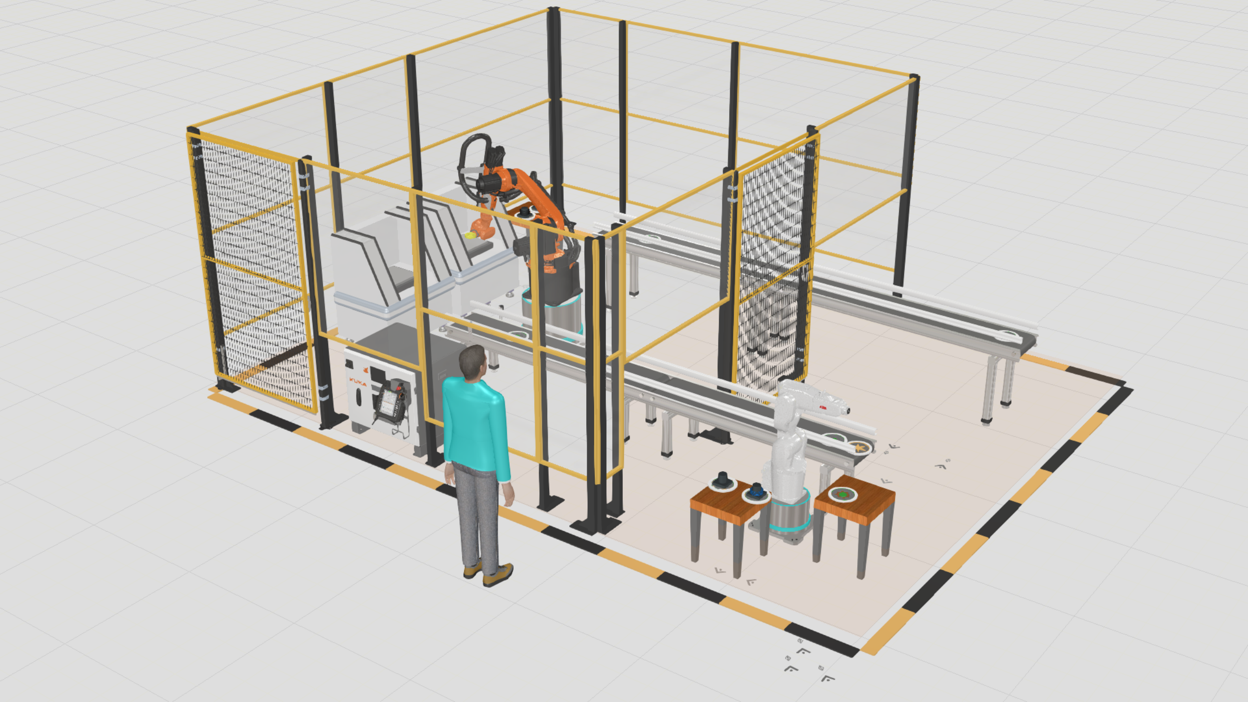


Digital Twins on Multi-Purpose Robotic Cell with Visual Components Simulation Software

Enabled by Visual Components

Master's thesis in Production Engineering

ABDULLAH MOHAMADEMIN
TAM NGUYEN

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2025
www.chalmers.se

Master's thesis 2025

Digital Twins on Multi-purpose Robotic Cell with Visual Components Simulation Software

Enabled by Visual Components

ABDULLAH MOHAMADEMIN
TAM NGUYEN

Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
Gothenburg, Sweden 2025

Digital Twins on Multi-purpose Robotic Cell with Visual Components Simulation Software
Enabled by Visual Components
ABDULLAH MOHAMADEMIN
TAM NGUYEN

Supervisors: Marcus Wagner, SKF & Huizhong Cao, Department of Industrial and Materials Science, Chalmers
Examiner: Björn Johansson, Department of Industrial and Materials Science

Master's Thesis 2025
Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Simulation of robot cell, made in Visual Components.

Typeset in LaTeX
Gothenburg, Sweden 2025

Digital Twins on Multi-purpose Robotic Cell with Visual Components Simulation Software
Enabled by Visual Components
ABDULLAH MOHAMADEMIN & TAM NGUYEN
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

This thesis demonstrates how a Digital Twin (DT) can be realized using Visual Components, either through direct connection to a robot controller or via Industrial Internet of Things (IIoT) software, to enable a more beneficial solution. A methodology on how to approach a DT implementation is proposed, integrating both the virtual and physical commissioning. Details include how to design a robot cell and a process in Visual Components, and how to pair data from sensors in the physical world to the simulation. The study also identifies key challenges of DT implementation in commercial contexts, such as cybersecurity and IIoT platform integration. Finally, the use of IIoT platforms Ignition and HighByte is explored, highlighting their respective challenges in DT development.

Keywords: Digital Twins, Virtual Reality, Industrial Internet of Things, Simulation, Ignition, HighByte, Visual Components, Virtual Commissioning.

Acknowledgements

We would like to express our deepest gratitude to our supervisors, Huizhong Cao and Marcus Wagner, whose expertise, guidance, and encouragement have been invaluable throughout this research. They helped us in succeeding with this thesis and to stay focused on the right things.

We also want to thank the MD team as a whole for their expertise and knowledge which they made available to us, with enthusiasm and encouragement. We also wish to acknowledge the Visual Components technical support team, for their help with the software, which made this research possible.

This thesis would not have been possible without the collective contributions of these extraordinary individuals, and for that, we are forever grateful.

Last but not least, we extend our sincere thanks to our friends and families, whose unending love, limitless support and unwavering belief in us kept us motivated through the challenges of this journey, motivation that has carried us not only through this thesis, but throughout our academic journey, and will continue to inspire us in the future.

Abdullah Mohamademin & Tam Nguyen, Gothenburg, June 2025

List of Acronyms

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

AI	Artificial Intelligence
CPS	Cyber-Physical Systems
DataOps	Data Operations
DM	Digital Model
DS	Digital Shadow
DT	Digital Twin
HRC	Human-Robot Collaboration
IIoT	Industrial Internet of Things
IoT	Internet of Things
LF	Learning Factory
OPC UA	Open Platform Communications Unified Architecture
PLC	Programmable Logic Controller
TRL	Technology Readiness Level
UNS	Unified Namespace
VR	Virtual Reality
VC	Visual Components

Contents

List of Figures

1

Introduction

In this initial chapter, an introduction to the thesis is given, narrowing in on the purpose of the thesis and what it entails. Next, a description of the aim is given with four objectives and two research questions. Lastly, relevant ethical aspects are also highlighted.

1.1 Background

The use of simulation software has become indispensable in modern manufacturing, enabling businesses to justify investments, plan optimal layouts, and validate cycle times for machines and robotic cells (Klingstam and Gullander, 1999). This category of tools allows companies to save time and resources when implementing new manufacturing processes (Guerra-Zubiaga et al., 2021).

Digital models (DM:s) enable virtual commissioning through simulation to describe a potential or actual physical manufactured process from the micro level to the macro level (Grieves and Vickers, 2017, p.94). Digital Twins (DT:s) can further give companies' simulations better accuracy and improved predictability by using the available data from the physical systems, and enabling real-time connectivity going both ways (Glaessgen and Stargel, 2012). The manufacturing industry is a promising context for the implementation of DT:s, and the potential for optimizations in maintenance and operations processes are abundant (Cimino et al., 2019). Though there are numerous incredible studies on Digital Twins, there remains a "black box" notion regarding its practical implementation.

A recent refurbishment in a large bearing company's workshop in Gothenburg has created an opportunity to design their robot cell in a digital environment and to integrate it with their innovation lab, which is an established hub for connecting physical machines in the workshop to the cloud. The robot cell, also called the demo cell, is supposed to be a demonstration cell that shows what technologies are being used by the company, and serves as a learning tool. This thesis aims to create a process and design of the demo cell, and to work towards a digital twin which the company has not done before, to enable future development of digital manufacturing, VR implementation, and data utilization for the production. The study will focus on the following 6 stages of DT development: Define, Plan, Concept, Design, Build, and Launch, based on a standard framework (Pang et al., 2021).

1.2 Aim

Seeing as digital twins are not widespread and established in manufacturing even after many years of being conceptualized, the challenges associated with implementing it are evident. This thesis therefore aims to work towards a digital twin implementation while documenting practical steps and hurdles. To achieve this, first a multipurpose layout and process concept has to be defined for the demo cell, which is going to be used for exhibition and learning about state-of-the-art technologies. The next step is to implement and build a digital model in Visual Components (VC), before implementing it in the physical domain. The expected outcome will be a digital twin implementation that can mirror and simulate a process in real-time by utilizing the IIoT platforms Ignition and HighByte, and be an educational platform to both showcase new technology and teach new workers in a collaborative manner in the future.

1.3 Objectives

The main objectives of this thesis are as indicated:

- Design and implement a process for the robot cell in the workshop to be commissioned.
- Work towards a digital twin in Visual Components of the robot cell, by connecting to the physical devices with the help of the Industrial Internet of Things (IIoT) platforms. Discuss cost-benefit and risks of DT.
- Establish a framework for learning and applying the simulation software capabilities and the digital twin technology within the department for future applications.
- Provide a pathway to utilize VR-headsets with digital twins for more efficacious learning and immersive showcasing.

1.4 Research questions

The following questions will be answered in this thesis:

RQ1: What are the main challenges in developing and implementing digital twins in robot cells?

RQ2: How can a company enable a digital twin in a factory setting, using the simulation software Visual Components, and Internet of Things (IoT) platforms HighByte and Ignition?

1.5 Ethical aspects

In this section, a few select ethical dilemmas are discussed that pertains to the project at hand. Using digital tools in an industrial setting and simulating parts of a manufacturing process, to ultimately automate it, presents potential issues that should be discussed.

1.5.1 Data management and security

When handling data in a manufacturing setting for automation and simulation, the data needs to be handled in an appropriate manner to prevent any malicious attackers from intruding and accessing intellectual property, and to protect safety-critical systems which rely on the continuous flow of information over the cloud (Riel et al., 2017). The use of digital twins and data flow in this project will take this into account and the local guidelines for handling data will be adhered to. This is especially important in the event of using a collaborative process with robots involved, placing an even greater emphasis on the data being managed correctly and reliably.

1.5.2 Simulation security and safety

Security and safety are two different terms, and a distinction needs to be made. Security relates to protection from external and deliberate factors like theft and cybersecurity, while safety is internal, and a protection from incidents, physical harm and accidents (Ali, 2023). Seeing as collaboration with the robots is a potential part of the thesis work, avoiding collisions between the robots and the users of the robot cells is paramount. The contexts which need to be considered are the physical realm which involves sensors, hardware and layouts, and the digital realm which involves the aforementioned data management and safety algorithms (Hollerer et al., 2021).

1.5.3 Job insecurity

The adoption of robots in workplaces has instilled concerns and feelings of job insecurity among employees (Wang et al., 2023). The feeling of inadequacy and replaceability increases when workers are performatively compared to the robots. However, providing the employees with insights about robots and making them perceive the robots as co-workers mitigates the impression of job insecurity (Wang et al., 2023). Further, this project will mainly develop the robots to execute tasks which are ergonomically bad for the humans, which can instead increase job security by way of promoting health and longevity.

1.6 Delimitations

Only the provided software and digital twin implementation of the demo cell is to be documented, which means that the implementation does not necessarily apply to all simulation software or IIoT solutions. The thesis will not focus on large scale digital twin implementation in a factory, although the conclusion will consider further possible developments and applications in a wider scope. A full digital twin of the entire demo cell and process, while possible for future development, requires more resources and time than this thesis allows for. Regarding Virtual Reality (VR) and creating a learning environment in VR, the potential of the implementation and gamification is explored for future work but not implemented.

1.7 Our contribution

This thesis provides the academic literature with a proposed framework of the practical implementation of a digital twin enabled by Visual Components, and practical guidelines in a manufacturing environment using a robot. Additionally, a discussion on the possible usecases of VR is explored in a manufacturing context, both for commissioning and as a form of learning.

2

Literature review

In the second chapter, the academic context and literature on the relevant subjects is explored. A literature review is a key step in gaining an understanding of how the research depicts the current state of a technological issue, and the development over time (Snyder, 2019). This chapter has been divided into two sections; the first section is pertaining to the digitalization of the manufacturing industry, the usage of simulation software, and the central concepts of Industry 4.0. The second section delves deeper into the implementation of Digital Twins, the different maturity levels of Digital Twins and best practices from the research. Also in this section is information about VR, VR implementation, and its potential use cases in the context of production and learning.

2.1 Digitalization in production

Digitalization is key to cultivate innovation for companies in the production sector, in order to maintain or even increase their market share and competitiveness (Ferreira et al., 2019). The focal point of this digitalization is connecting the industrial machines to the IIoT, and utilizing the process data to improve the production efficiency (Alcácer and Cruz-Machado, 2019).

There are three different levels of complexity in terms of digital twins; Digital Model, Digital Shadow and Digital Twin (Paredis et al., 2021). A Digital Model (DM) has a physical object and a simulated version with no exchange of data between the two, updates have to be made manually. A Digital Shadow (DS) has data being sent from the physical object to the simulation, allowing the simulation to mirror what is happening in real life. A Digital Twin (DT) has bi-directional dataflow which means that parameters of the physical object can be changed from the digital side, which allows for process improvements, parameter changes and optimized maintenance (Paredis et al., 2021).

2.1.1 Industry 4.0/5.0

Industry 4.0 is the fourth industrial revolution in the manufacturing industry, consisting of many new innovations, of which the focus relevant to this project is mostly centered around Cyber-Physical Systems (CPS), Big Data management, merging the virtual and physical worlds through IIoT, and real-time communication (Alcácer and Cruz-Machado, 2019). In order to achieve and arrive at an Industry 4.0-compliant process, a number of the aforementioned concepts and systems have to be in place for said process. The manufacturing sites at the company need to be able to monitor the process data, utilize and understand the flow of data and then improve the process, predict the need for maintenance, among other things.

While Industry 5.0 has been conceived and is the state-of-the-art in manufacturing development, its concepts and the level of Industry 4.0 maturity required to begin working towards Industry 5.0 are advanced (Maddikunta et al., 2022). The scope of this project is more suited towards implementing a solution that is compatible with Industry 4.0 concepts, and the focus is thus determined accordingly.

2.1.2 Simulation

A simulation is a virtual representation of the real world created by a software (Kleijnen, 1993). By replicating the existing real-world machines and maneuvers, the simulation can illustrate different scenarios and give data that can be analyzed and improved before applying it to the real world. There is also the potential to generate new components and machines if needed in order to enhance the cell's performance and propose new solutions to representatives in the company.

Using simulation programs to test new layouts and production lines, or to test new changes to existing ones, is a cost-effective way to justify the investments and to shorten the development cycle (Oppelt and Urbas, 2014). The use of simulation programs has evolved over the years, with manufacturing companies nowadays focusing more on connecting the simulations to the real production lines to support operation and maintenance (Rodič, 2017). Rodič summarizes the change in the use of simulation software with three points; the first point is about integration and connectivity in a wide information system. The second point is to model with a high level of fidelity and resolution, with little to no abstraction, and the final point is that the construction of models is data-based (Rodič, 2017).

In the future it is possible to combine these goals when using a simulation program, and using artificial intelligence (AI), Big Data and other Industry 4.0 tools (Arnarson et al., 2023). Simulation programs can be used in conjunction with algorithms to calculate and optimize any given production line, with multiple potential solutions based on the level of complexity desired, as shown in Figure 2.1. However, the basic functions of Digital Twin and AI utilization for the company in question are not yet at a mature level.

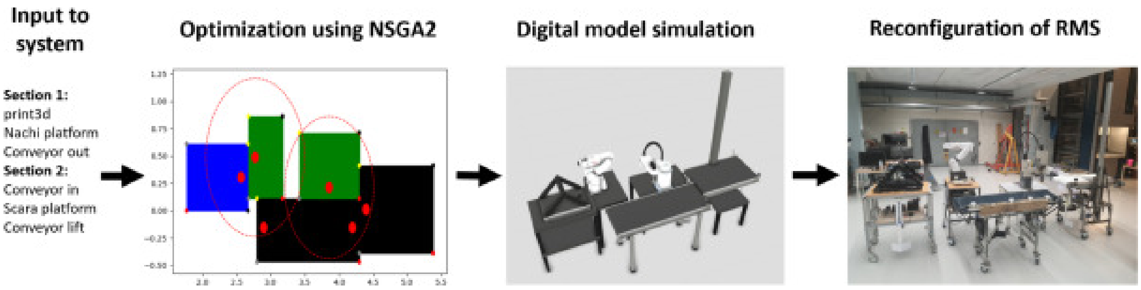


Figure 2.1: Illustration of using AI model for optimization of layout in a simulation (Arnarson et al., 2023)

2.1.3 Architecture description of IoT

In order to enable connectivity between a physical system and a simulation model, an IoT platform with connected devices is needed (Guth et al., 2018). The paper also explains that an IoT platform allows users to collect the data and analyze it, giving projections of component lifespans and various recommendations for the operator.

The architecture used to describe different layers is derived from an IoT reference architecture presented by Domínguez-Bolaño et al.(2024). As shown in Fig 2.2, there is a connection from the physical components where sensors capture information, e.g. detecting an entrance to the robot cell. This information is relayed to the applications through firewalls and networks to be acted upon. Eventually, the system acts on the information received by using the actuators, which converts a command to a physical action based on directives from the IoT platform. The data flow process goes through every layer following the correct standards to ensure robustness for the IoT platform (Domínguez-Bolaño et al., 2024).

Although an IoT platform has different capabilities such as user-centered data visualization, management of systems, data security and storage, and use of applications, an IoT platform needs IoT gateways to communicate with other devices with common communication networks, data formats and data layer protocols. Security is important at all levels and is crucial in ensuring that the company's confidential information and IoT platform are not breached (Domínguez-Bolaño et al., 2024). On the right side of Figure 2.2, the management block oversees the process and handles fault exceptions.

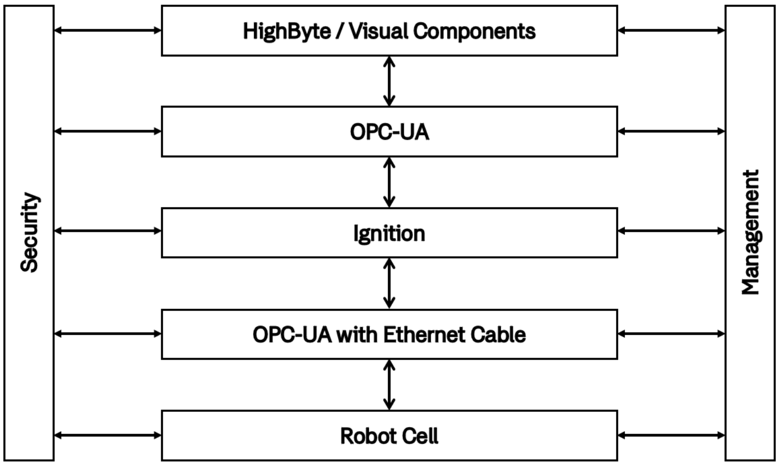


Figure 2.2: Illustration of the IIoT architecture, adopted by Domínguez-Bolaño et al., 2024.

2.1.4 Cyber-Physical Systems and Industrial Internet of Things

Cyber-Physical Systems is a combination of technologies that connect the physical and computational capabilities of a company, and is the core enabler of Industry 4.0 (Trappey et al., 2016). CPS can be described as a control unit which controls sensors and actuators in the physical world, while collecting the data to feed the digital representation (Jazdi, 2014). Combining a CPS with the implementation of the IIoT is how you implement Industry 4.0, as shown in the Venn diagram in Figure 2.3 (Sisinni et al., 2018). Sisinni et al. further explain the IoT and the IIoT, and the distinction between them, with IoT being the consumer-related devices' connectivity to servers and other devices, while IIoT is about connecting industrial machines and control systems with the companies' information systems and business processes. The different components of IIoT can be defined in three layers: the sensing layer, where sensors and data is collected, the network layer, which is the transportation of the data, and the service layer, where the data is processed and visualized (Atzori et al., 2010).

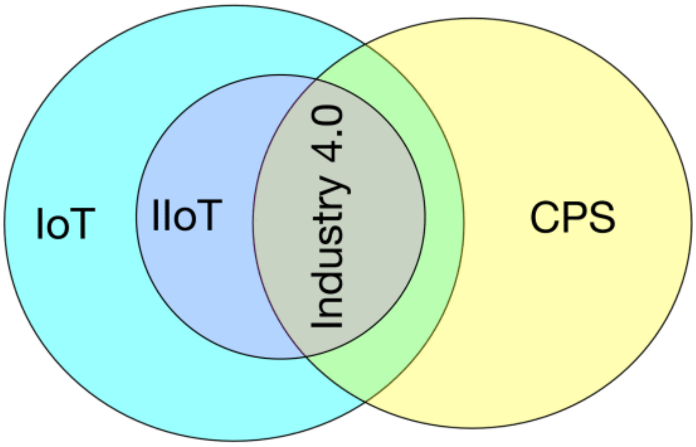


Figure 2.3: Venn diagram of how IIoT, CPS and Industry 4.0 intersect (Sisinni et al., 2018)

IIoT is reliant on the flow of data from different sensors and datapoints, The data generated can, as seen in one example, reach terabytes per minute (Sisinni et al., 2018). Therefore, data management must be handled appropriately.

2.2 Digital Twin

A Digital Twin is a mirror image between a simulated process and the physical process that takes place in real time, creating a cooperation between the simulation model that runs alongside the real-time process, which can provide essential data to develop the process itself (Batty, 2018). There are different levels of maturity for a digital representation of a physical model. It ranges from a simplistic digital model that is a snap-shot representation of how the physical system is, to a more complex digital shadow (DS) that is updated with live data from the physical model, and finally an advanced digital twin which has data going both directions (Fuller et al., 2020).

In the relationship between the hardware and software, there are three main differences between DT and conventional simulation: persistence, insight, and explainability (Douthwaite et al., 2021). Douthwaite et al. (2021) detail the three differences as follows: Persistence is the constant modelling, maintenance and saving of the system, with bi-directional information flow and a record being kept of its lifecycle. Insight is when a DT gives deeper information and predictions regarding the status or health of a component in the system, as opposed to having a static state of health for all components in a regular simulation. Explainability is the ability of a DT to diagnose failures and the reasons behind them, enabling further improvements to reliability and safety of a system.

The Digital Twin concept can also be used for effective learning in the form of a learning factory (LF), which is defined as an idealized replica of parts of a system used for learning purposes (Baena et al., 2017). The authors posit that using such a learning environment can help Industry 4.0 capabilities. Related to this project, using Digital Twin concepts in conjunction with the demo cell as a form of a learning factory can augment the efficacy in learning how digital twins work (Nava-Téllez et al., 2023).

When implementing a digital twin, there are hurdles and hardships that need to be taken into consideration. Among those are that documentation of the implementation of DT:s are vague and it can be hard to see advantages of implementing it, the goals and proposed plans for implementing DT:s can be too ambitious, and the overall comprehension level for DT implementation is often low (Kober et al., 2024). To overcome these hurdles, Kober et al. recommend a selection of practices to succeed with a DT implementation; Defining clear objectives, starting with a small scale DT, and empowering stakeholders to utilize data-driven decision-making. However, none of the aforementioned studies are in the form of a practical walkthrough of how to implement a Digital Twin, combining knowledge about simulation software, hardware and IIoT, documenting the process and serving as a guide simultaneously. Although one study does document such granular details of implementing DT, using a software solution called Kepware to connect a lab-factory to a digital twin software called Emulate3D, it focuses on a different set of applications and software (Erdal and Gubartalla, 2024). The aforementioned thesis served as an inspiration to document a DT implementation in a similar way, using Visual Components, IoT platform software, and methods employed in a large company.

Digital Twin technology is not widely implemented in the mainstream manufacturing companies, which indicates that it ranks quite low on NASA's Technology Readiness Level (TRL), which is a measurement of how mature and widely implemented a technology is (Manning, 2023). There is therefore a gap where this project can contribute both to the academic literature but also the company in question.

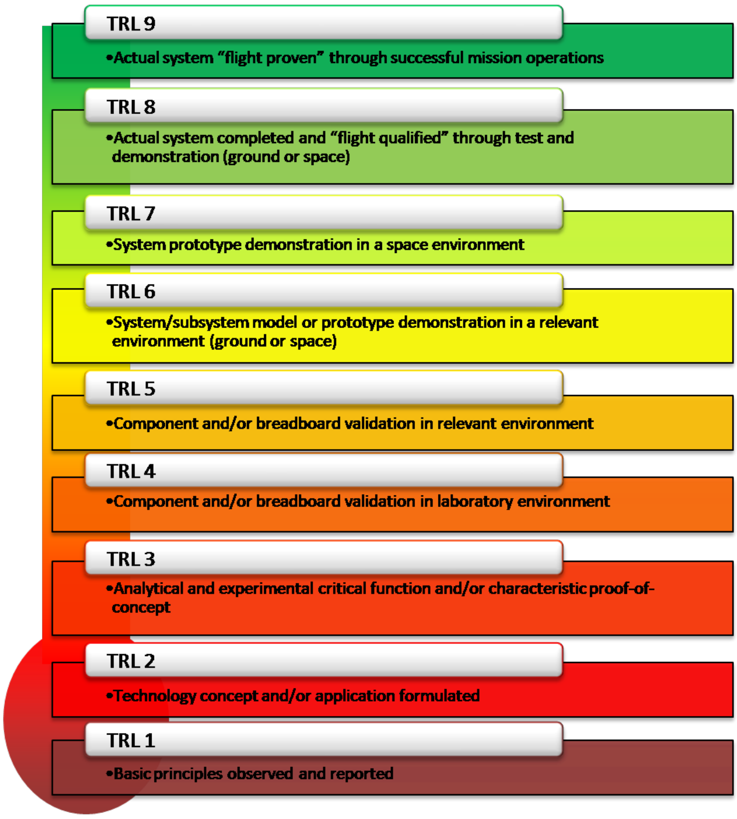


Figure 2.4: The different levels of technological readiness (Manning, 2023)

The aforementioned Digital Twin implementation guidelines align quite well with the scope of this project, namely a pilot in achieving Digital Twin in a controlled, smaller scale environment. The usage of data and collaboration between the operational stakeholders and the IT department is another challenge for the company, where knowledge-sharing needs to take place in a harmonious and sustainable way (Kober et al., 2024).

When trying to implement a digital twin of the robot cell, various sensors are needed in the cell to extract the appropriate data from the process, which will serve as the basis for the real-time communication between the DT and the physical robot cell. This digital representation combined with data from the sensors will also serve as the basis for a VR implementation (Pérez et al., 2020).

2.2.1 ISO 23247 framework for implementing Digital Twins

The ISO 23247 standard is a framework for supporting DT implementation in manufacturing settings (Shao et al., 2021). It consists of four standard parts:

(1) General principles for developing DT:s in manufacturing.
(2) Reference architecture.
(3) List of attributes of observable elements.
(4) Requirements for information exchange.

The first part gives an overview of the terminology used in digital twin implementations along with specifications of DT:s (Shao et al., 2021). The second part provides a reference architecture DT:s in manufacturing, consisting of four domains: Observable manufacturing domain, Data collection and device control domain, Core domain, and User domain. These domains are different parts of a digital twin solution in the standard. The third part of the standard is regarding the attributes of the observable elements, which in this case is the components and objects out in the cell, and how the digital representation of the DT is fed information from them, both static and dynamic. The fourth and final part of the standard is related to information exchange, and the technical requirements for data transfer between domains (Shao et al., 2021).

2.2.2 Virtual Reality integration

A VR headset is a tool that sends an environmental sense stimulation to an individual to their brain from the eyes. Using a VR headset is a way to engage workers and learners and give an immersive look into a process, to potentially teach about the process itself and safety practices. It can be developed into a crucial tool for the future where it facilitates training. The VR headset can also be utilized for project planning where safety measures, virtual clashes and improvements to the workflow can be tested before putting the company's resources at stake (Lavalle, 2023).

In the context of this project, VR headsets can be used in the future to visualize the digital representation of the demo cell. Using sensors in relevant positions throughout the process, the VR interface can plug in to the digital twin as a standalone module, with which the visualization will be more tangible. Using VR is also more immersive in terms of human-robot collaboration than a simulation program without VR (Pérez et al., 2020).

In terms of the learning process and using VR, one study showed an increase in learning efficacy and reductions in cognitive load when using VR to learn about robot kinematics, by conveying the complex concepts in an understandable way (Tarng et al., 2024). This is indicative of a potentially powerful tool for learning other complex matters, such as DT:s and automated processes. Another study showed similar levels of learning efficacy when utilizing VR compared to physical training, but advocated that the decrease in resources needed and the inherent increase in safety made it a viable option for learning about Industry 4.0 concepts (Martínez-Gutiérrez et al., 2023).

2.2.3 Robot cell application

Industrial robots have been used in factories for decades already, following specific programs independently to automate burdensome tasks, with strict constraints to ensure safety such as cells and safety doors. Nowadays research and development is mainly geared to increasing the collaborative element of robots, by increasing their awareness and safety. This collaboration is called Human-robot collaboration

(HRC), and has various levels of engagement as seen in Figure 2.5 (Grau et al., 2020).

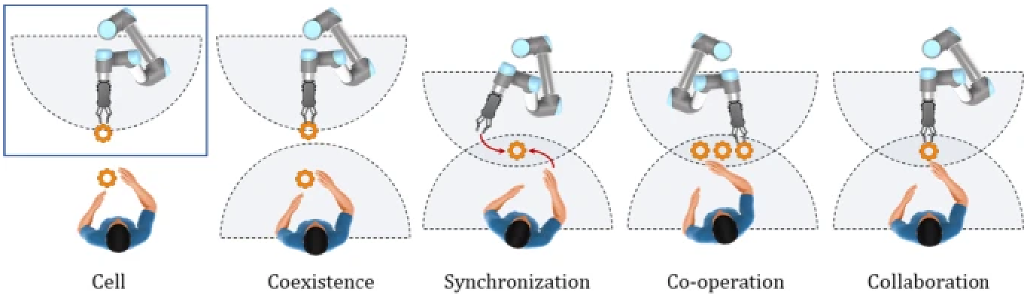


Figure 2.5: The diferent levels of engagement and collaboration between robot and human (Malik and Bilberg, 2019)

The lowest level of engagement is when the robot is in a cell, isolated from the human. The next level is coexistence, where the robot is working alongside the human worker, but with no shared workspace. Moving up one level, synchronization is when the robot and the human worker have a shared workspace, with alternated use or access of the shared workspace. Cooperation is the level in which the robot and human worker can be in the shared workspace simultaneously, however they work on different parts. The highest level of engagement is called collaboration, where the robot and the human worker can work simultaneously on the same part in the shared workspace. This requires the robot to be dynamic and be able to react to approaching objects in real time (Malik and Bilberg, 2019).

Since there is a plan to use a collaborative robot (cobot) in the cell, ensuring safety of operators is critical, and one way of doing that is by implementing scenarios in a DT environment to raise awareness and increase understanding of potential safety issues that could arise, and to integrate and revise the design to mitigate the risks beforehand (Douthwaite et al., 2021).

The implementation of the digital twin, using VR, and achieving a level of collaboration in the robot cell are goals that are interconnected, as seen in this section. Enabling one of these avenues in this thesis will ease the process of accomplishing the other aforementioned goals for the company.

3

Methodology

This chapter presents the methodology. In terms of work philosophy, the way of work was an agile form that is fitting for an iterative and incremental approach in a constantly changing context (Cohen et al., 2004, p.12). There was a preliminary planning which was adjusted as needed depending on the feedback and new insights received over the course of the project. Moreover, the feedback during the project was an assurance that the end result was relevant and helpful for the company.

3.1 Literature study

A literature study was conducted to know more about the field of the thesis, and to get to know the jargon of the subjects, e.g. the terms for different levels of collaboration, and guidelines for succeeding with the implementation of a Digital Twin.

To gather this relevant information, a multitude of websites, search engines and search terms were used. The two main academic databases were Scopus and Google Scholar. Some sources were also found using regular Google Search. The various search strings included but was not limited to: "robot cell", "digital twin", "virtual reality", "industry 4.0", "simulation", "simulation safety", "digitalization in manufacturing", "VR in manufacturing", "collaborative robots" etc. Various combinations of the different search strings was also used to find relevant publishings with overlap between the subjects, increasing the applicability of the paper. Additionally, the year range function was used, which was helpful in determining papers that are seminal for the subject, and also to find papers that describe the state-of-the-art, which can be found in the previous chapter.

3.2 Stakeholder analysis

To increase understanding of the robot cell design phase in this project, a stakeholder analysis was conducted in parallel to the literature study, collecting qualitative data from subject matter experts. Even if this part of the process may be perceived as lacking in value for the digital twin implementation, the fact is that it is dependent later down the line on having an accurate digital model as a foundation, which should work the first time without needing rework or additional time and resources.

The analysis was based upon qualitative interviews with different stakeholders within the department, e.g. project managers, machine safety experts and automation specialists. This provided an overview of the purpose of the project and suggestions on different ways to configure the cell. The desired takeaway from the interviews was to have clear purpose with the demo cell. Having a clear understanding of the end users' vision from the very beginning was helpful in achieving a desired outcome which benefits the company.

The qualitative data was gathered by conducting semi-structured interviews, where the interviewer can ask follow-up questions to understand the interviewee's unique perspective (Adeoye-Olatunde and Olenik, 2021). Answers were recorded through taking notes. The purpose of the interviews was to understand the different perspectives from the different disciplines in the team, in order to create the most useful work case scenario. Follow-up meetings were also scheduled with the team all together to show the prototypes, in order to reassure alignment and discuss further improvements. Evidently, finding insights and creating interpretations are essential when examining the qualitative data (Al Dahdouh, Alaa A., 2018).

3.3 Simulation and Virtual Commissioning

The usage of a simulation program, Visual Components in this case, and the knowledge from the stakeholder analysis, was the base to creating a functioning layout and simulation of the robot cells, which was then commissioned in the physical domain. Measurements of the available hardware was inserted into Visual Components in order to achieve a correct scale of components. Visual Components has a catalogue with many robot brands and types, including the ones used in this project, which meant that it was simple to establish a correct virtual representation of the two robots.

3.4 Physical environment establishment

The virtual commissioning of the software Visual Components has then been implemented in the physical robot cell station at the company. The lab environment consists of a cell that is 6 x 4.5m with two robots and conveyor belts. Safety fences, safety tunnels, sensors and a safety door are also installed, along with work tables inside and outside of the fencing.

3.4.1 Robots & fencing

The two robots used in this project are an ABB robot and a KUKA robot, with different purposes in the process. The ABB robot model designation is IRB 1200, a compact, flexible small robot of the 7kg payload/0.7m reach variant (ABB, 2025). This robot is limited in its functionality and will be used as more of a cobot in the process. It has safety features that enables a safe cooperation in a shared workspace between human and robot.

The KUKA robot model designation is KR22-R1610-2, and it is larger than the ABB, with a payload rating of 22kg and a reach of 1612mm (KUKA, 2025). This robot has to be used inside the fences and out of reach of any human due to its higher speed and force generation. Moreover, the robot has to have safety measures, such as only working when the door is locked, or slowing down in different positions to minimize the risk of colliding with either the workpiece or the machine.

The fences cover 3.9 x 4.5m of the lab environment, and are made of extrusions with plexiglass panels installed in between, which gives spectators good visibility. There is also a door with a magnetic breaker contact, which stops the process entirely if opened.

3.4.2 Grease & capping machines

The main machines in terms of the process and value-adding are the greasing station and the capping machine. The greasing station fills the naked bearing with the selected type of grease, which in the simulation is illustrated by changing the colour of the bearing. The bearing also has to go to the capping machine, where the sealing cap is installed by the KUKA robot. The exact details of the process are described in the results section.

3.4.3 Risk assessment of physical environment

An obligatory step in order to build anything at the company in question is to do a risk assessment. This begins with the help of the a safety expert with experience naming common risks and, grouping them by their origin and source of risk. Next is ranking the risk in four different aspects; seriousness, exposure, occurrence, and avoidance, which results in a risk number. This risk number is then compared to the risk number once measures have been taken hopefully resulting in a reduction of risk. If the reduction in risk is inadequate, further measurements have to be taken, until the risk is at an acceptable level.

3.5 Technical pathway towards Digital Twins

After completing the development of the simulation of the cell, the next step is to leverage different tools and technologies to achieve a functioning digital twin. The development process is done with an iterative and continuous method, with the first step being to define the robot cell in the "Define" stage as seen in Figure 3.1, before deciding on a process in the "Plan" stage, and developing a simulation concept that is representative in the "Concept" and "Design" stages. Afterwards, the physical cell can be commissioned and future developments can be envisioned from there. The "Operate" and "Service" stage consist of connecting all the sensors, robots and machines to a PLC and implementing a full digital twin, and doing the relevant maintenance. These two stages are greyed out as this thesis did not quite reach the stages past "Launch".

By using the simulation from Visual Components, implementing and driving the installation to connect the machine to the digital lab, and creating a digital twin, a practical framework emerges for applying the digital twin technology in a standardized way for the engineers. Highbyte and Ignition are two complementary digital platforms that enable this IIoT solution and connect to both the simulation software and the physical robot cell.

The digital twin framework can also be utilized for training and upskilling purposes, showcasing the live data and how the process works in a digestible format.

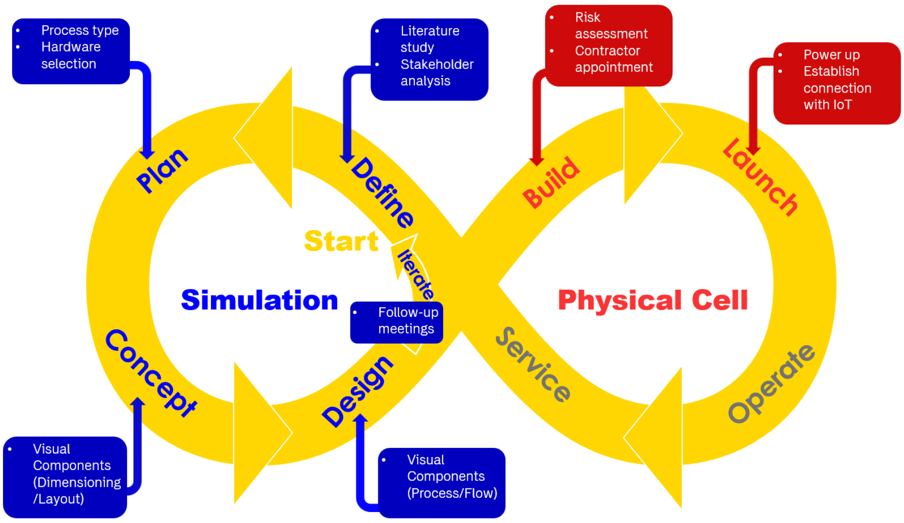


Figure 3.1: Development loop for the robot cell using simulation, inspired by Pang et. al (Pang et al., 2021). Greyed out parts not covered in this thesis.

3.5.1 Simulation software

Visual Components is a tool that can illustrate and simulate different production flows to optimize them, and expose inefficiencies before applying a production to the physical world (Visual Components, 2025b). The software has a catalogue with accurate models of a multitude of components, including robots, machines and other industry tools. Additionally, there are capabilities in the program where you can model or program different components for a more realistic simulation. There are different features and add-ons to the program that enhances the user's ability to simulate or in this case, create a DT (Visual Components, 2025b).

Moreover, the add-on needed to connect with the project's KUKA robot is the KUKA.Sim add-on. This add-on enables the connectivity with the robot and VC, connecting to the robot's controller. The connectivity can be chosen to be only from the robot controller to the VC as a DS or an actual DT where both can send and receive information and commands.

A more advanced version of connecting to components in the robot cell is through using the Connectivity tab in VC. Here it is possible to connect to IP addresses with various data transfer protocols and communicate information back and forth, which is explained in 3.5.2. Also in the Connectivity tab, variables can be paired either in the "Simulation to server" section, to have the real robot follow the simulation, or by pairing variables in the "Server to simulation" section, to have the simulation follow the real robot, as seen in A.8. If the variables are paired in both sections, then it counts as a true DT, while pairing the variables only in the "Server to simulation" section results in a DS.

3.5.2 Communication protocol standard for DT

The data exchange standard for this project was Open Platform Communications Unified Architecture (OPC UA). OPC UA was used for this project based on recommendations from the company, as it is open-source and has many advantages. It is a service-oriented architecture geared towards industrial applications, to enable secure process automation and interoperability (Leitner and Mahnke, 2006). OPC UA gives the user a single, interoperable way to access data, whether it is current data, historical data, or alarms and events, from the factory floor to the enterprise. It also has a security infrastructure which is based on secure networks and message verifications with timestamps and ID:s, and encryptions Leitner and Mahnke, 2006.

OPC UA uses Ethernet-based networking, and one of its strengths is the real-time communication capability (Siemens, 2025). There are OPC servers and OPC clients, OPC servers are responsible for providing data to other systems, PLCs are an example of an OPC server, and OPC clients, i.e. the enterprise system, consume the data provided by the OPC server and can also send commands to the server (MachineMetrics, 2025). OPC UA was used in this thesis to send data from the robot to the simulation, using "tags" which contain live values from the robot, e.g. axis position and speed.

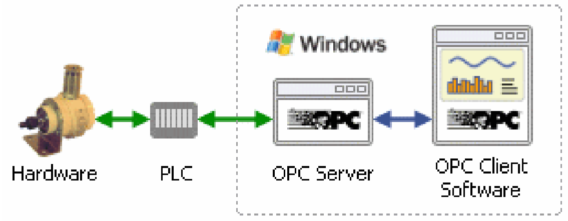


Figure 3.2: Data flow using OPC UA protocol (MachineMetrics, 2025)

3.5.3 IIoT platform

For the architecture and the dataflow between the physical robot and the simulation, there needs to be an exchange of data of various formats between different platforms, with firewalls and safety measures. For this to work, there are powerful software tools and platforms which enable this communication. Ignition is a market-leading application platform designed for industrial data (Harrington, 2025). It can function as an IIoT platform, and offers a broad range of application-building capabilities for on-site use cases, device connectivity, and application adaptation to unique plant requirements (Harrington, 2025). Ignition serves as the hub which relays the tag/parameter values from the robot and the shopfloor layer of the network, as seen in Figure 3.3. This data can then be passed on to a simulation program or a DataOps (Data Operations) platform, inside the firewall of the operational network.

Highbyte is an industrial DataOps enterprise platform that helps make industrial data more usable and digestible. HighByte supports various cloud platforms like AWS, Azure, and Google Cloud. HighByte has features such as connection modules which helps it seamlessly collect data from other IoT platforms such as Ignition, and "pipelines" that can be configured to move datasets efficiently. It helps make integrations between physical machinery and the IoT much simpler and easier to understand through visualizing where the data is going and what the data consists of (Harrington, 2025).

The complementary roles of HighByte Intelligence Hub and Ignition make a DT implementation possible as seen in Figure 3.3; HighByte integrates data from multiple systems (e.g., MES, ERP) and publishes it into a Unified Namespace (UNS). Ignition then uses this standardized data for process control without being overloaded by unnecessary data (Harrington, 2025).

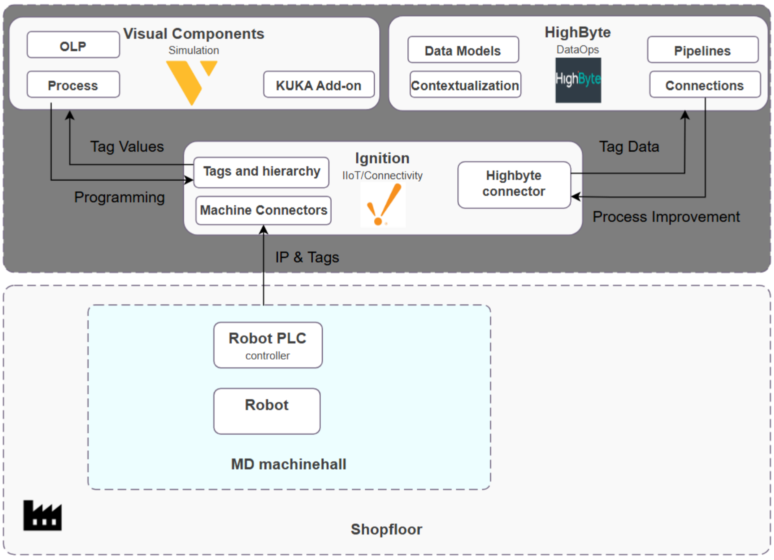


Figure 3.3: Dataflow for DT realization, using different IoT software for maximum functionality

It is possible to have connectivity between the robot and Visual Components directly so long as the robot has a connection and an IP address which the simulation can connect to. This would simplify the dataflow for the DT implementation at the cost of the functionalities which Highbyte brings and can be seen in Figure 3.4.

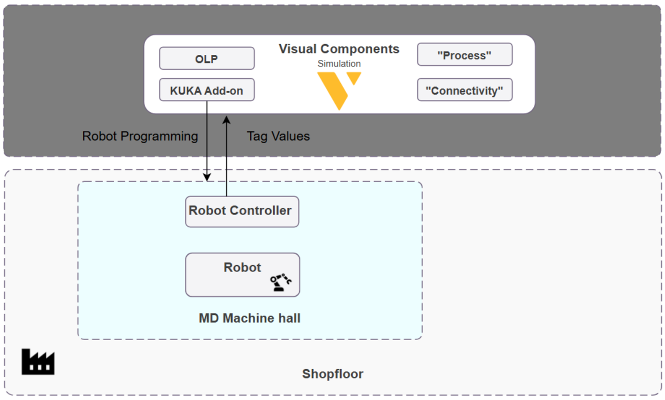


Figure 3.4: Dataflow for DT realization, using direct VC to robot connection

4

Results

This chapter details each step of the project in chronological order. The first section is related to the simulation. It describes all the tasks that were done in order to develop the simulation in an efficient way, the deeper nuances of programming in Visual Components and the different ways of implementing the process. The second section is regarding the commissioning and the physical rendering of the robot cell. The final section is about the process of implementing a DT, the prerequisites and the tools which are needed.

4.1 Simulation

A simulation was created using VC to display a functioning layout before building it in the physical demo cell. The simulation needed to align with the company's desires and the plan for the demo cell, even if it was vague in the initial stage. This knowledge was gained by having semi-structured individual interviews with every member in the team. Thereafter, a simulation was showcased every other week with the team altogether to show progress, reassure alignment and discuss improvement.

4.1.1 Stakeholder Analysis

The main foci of the aforementioned interviews were to understand the interviewee's idea of how the process should look and to gather other desired features in the demo cell. Some members did not have any actual process idea in mind, but the main reoccurring themes were to have safety features which enables a human to work with a robot, and something that was linked to the production, such as auto-resetting and having bearings in the process. A more comprehensive process idea that was mentioned by a few interviewees was an idea called "Grease & Capping", which was ultimately implemented. This approach was appreciated by the team due to the fact that this process idea has contemporary capabilities to showcase the method of production that the company is striving for, where auto-resetting and collaboration between human and robot is applied.

Additional interviews and discussions were held regarding the value and risks of implementing DT for a large company. The stakeholders expressed their concerns for safety and security, with the possibility to control a physical robot remotely posing possible threats to the operators' safety, and security concerns amidst rampant cyberattacks. The stakeholders also mentioned that additional resources and planning are required to enable bi-directional control, which is not considered cost-effective. The primary perceived advantage by the stakeholders with a DT, as opposed to a DS, is the ability to continually adjust process parameters as consumables wear down over time, e.g. a grinding wheel or a grip tool. The ability to change parameters and other forms of control that a digital twin brings also comes with an added security risk of cyberattacks having great consequences.

4.1.2 Layout Planning

Having gained an understanding of the process plan which is detailed in sections 4.1.2 and 4.1.3, the next step was to have the robots, machines and conveyors arranged inside the given restricted area of 6 x 4.5m. To enhance the exhibit of safety in cooperation between human and robot, it was decided to leave approximately half of the area with no fences in order to implement HRC with the second robot. An initial layout was then created as seen in Figure 4.1.

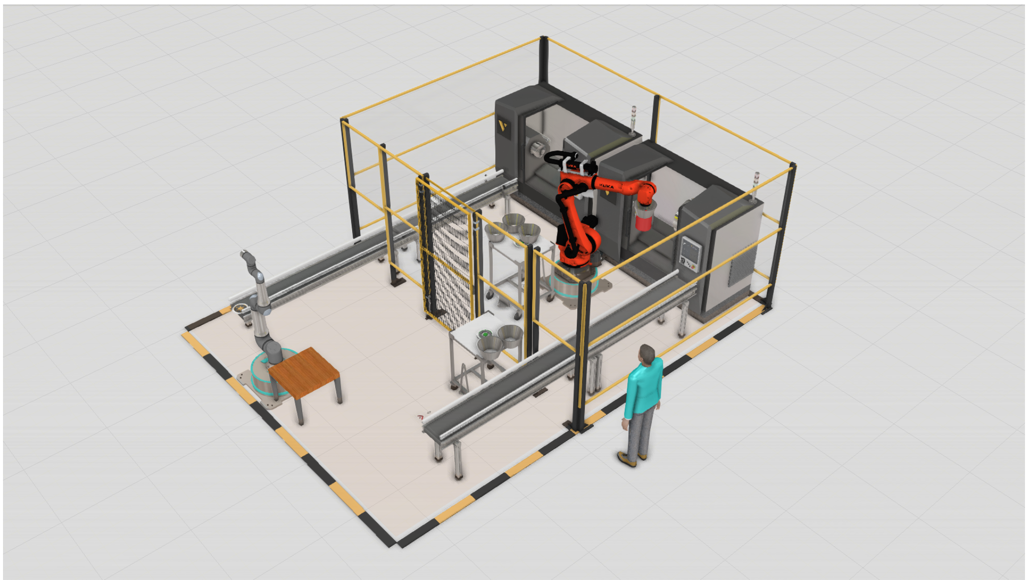


Figure 4.1: First draft of the demo cell layout.

After some changes to the available machinery due to circumstances at the company, the robots that were used in the simulation and allocated to the demo cell were no longer available. The robots that were subsequently allocated to the project, the KUKA KR22 and the ABB IRB1200, had a smaller reach, which meant that a rearrangement had to be made in the layout concerning the robot's location. In the same stage of development, the machines in which the greasing and capping were done changed to smaller white ones. They were deemed to be more accurate in terms of scale after looking at the real-life implementation of the process in a presentation.

These changes came to light during an alignment meeting with the team, which helped steer the demo cell simulation in a slightly different direction that was more in line with the expectations of the team. Figure 4.2 shows the second draft. Other improvements made to the second draft include but are not limited to: Accurate fence lengths according to the existing fencing, implementation of conical "caps" of different colours to signify different types of capping, cap holders which automatically are transported in and out when needed (auto-resetting), and overall efficiency improvements in the robot movements.

A second alignment meeting was then held and the simulation gave the team a positive impression overall. A few small changes were suggested and a general approval to start the commissioning process was given.

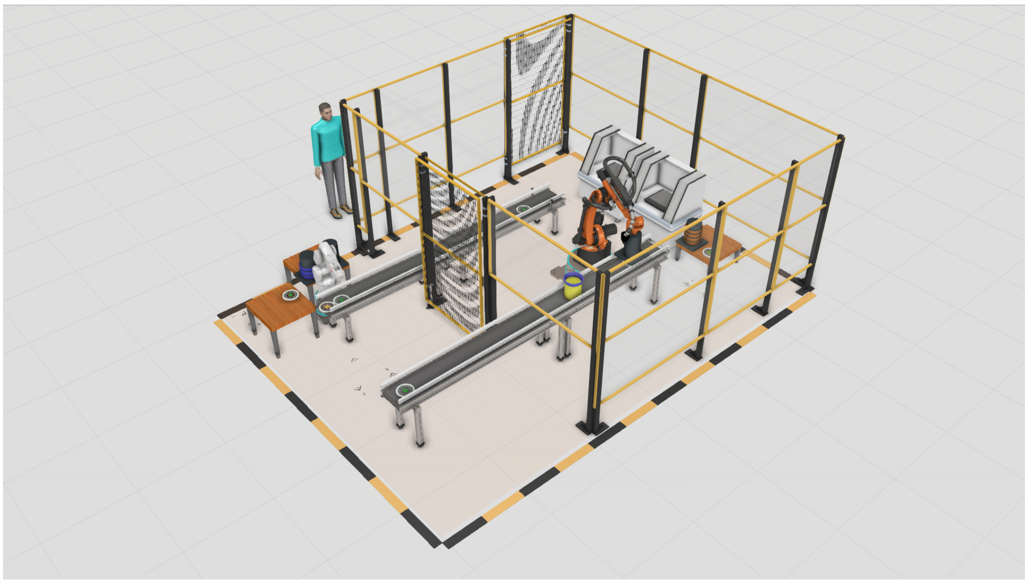


Figure 4.2: Second draft of the demo cell layout.

The final version of the simulation included important improvements, albeit not visually striking. The workpieces were updated to accurate CAD models of bearings and caps, the robots now returned to their original positions after completing a task, and the height of the robots, conveyors and tables were adjusted. See Figure 4.3.

Two important changes made that have no visual cues are the streamlining of flows and the correction of the coordinate system. Previously there were multiple process flows, based on what product type was chosen, that were running the program in a non-intuitive way. In the final version there are only two flows, one for manufacturing and one for resetting, which is easier to grasp and understand. The second change was due to the robot cell not being aligned with the coordinate system in the simulation which made it difficult to take measurements. All components were moved to coincide with the origin both in terms of orientation and location, which later on made it possible to extract relevant coordinates for the hole drilling of the robot base.

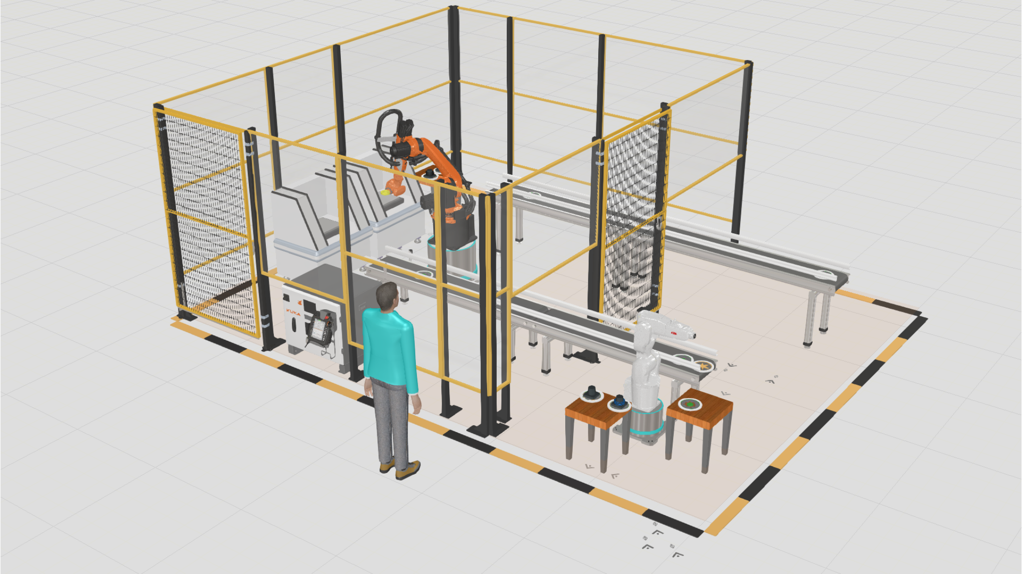


Figure 4.3: Final version of the demo cell simulation.

4.1.3 Production Process

The main goal of developing the production process was to create a model which can be used to plan the physical domain, focusing on the placement of all objects. To facilitate this process, VC was utilized to give precise measurements of different objects' locations' in relation to other objects. Accurate models of robots were placed using the eCatalog, in addition to machines with similar measurements and CAD models of products, in order to give a clear visualization of the future layout of the physical cell. However, exact knowledge about the process and space for different movements was still unknown at this stage.

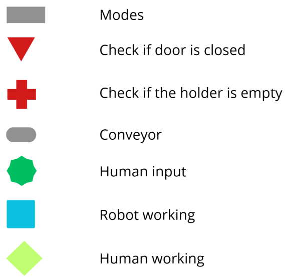


Figure 4.4: Legend for production process flow.

In order to determine the spacing and movement patterns of the robot, the next task was to create a process with the knowledge gained from the stakeholder analysis. Different stages of the process are categorized according to Figure 4.4. The simulation had two modes represented by two "flows" as seen in Figure 4.5, a production mode and a resetting mode.

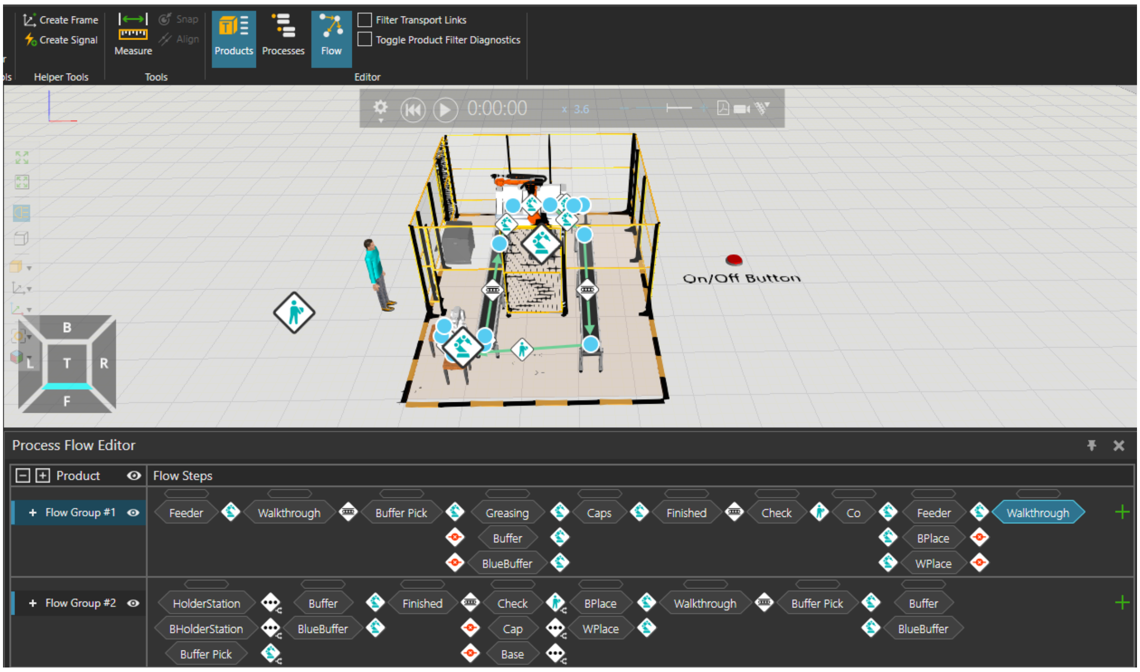


Figure 4.5: Overview of the flow function in VC

The production mode was undertaken first and the build-up of the process can be seen in Figure 4.6. Initial versions were conceived without using safety checking statements due to their complexity to program. Another simplification was the interpolation transport feature in VC, where actual movement patterns from the human and robots were not needed, avoiding small errors related to robot reach for instance, which can interrupt the whole simulation and require troubleshooting.

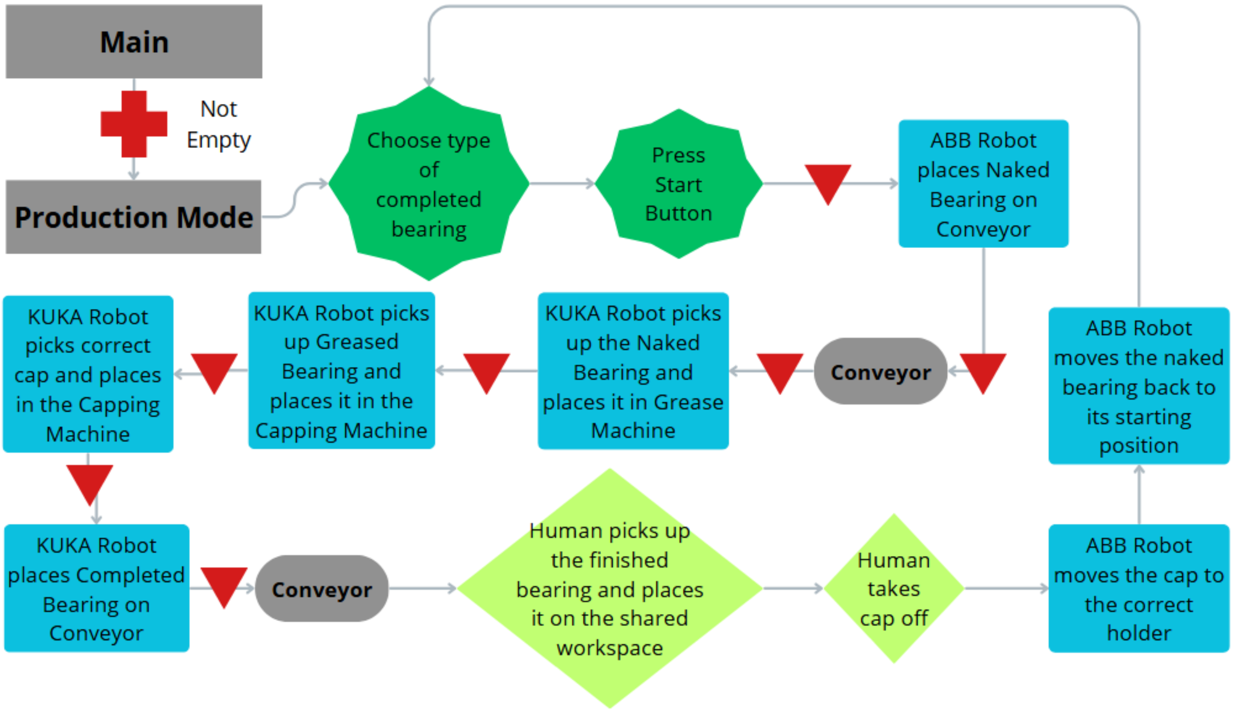


Figure 4.6: The flowchart of the production process.

The next part was to develop the resetting-mode as depicted in Figure 4.7, still without using any safety checking statements and using the interpolation transport function. The simulation also went from having a button to switch between the two different flows which can be seen in Figure 4.5. Another development was implementing a statement which checks automatically when to switch flow from production to resetting mode. This was done in VC through the "Process" tab where every station has their own programming, as seen in A.5. The Process tab was also used to detect what type of product (component) arrives at a specific node (blue dot with label), which ultimately led to a specific product assembly being produced, as seen in A.4. In total, eight product variants could be produced in this simulation with minimal resetting time, thanks to the automatic detection of when resetting was needed.

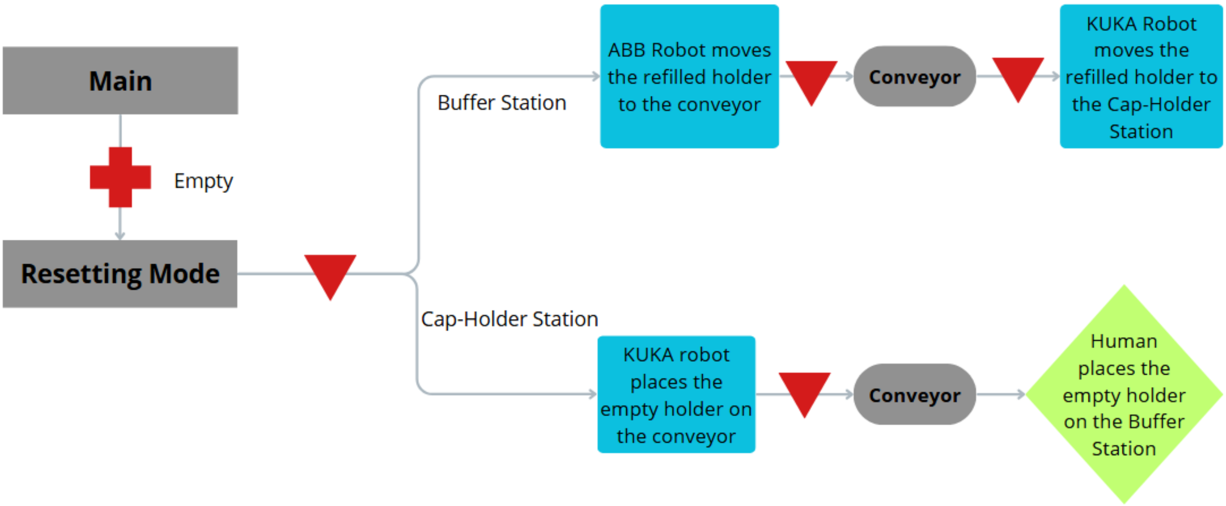


Figure 4.7: The flowchart of the resetting process.

After accomplishing that, a check-statement for the door being opened was included in the programming, to stop production if the door was opened any time during the process, which can be seen in A.5. The statement "Angle == 0" checks that the door is closed.

With everything related to the process and flow in place, the transportation mode was changed from interpolation, which is an automatic transportation, to the correct transport type, which was one of the robots or a human worker. This final step unveiled collisions and disunity between human, robots and machines. Additional changes were made to the model and different stations were reprogrammed in order to resolve the problems. Among these changes was programming different movement patterns for the robot and the human to create a more efficient and realistic process.

4.2 Physical Commissioning

With the simulation completed and the process mature enough according to the team at the company, the commissioning could commence. Due to time constraints, only the main KUKA robot was installed, without any fencing or machines. In order to authorize this installation a risk assessment had to be conducted beforehand.

4.2.1 Risk assessment

The risk assessment was conducted using a template provided by the safety engineer at the company, which has a rating system for different levels of risk and seriousness, which can be seen in A.1. The risk assessment was done with the safety engineer and was in the form of a brainstorming meeting to identify the risks, followed by evaluating and calculating the corresponding risk number for each risk which can be seen in A.2. If the number was deemed to high, measures had to be taken and the risk number had to be recalculated which can be seen in A.3.

4.2.2 Robot installation

Using the robot's coordinates from the simulation, markings were made on the floor for a contractor to come and drill holes for the robot installation. Afterwards the robot was installed along with a KUKA KR C4 robot controller. The robot controller was also added to the simulation at this stage. Finally, the robot was plugged in, and with the help of robot specialists at the company, the setup was successful and the robot could be jogged.

4.3 Digital Twin Implementation

With the robot in place and operable, the Digital Twin implementation was the next focus of the project. Enabling a Digital Twin with just the robot resulted in overarching practical experience for how to enable DT with other components in the future.

4.3.1 Robot connectivity

Using an Ethernet cable and the KUKA.Sim add-on, connecting to the robot through Visual Components was straightforward. After making sure that the controller version is the same in the simulation as the real controller, it was simply a matter of selecting the Motion Execution mode "Controller" as seen in A.6, to make the simulation follow the programming and movement on the controller. Afterwards, the IP address of the controller was configured in the simulation and with a successful connection established, it was possible to press play in VC and see the simulation follow the real robot's movements, as seen in Figure 4.9.

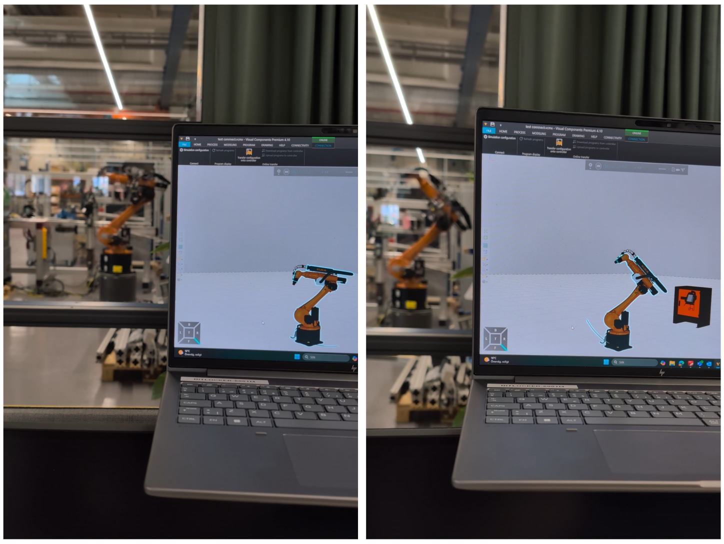


Figure 4.8: VC following robot movement in real-time

This way of connecting corresponds to Figure 3.4, a simple way of connecting with the robot without the use of an IoT platform. Although there is possibilities to transfer programs and movements from VC to the controller and to control/jog the robot from VC, it requires overwriting current files on the controller which was not possible in this application, due to important pre-existing programs and files. The KUKA.Sim add-on did not provide live viewing of values of all parameters, nor did it allow the possibility to choose which parameters to pair with various parts of the virtual robot. Additionally, KUKA.Sim only establishes a connection with the KUKA robot, and does not have the capability to connect with various sensors and other robots through a PLC. For the PLC implementation to work, a connection needs to be established using IoT platforms and communicating with the OPC UA protocol.

4.3.2 IIoT connectivity

An important aspect of implementing DT for the company in question was to be able to extract valuable information and process it. There is an established IoT architecture with certain software such as Ignition and HighByte which the company utilizes. Though the previous section had a bi-directional connection through VC to the physical KUKA-robot in the cell directly, it lacked modularity and was not a general solution for robots of different brands. Figure 2.2 illustrates the IIoT architecture which was employed in the second phase of the DT implementation, based on Figure 3.3.

The practical way of implementing this was more complicated than the previous method with the KUKA.sim add-on. First, the controller had to change the IP address to one which the firewall allows information to pass through with. Following that, the controller was connected to a switch using an Ethernet cable, and from there, the Ignition software could establish a connection with the robot controller and extract live values from selected tags. The selected tags in this project was the different axis values and other parameters such as speed, safety trips etc. These tags relay the live values from the robot and provide the simulation with the information it needs to mirror the real robot cell. HighByte could from there visualize and contextualize the data using a module that was connected to Ignition. Visual Components also accessed these parameters' values in parallel from Ignition to display the simulation side of the DT.

In Visual Components, the Connectivity tab was used to establish an OPC UA server, which communicated with Ignition using OPC UA. In the Connectivity tab, as seen in A.7, many different supported servers for different robot brands can be established.

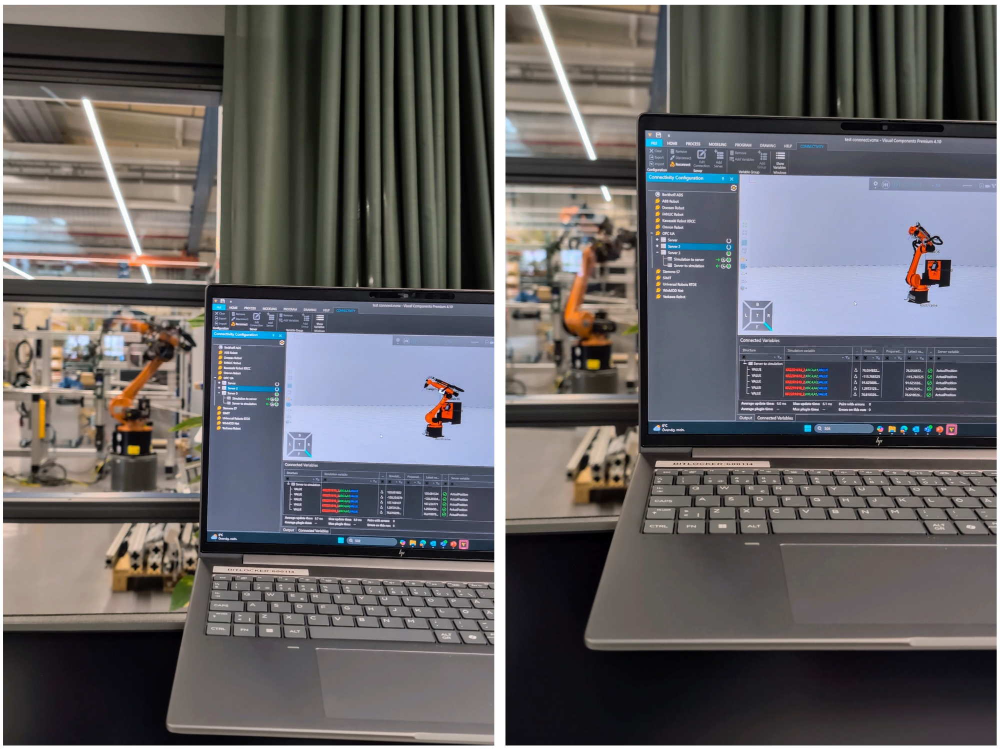


Figure 4.9: Digital Twin using OPC UA and pairing tags

When pairing the variables in the Connectivity, the parameters were paired using "Server to Simulation" only which means that the implementation was a DS instead of a DT, although pairing the same variables in "Simulation to Server" is all that is needed for a DT implementation. The axis values were paired to the axis parameters of the virtual KUKA robot, which then allowed the simulation to work as a Digital Shadow of the physical robot, as seen in A.9.

5

Discussion

In the discussion chapter, the research questions are revisited and answered based on the literature review and the results, before discussing the methodology. Consideration will also be given to the tools and technologies' potential gains, if they were deemed substantial enough to warrant the investment of resources.

5.1 Visual Components for layout planning and manufacturing process

The simulation software used in this thesis was Visual Components, which proved to be a powerful software with great capabilities and hardware support from different brands. The results achieved in developing the robot cell and the process using VC, cements the use of simulation software as a quintessential part of digital commissioning. Multiple uncertainties and issues were resolved, transformative modifications were also made with relative ease compared to not using simulation software in the pre-commissioning phase.

The manufacturing process was developed in the "Process" tab which felt convoluted at times with a myriad of options and menus. Some may perceive as a negative aspect, however it does indicate that VC is a potent software that can be used in a variety of contexts. Overall, the approach taken with VC for this thesis was satisfactory, and using Visual Components as part of the virtual commissioning of a robot cell or production line would rank highly on an reward/effort matrix.

The Connectivity tab was used to pair the variables from the physical robot to the simulation. In the future, the variable pairing function can be used for pairing sensors, conveyors and other variables, which the PLC handles, with their counterpart in the simulation.

5.2 Digital Twin implementation

The Digital Twin implementation was largely successful and a fully functional connection to the robot was established. The integration of HighByte as visualized in the format shown in Figure 2.2, was not explored, however it is ready to be set up and operational. The infrastructure is mostly in place and with a few tweaks, it should be possible to have the parameters and tags going through Ignition and to

HighByte for analysis and process recommendations. This analysis can improve reliability of components, lead to less downtime, more consistent quality, and improved profitability.

> **RQ1:** What are the main challenges in developing and implementing digital twins in robot cells?

The DT implementation was not as straight-forward as expected, and difficulties were mainly encountered when trying to connect HighByte with VC. The literature mentioned the fact that it was easy to be too ambitious, the advantages of implementing it can be hard to achieve, and that documentation on implementing DT:s are vague (Kober et al., 2024). This thesis showed that a functional digital twin can be achieved quite easily by connecting directly into the machinery, however, in order to benefit from DT:s, there has to be a holistic approach, connecting through IIoT platforms, and using PLC:s to oversee the complete cell and not just a robot. Only then will the DT infrastructure be able to generate useful data for the company, giving predictive and prescriptive information which can be stored and analysed.

This connection is where the difficulties of implementing DT:s appeared, as the integration was difficult to establish between different IIoT platforms such as Ignition and HighByte with simulation software, Visual Components in this case. HighByte and VC did not cooperate as expected. The initial plan was to go through HighByte to Visual Components, thus having a top-to-bottom dataflow architecture. However it appeared that both Visual Components and HighByte only work as OPC clients, they both consume data provided by an OPC server. One way to make the IIoT infrastructure work was therefore to connect VC and HighByte directly to Ignition which acts as a OPC server. Ignition can provide data to VC from the PLC that contains all the relevant tags to enable a DT. At the same time, this data can be sent to HighByte to be prepared for analysis and contextualization, which is its primary purpose.

Being able to identify what tags of information is another challenge, due to a balance that needs to be struck in order to, (a) be able to have a functioning digital twin and, (b) gather valuable data for analyses, without collecting too many datapoints was also difficult to decide.

In order to increase the Technology Readiness Level of Digital Twins, it is not only the implementation and technical challenges that are hurdles which need to be overcome. Security and safety is also an important aspect according to the stakeholders at the company that needs to be taken into careful consideration. If a simulation engineer by mistake presses a button or jogs a robot that an operator is working on closely, accidents can occur. For this to be prevented, there needs to be safety precautions in place. With regard to security, a breach of the network by a perpetrator could potentially lead to crashed machines and cause great harm. These risks lead to a higher risk/reward ratio when having bi-directionality, and when comparing the effort required to ensure the safety and security of the company, it classifies as higher effort and not that much more impact than a simpler Digital Shadow, as seen in Figure 5.1.

A simple digital model on the other hand has a low barrier of entry to being used by companies, and has benefits in the commissioning phase, although it is not extremely impactful and novel, as made evident in this thesis, with the VC simulation of the process not being able to give feedback and process improvement suggestions based on data collection.

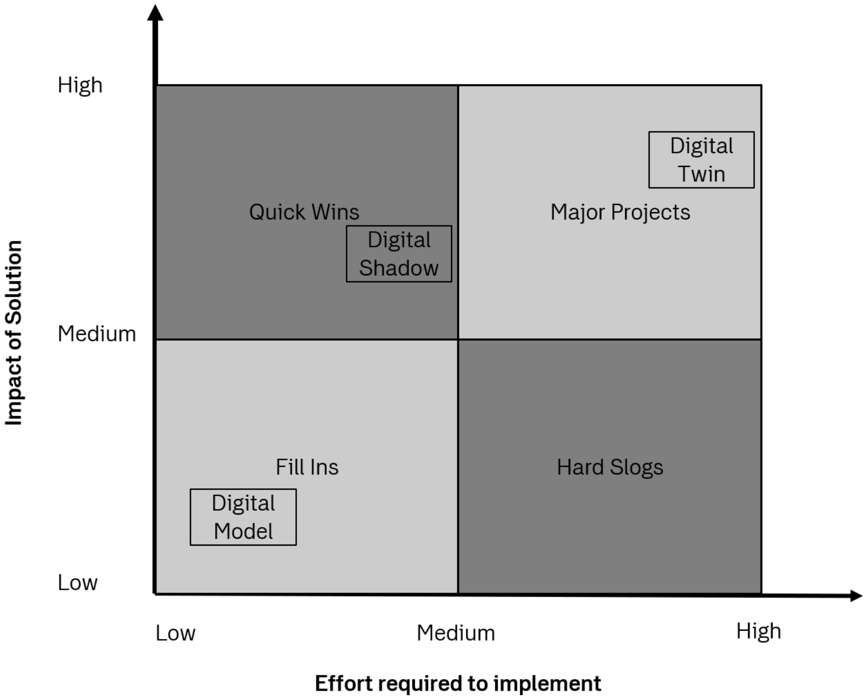


Figure 5.1: The different Digital Twin levels and their impact versus reward for a company

It is crucial for companies to enable some form of a DT or DS that utilizes IoT platforms, in order to extract the maximum value out of the process data which is generated in the factories. Having an automatic feedback loop for the process to reach a true Digital Twin does not have much more value for a company compared to the increased effort required for a safe and secure implementation. A Digital Shadow therefore emerges as a happy medium with which analysts and engineers can extract valuable information for the process manually, without having to implement stringent and complicated systems.

5.3 Ignition and HighByte

Ignition and HighByte have a good synergy which was utilized in this project. Ignition was used as a funnel to send the relevant data parameters for HighByte, which subsequently processed the data. Future applications can include HighByte and VC as parallel beneficiaries of data that comes from a PLC, through Ignition.

> **RQ2:** How can a company enable a digital twin in a factory setting, using the simulation software Visual Components, and IoT platforms Highbyte and Ignition?

The first step to enabling the DT with these IoT platforms was to establish a connection to the robot with Ignition, using the OPC UA data exchange standard, and setting up the endpoint address, naming the connection etc. Afterwards, it was possible to browse for tags and drag them in to this connection. This connection was then utilized by HighByte to visualize. The next step was to send the data from Ignition to Visual Components. More robust and versatile methods to enable a DT in Visual Components can be explored in future projects. This solution was not a plug-and-play solution, rather the setup took some effort to make everything work.

In order for the data from the robot to reach the operational layer of the network, a static IP address had to be assigned to the controller. This is done to have tighter access control and to be able to monitor the traffic. In a factory environment, a PLC would also be assigned a static IP address, to ensure that the data reaches the IIoT platform while adhering to the cybersecurity requirements. Likewise, the robot programming and the process improvements which the simulation and IIoT platform will want to relay back to the PLC would be devices using static IP addresses that are whitelisted by the firewall.

In summary, the key steps for a general implementation of a digital twin in a factory setting would be:

1. Establish connection between IIoT platforms and physical components.

2. Determine and implement the variable pairings needed for the DT and data analysis.

3. Decide on IP and data transfer configuration with safety/security in mind.

5.4 Methodology

The approach in this thesis was successful, inspired by input from the supervisors. From the qualitative study which gave a good understanding of what has been done with Digital Twins in the academic field and how it has been implemented in other contexts, to what the team at the company expected from the project. Using Visual Components to aid the process of developing the cell, and in the physical commissioning, showed that using simulation is paramount to the success of a greenfield project.

However, there were obstacles along the way that could have been prevented, which hampered progress of the project. Issues with software licensing, administrative delays, and changes in the scope caused delays and non-productive time. These issues are common in projects and one solution could be to plan for these idle hours by preparing tasks that can be executed in parallel. Naturally, the demo cell and its development was not the main priority in the mind of the team members, as they had their own tasks. It was however rarely difficult to get the assistance that was needed.

In terms of the interviews, semi-structured interviews gave neutral answers from the interviewees, in addition to keeping the answers from previous interviews under wraps. This allowed each interviewee to focus on the topic from a personal perspective and to develop ideas without being influenced by other colleagues. This was immensely helpful thanks to the different kinds of expertise that was prevalent within the team. One possible way of improving this stage of the methodology would have been to send out questions about the demo cell in advance, based on the fact that the interviewees had to think for prolonged amounts of time during the interview, which could have resulted in suboptimal answers and ideas.

Building the robot cell from a simulation into the physical world and developing the process is realizable. Naturally, there are further changes and optimizations that can be made in the simulation and the process to enhance robustness and efficiency, but the current simulation of the process is accurate enough to implement in the physical cell, according to the team members. However, even though creating a DT between the simulation and physical cell with all the sensors, safety features, and other moving parts requires investing more resources and time, it is still a viable and realistic goal.

5.5 Limitations

There were limitations that prevented this project to explore other possibilities, e.g. VR usage with Visual Components. In order to connect the provided VR headsets with VC, there were applications needed which went against the company's cybersecurity guidelines. The KUKA.sim Add-on tool was limited in its usage, firstly due to the brand limitation, and secondly due to the lack of optionality to connect different sensors, emergency buttons, and other machine parameters to VC simultaneously.

5.6 Future work

Moving forward with this project, there are many avenues of development that can be explored. One path is to create a complete and functional DT with the IIoT platforms provided and Visual Components. Accomplishing this would entail building the demo cell as designed in the simulation, everything from the safety functions to implementing sensors on the demo cells with machines connected. This will be a stepping stone towards the implementation of a full DT of the R&D shop-floor, which would be the next step. A more evaluated risk assessment should be done in the future when the circumstances of the robot cell changes, as the current phase only have the robot moving manually at a slow pace. Building out the cell to operate the robot at full speed, with fencing and machines, will require revisiting the risk assessment at each stage.

Another aspect that can be explored is the human and robot collaboration in the demo cell, investigating how a DT is leveraged in that collaboration. The level of engagement achieved was the lowest one with the KUKA robot, as it is isolated. The ABB robot should have higher levels of collaboration. There is also room for further developing the demo cell by integrating modern safety methods and security features, with appurtenant informational notes placed around the demo cell. Examples of such safety features to use on the conveyor entry holes are; muting by using light curtains, tunnels which physically prevent sticking an arm in to the robot cell, and distance sensors to adapt the speed of the robot which is outside the fencing.

Exploring the use of VR with the simulation as a basis, and integrating VR to the demo cell to where it can be used as a learning tool has great potential. VR can be used for safety education or showcasing state of the art technology of the company without needing to actually work in the shop floor.

6

Conclusion

This project showcases that a DT can be achieved using Visual Components in different ways. One way is to directly connect a robot controller to Visual Components and write programs from VC to the physical robot, or to have the simulation follow and display the movements and programming of the physical robot in real-time. Another way is to have IIoT software like Ignition between the simulation and the physical robot, in order to create a more functional solution that can contextualize data. This contextualisation can be done using an IIoT platform primarily used for data processing and operations such as HighByte.

The project provides a clear framework of how DT:s can be accomplished and sustained through a infinite loop model that considers both the virtual commissioning and the physical commissioning as part of achieving a fully functioning Digital Twin. The proposed methodology consists of designing a robot cell and a process in VC, before installing the machines and components, and establishing a connection to the physical components in order to have a fully functioning DT.

This thesis also delivers insights to the hindrances that DT implementations encounter in a commercial context; companies have to put an emphasis on safety and security regarding the data transfer between the simulation and the physical world, the connection between licensed software is not always easy and straight-forward, and sifting through the available data that will benefit the company is resource-intensive. A general method for implementing digital twins in this context is by first establishing a connection between IIoT software and physical components, before pairing the relevant variables while having cybersecurity measures in place for data transfer and bi-directional dataflow. In order to decrease the effort required and to enable the utilization of data analysis platforms, companies can utilize Digital Shadows, which bring about a majority of the benefits a Digital Twin has, with lesser requirements on cybersecurity.

This thesis serves as a basis for future developments of DT implementations with PLC integration and more components in a production context, and related technologies such as VR usage for learning purposes.

References

ABB. (2025). Irb 1200 [Accessed 21-04-2025]. https://new.abb.com/products/robotics/robots/articulated-robots/irb-1200

Adeoye-Olatunde, O. A., & Olenik, N. L. (2021). Research and scholarly methods: Semi-structured interviews. *Journal of the American College of Clinical Pharmacy*, *4*(10), 1358–1367.

Al Dahdouh, Alaa A. (2018). Visual Inspection of Sequential Data: A Research Instrument for qualitative data analysis. *NSUWorks*.

Alcácer, V., & Cruz-Machado, V. (2019). Scanning the industry 4.0: A literature review on technologies for manufacturing systems. *Engineering science and technology, an international journal*, *22*(3), 899–919.

Ali, W. (2023, October). Difference between safety and security: 10 major differences. https://www.hseblog.com/difference-between-the-safety-and-security/

Arnarson, H., Yu, H., Olavsbråten, M. M., Bremdal, B. A., & Solvang, B. (2023). Towards smart layout design for a reconfigurable manufacturing system. *Journal of Manufacturing Systems*, *68*, 354–367.

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer networks*, *54*(15), 2787–2805.

Baena, F., Guarin, A., Mora, J., Sauza, J., & Retat, S. (2017). Learning factory: The path to industry 4.0. *Procedia manufacturing*, *9*, 73–80.

Batty, M. (2018). Digital twins. *Environment and Planning B: Urban Analytics and City Science*, *45*(5), 817–820.

Cimino, C., Negri, E., & Fumagalli, L. (2019). Review of digital twin applications in manufacturing. *Computers in industry*, *113*, 103–130.

Cohen, D., Lindvall, M., & Costa, P. (2004). An introduction to agile methods. *Adv. Comput.*, *62*(03), 12.

Domínguez-Bolaño, T., Campos, O., Barral, V., Escudero, C. J., & García-Naya, J. A. (2024, January). An overview of iot architectures, technologies, and existing open-source projects. https://arxiv.org/abs/2401.15441

Douthwaite, J. A., Lesage, B., Gleirscher, M., Calinescu, R., Aitken, J. M., Alexander, R., & Law, J. (2021). A modular digital twinning framework for safety assurance of collaborative robotics. *Frontiers in Robotics and AI*, *8*, 758099.

Erdal, L., & Gubartalla, A. (2024). Dynamic digital twin through vr, enabled by emulate3d. http://hdl.handle.net/20.500.12380/308660

Ferreira, J. J., Fernandes, C. I., & Ferreira, F. A. (2019). To be or not to be digital, that is the question: Firm innovation and performance. *Journal of Business research*, *101*, 583–590.

Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: Enabling technologies, challenges and open research. *IEEE Access*, *PP*, 1–1. https://doi.org/10.1109/ACCESS.2020.2998358

Glaessgen, E., & Stargel, D. (2012). The digital twin paradigm for future NASA and US Air Force vehicles. *53rd AIAA/ASME/ASCE/AHS/ASC structures, structural dynamics and materials conference*, 1818.

Grau, A., Indri, M., Bello, L. L., & Sauter, T. (2020). Robots in industry: The past, present, and future of a growing collaboration with humans. *IEEE Industrial Electronics Magazine*, *15*(1), 50–61.

Grieves, M., & Vickers, J. (2017). Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. *Transdisciplinary perspectives on complex systems: New findings and approaches*, 94.

Guerra-Zubiaga, D., Kuts, V., Mahmood, K., Bondar, A., Nasajpour-Esfahani, N., & Otto, T. (2021). An approach to develop a digital twin for industry 4.0 systems: Manufacturing automation case studies. *International Journal of Computer Integrated Manufacturing*, *34*(9), 933–949.

Guth, J., Breitenbücher, U., Falkenthal, M., Fremantle, P., Kopp, O., Leymann, F., & Reinfurt, L. (2018). A detailed analysis of iot platform architectures: Concepts, similarities, and differences. In *Internet of everything: Algorithms, methodologies, technologies and perspectives* (pp. 81–101). Springer. https://doi.org/10.1007/978-981-10-5861-5_4

Harrington, J. (2025). HighByte + Ignition: Two powerful solutions in your modern data architecture [Accessed 21-04-2025]. https://www.highbyte.com/blog/highbyte-and-ignition-two-powerful-solutions-in-your-modern-data-architecture

Hollerer, S., Fischer, C., Brenner, B., Papa, M., Schlund, S., Kastner, W., Fabini, J., & Zseby, T. (2021). Cobot attack: A security assessment exemplified by a specific collaborative robot. *Procedia Manufacturing*, *54*, 191–196.

Jazdi, N. (2014). Cyber physical systems in the context of industry 4.0. *2014 IEEE international conference on automation, quality and testing, robotics*, 1–4.

Kleijnen, J. P. (1993). Simulation and optimization in production planning: A case study. *Decision Support Systems*, *9*(3), 269–280.

Klingstam, P., & Gullander, P. (1999). Overview of simulation tools for computer-aided production engineering. *Computers in industry*, *38*(2), 173–186.

Kober, C., Medina, F. G., Benfer, M., Wulfsberg, J. P., Martinez, V., & Lanza, G. (2024). Digital twin stakeholder communication: Characteristics, challenges, and best practices. *Computers in Industry*, *161*, 104135.

KUKA. (2025). Kr 22 r1610-2 [[Accessed 21-04-2025]]. https://my.kuka.com/s/product/kr-22-r16102/01t58000005QGK0AAO?language=en_US

Lavalle, S. M. (2023). *Virtual reality*. Cambridge University Press.

Leitner, S.-H., & Mahnke, W. (2006). OPC UA–service-oriented architecture for industrial applications. *Softwaretechnik-Trends Band 26, Heft 4*.

MachineMetrics. (2025). Connecting Devices and PLCs with OPC-UA [[Accessed 17-04-2025]].

Maddikunta, P. K. R., Pham, Q.-V., Prabadevi, B., Deepa, N., Dev, K., Gadekallu, T. R., Ruby, R., & Liyanage, M. (2022). Industry 5.0: A survey on enabling technologies and potential applications. *Journal of industrial information integration*, *26*, 100257.

Malik, A. A., & Bilberg, A. (2019). Developing a reference model for human–robot interaction. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *13*(4), 1541–1547.

Manning, C. G. (2023, September). Technology readiness levels. https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/

Martínez-Gutiérrez, A., Díez-González, J., Verde, P., & Perez, H. (2023). Convergence of virtual reality and digital twin technologies to enhance digital operators' training in industry 4.0. *International Journal of Human-Computer Studies*, *180*, 103136.

Nava-Téllez, I. A., Elias-Espinosa, M. C., Escamilla, E. B., & Saavedra, A. H. (2023). Digital twins and virtual reality as means for teaching industrial robotics: A case study. *2023 11th International Conference on Information and Education Technology (ICIET)*, 29–33.

Oppelt, M., & Urbas, L. (2014). Integrated virtual commissioning an essential activity in the automation engineering process: From virtual commissioning to simulation supported engineering. *IECON 2014-40th Annual Conference of the IEEE Industrial Electronics Society*, 2564–2570.

Pang, T. Y., Pelaez Restrepo, J. D., Cheng, C.-T., Yasin, A., Lim, H., & Miletic, M. (2021). Developing a digital twin and digital thread framework for an 'industry 4.0'shipyard. *Applied Sciences*, *11*(3), 1097.

Paredis, R., Gomes, C., & Vangheluwe, H. (2021). Towards a family of digital model/shadow/twin workflows and architectures. *IN4PL*, 174–182.

Pérez, L., Rodríguez-Jiménez, S., Rodríguez, N., Usamentiaga, R., & García, D. F. (2020). Digital twin and virtual reality based methodology for multi-robot manufacturing cell commissioning. *Applied sciences*, *10*(10), 3633.

Riel, A., Kreiner, C., Macher, G., & Messnarz, R. (2017). Integrated design for tackling safety and security challenges of smart products and digital manufacturing. *CIRP annals*, *66*(1), 177–180.

Rodič, B. (2017). Industry 4.0 and the new simulation modelling paradigm. *Organizacija*, *50*(3), 193–207.

Shao, G., et al. (2021). Use case scenarios for digital twin implementation based on iso 23247. *National institute of standards: Gaithersburg, MD, USA*.

Siemens. (2025). OPC UA – Structured data up to the cloud [[Accessed 17-04-2025]].

Sisinni, E., Saifullah, A., Han, S., Jennehag, U., & Gidlund, M. (2018). Industrial internet of things: Challenges, opportunities, and directions. *IEEE transactions on industrial informatics*, *14*(11), 4724–4734.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of business research*, *104*, 333–339.

Tarng, W., Wu, Y.-J., Ye, L.-Y., Tang, C.-W., Lu, Y.-C., Wang, T.-L., & Li, C.-L. (2024). Application of virtual reality in developing the digital twin for an integrated robot learning system. *Electronics*, *13*(14), 2848.

Trappey, A. J., Trappey, C. V., Govindarajan, U. H., Sun, J. J., & Chuang, A. C. (2016). A review of technology standards and patent portfolios for enabling cyber-physical systems in advanced manufacturing. *Ieee Access*, *4*, 7356–7382.

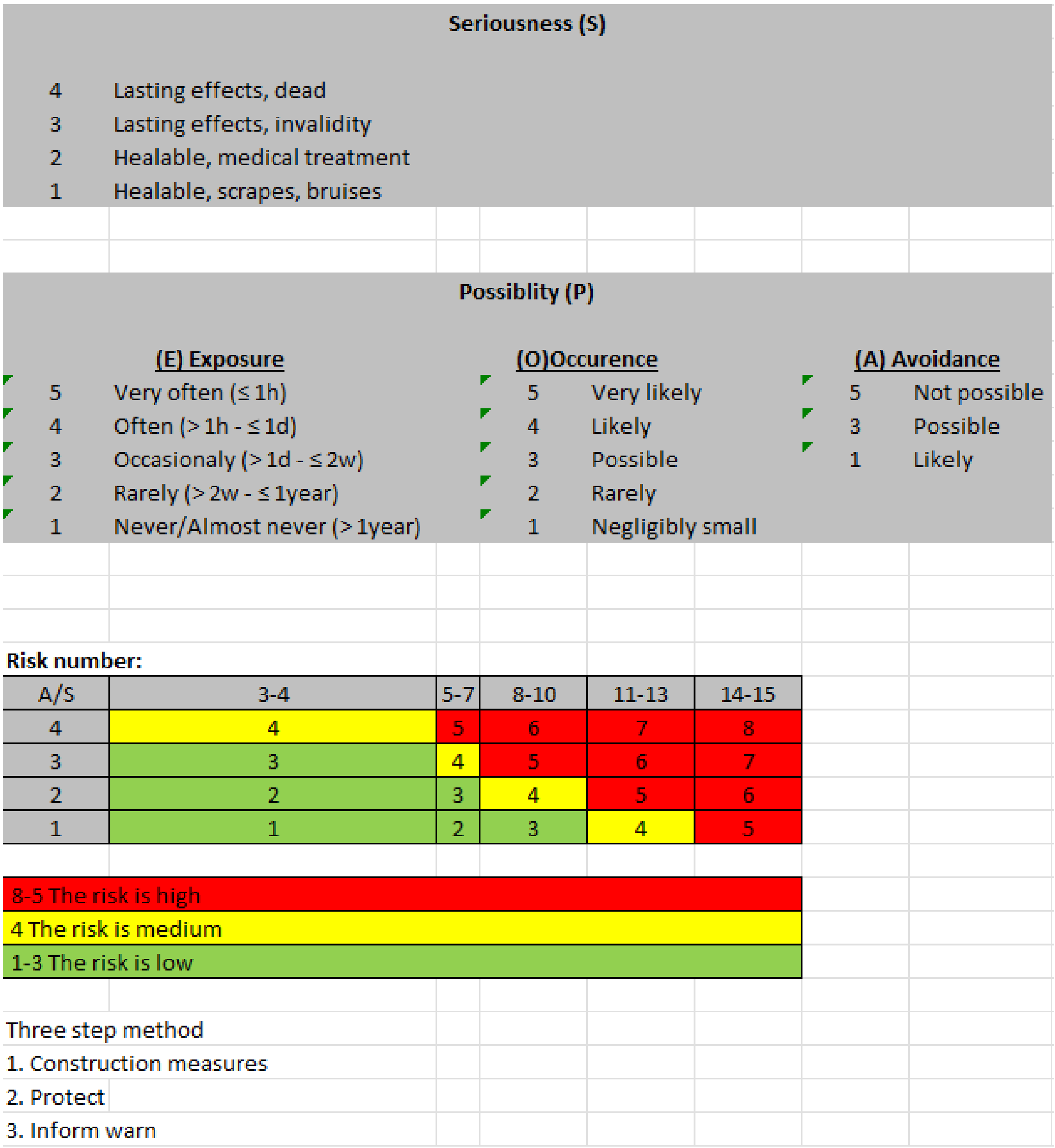
Visual Components. (2025a). Connect a remote opc ua server [Accessed 17-05-2025]. https://academy.visualcomponents.com/lessons/connect-a-remote-opc-ua-server/

Visual Components. (2025b). Manufacturing simulation [Accessed 21-04-2025]. https://www.visualcomponents.com/products/manufacturing-simulation/

Wang, P. X., Kim, S., & Kim, M. (2023). Robot anthropomorphism and job insecurity: The role of social comparison. *Journal of Business Research*, *164*, 114003.

A

Appendix



Seriousness (S)

4	Lasting effects, dead
3	Lasting effects, invalidity
2	Healable, medical treatment
1	Healable, scrapes, bruises

Possiblity (P)

	(E) Exposure		(O)Occurence		(A) Avoidance
5	Very often (≤ 1h)	5	Very likely	5	Not possible
4	Often (> 1h - ≤ 1d)	4	Likely	3	Possible
3	Occasionaly (> 1d - ≤ 2w)	3	Possible	1	Likely
2	Rarely (> 2w - ≤ 1year)	2	Rarely		
1	Never/Almost never (> 1year)	1	Negligibly small		

Risk number:

A/S	3-4	5-7	8-10	11-13	14-15
4	4	5	6	7	8
3	3	4	5	6	7
2	2	3	4	5	6
1	1	2	3	4	5

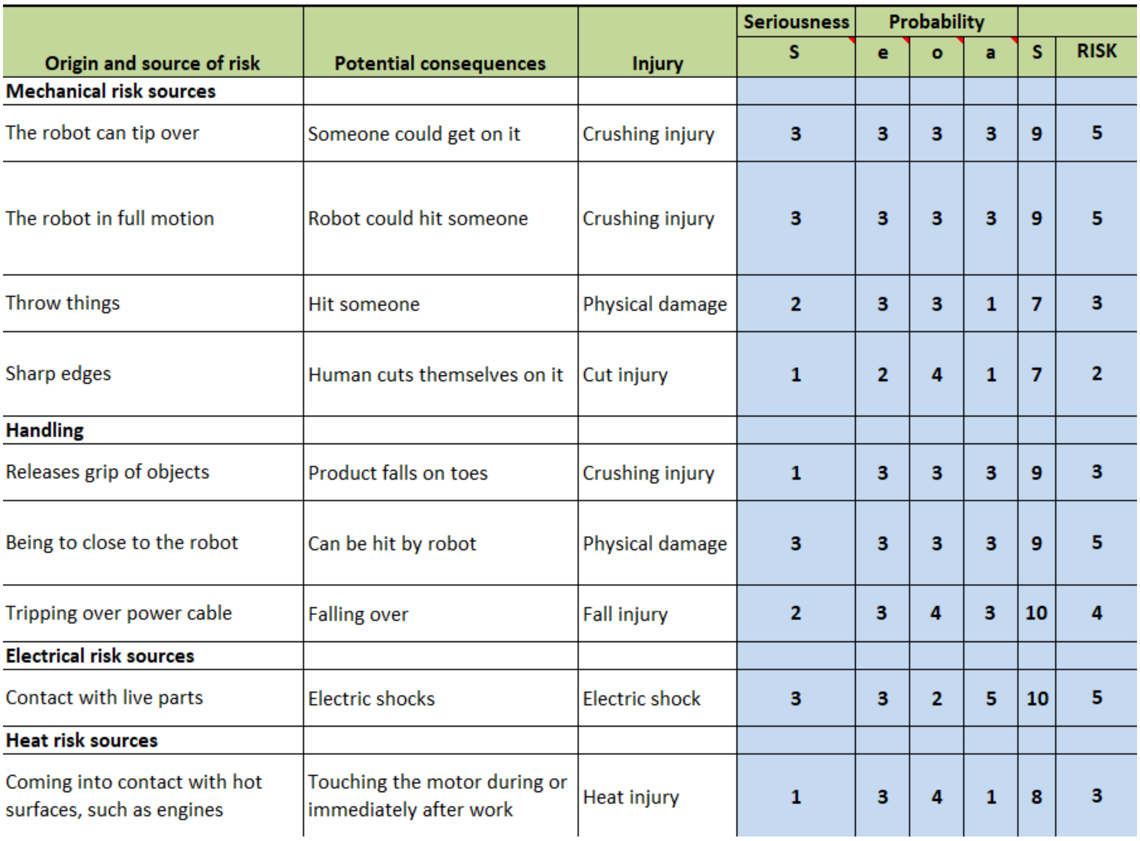
8-5 The risk is high

4 The risk is medium

1-3 The risk is low

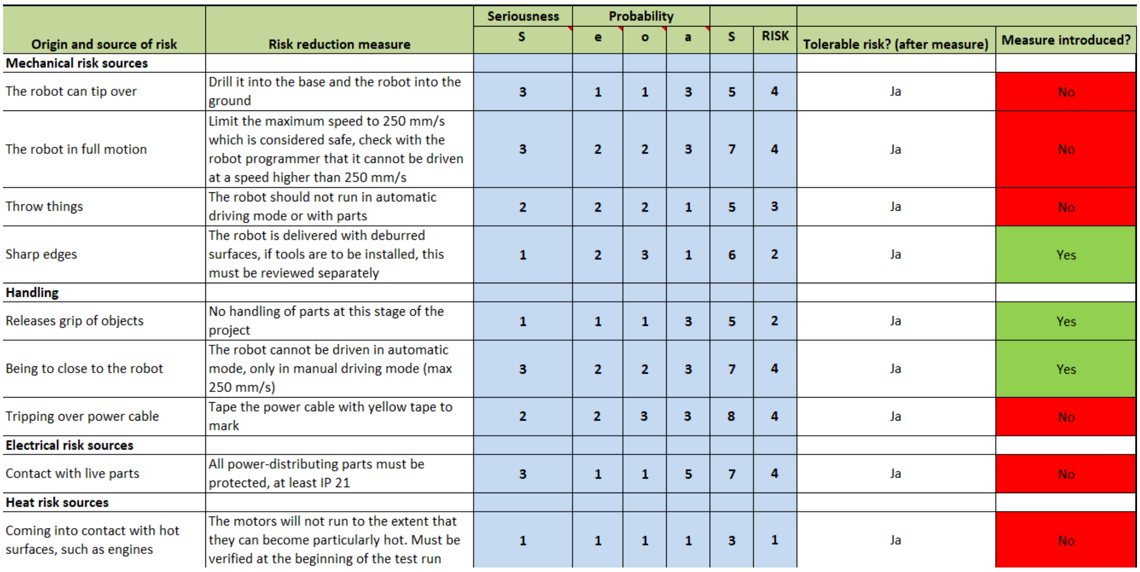
Three step method
1. Construction measures
2. Protect
3. Inform warn

Figure A.1: The ranking strategy for the risk assessment



Origin and source of risk	Potential consequences	Injury	Seriousness	Probability				
			S	e	o	a	S	RISK
Mechanical risk sources								
The robot can tip over	Someone could get on it	Crushing injury	3	3	3	3	9	5
The robot in full motion	Robot could hit someone	Crushing injury	3	3	3	3	9	5
Throw things	Hit someone	Physical damage	2	3	3	1	7	3
Sharp edges	Human cuts themselves on it	Cut injury	1	2	4	1	7	2
Handling								
Releases grip of objects	Product falls on toes	Crushing injury	1	3	3	3	9	3
Being to close to the robot	Can be hit by robot	Physical damage	3	3	3	3	9	5
Tripping over power cable	Falling over	Fall injury	2	3	4	3	10	4
Electrical risk sources								
Contact with live parts	Electric shocks	Electric shock	3	3	2	5	10	5
Heat risk sources								
Coming into contact with hot surfaces, such as engines	Touching the motor during or immediately after work	Heat injury	1	3	4	1	8	3

Figure A.2: Risk assessment before measures



Origin and source of risk	Risk reduction measure	Seriousness	Probability						
		S	e	o	a	S	RISK	Tolerable risk? (after measure)	Measure introduced?
Mechanical risk sources									
The robot can tip over	Drill it into the base and the robot into the ground	3	1	1	3	5	4	Ja	No
The robot in full motion	Limit the maximum speed to 250 mm/s which is considered safe, check with the robot programmer that it cannot be driven at a speed higher than 250 mm/s	3	2	2	3	7	4	Ja	No
Throw things	The robot should not run in automatic driving mode or with parts	2	2	2	1	5	3	Ja	No
Sharp edges	The robot is delivered with deburred surfaces, if tools are to be installed, this must be reviewed separately	1	2	3	1	6	2	Ja	Yes
Handling									
Releases grip of objects	No handling of parts at this stage of the project	1	1	1	3	5	2	Ja	Yes
Being to close to the robot	The robot cannot be driven in automatic mode, only in manual driving mode (max 250 mm/s)	3	2	2	3	7	4	Ja	Yes
Tripping over power cable	Tape the power cable with yellow tape to mark	2	2	3	3	8	4	Ja	No
Electrical risk sources									
Contact with live parts	All power-distributing parts must be protected, at least IP 21	3	1	1	5	7	4	Ja	No
Heat risk sources									
Coming into contact with hot surfaces, such as engines	The motors will not run to the extent that they can become particularly hot. Must be verified at the beginning of the test run	1	1	1	1	3	1	Ja	No

Figure A.3: Risk assessment after measures

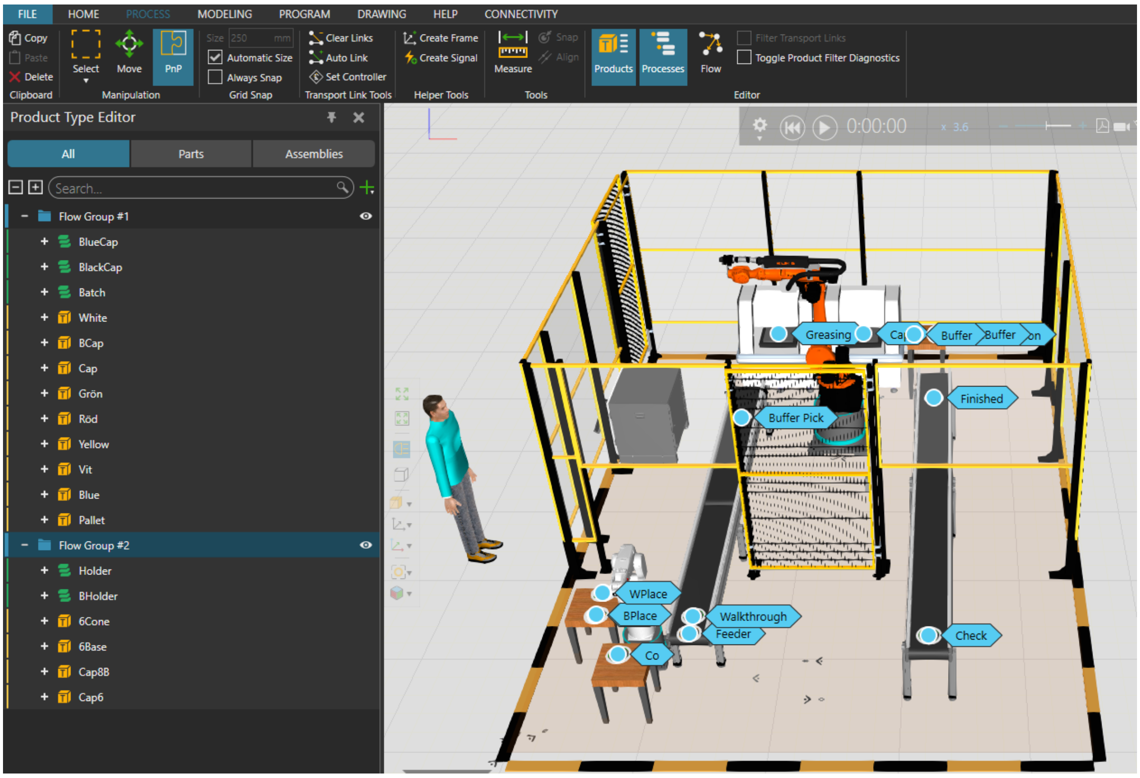
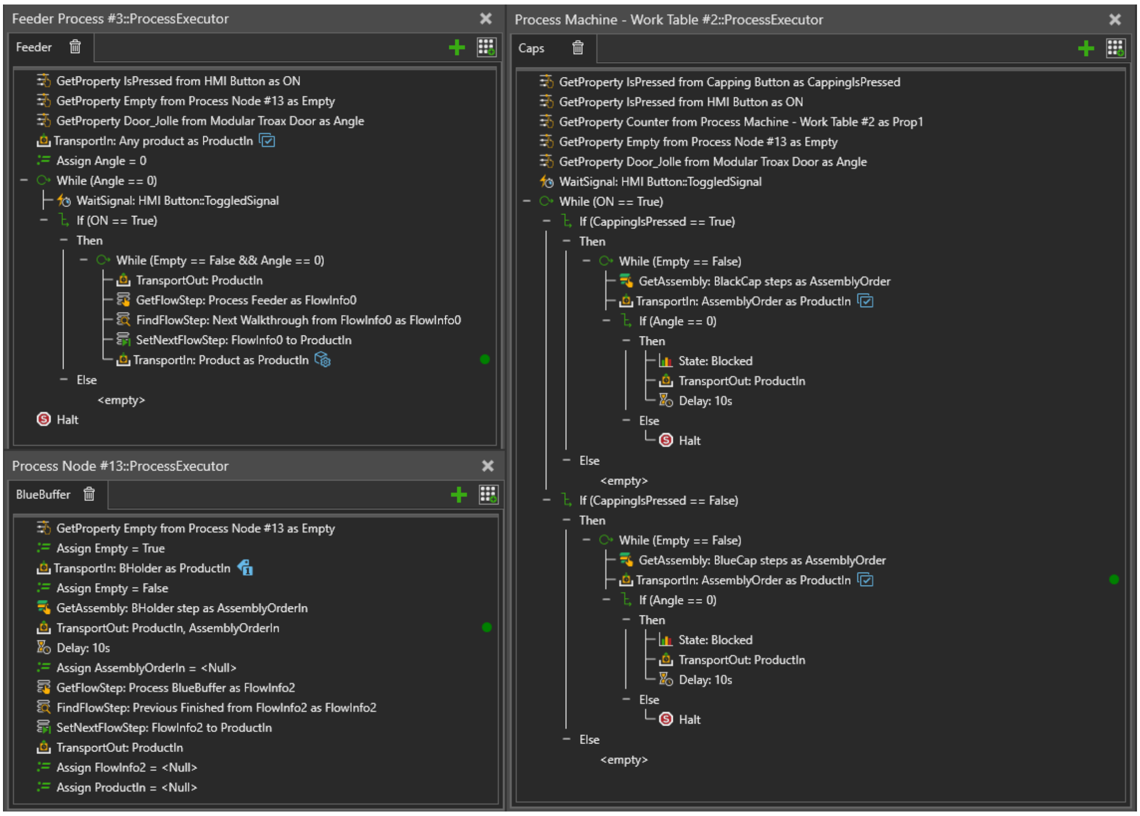


Figure A.4: Overview of the process function in VC


Feeder Process #3::ProcessExecutor

Feeder

```
GetProperty IsPressed from HMI Button as ON
GetProperty Empty from Process Node #13 as Empty
GetProperty Door_Jolle from Modular Troax Door as Angle
TransportIn: Any product as ProductIn
Assign Angle = 0
- While (Angle == 0)
    WaitSignal: HMI Button::ToggledSignal
  - If (ON == True)
    - Then
      - While (Empty == False && Angle == 0)
          TransportOut: ProductIn
          GetFlowStep: Process Feeder as FlowInfo0
          FindFlowStep: Next Walkthrough from FlowInfo0 as FlowInfo0
          SetNextFlowStep: FlowInfo0 to ProductIn
          TransportIn: Product as ProductIn
    - Else
        <empty>
Halt
```

Process Node #13::ProcessExecutor

BlueBuffer

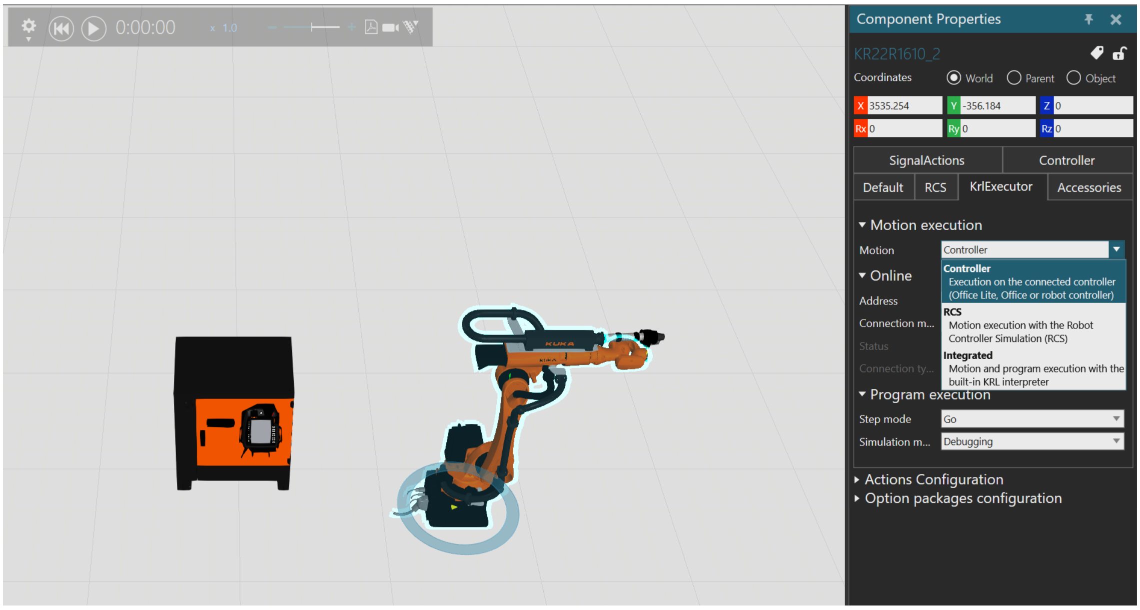
```
GetProperty Empty from Process Node #13 as Empty
Assign Empty = True
TransportIn: BHolder as ProductIn
Assign Empty = False
GetAssembly: BHolder step as AssemblyOrderIn
TransportOut: ProductIn, AssemblyOrderIn
Delay: 10s
Assign AssemblyOrderIn = <Null>
GetFlowStep: Process BlueBuffer as FlowInfo2
FindFlowStep: Previous Finished from FlowInfo2 as FlowInfo2
SetNextFlowStep: FlowInfo2 to ProductIn
TransportOut: ProductIn
Assign FlowInfo2 = <Null>
Assign ProductIn = <Null>
```

Process Machine - Work Table #2::ProcessExecutor

Caps

```
GetProperty IsPressed from Capping Button as CappingIsPressed
GetProperty IsPressed from HMI Button as ON
GetProperty Counter from Process Machine - Work Table #2 as Prop1
GetProperty Empty from Process Node #13 as Empty
GetProperty Door_Jolle from Modular Troax Door as Angle
WaitSignal: HMI Button::ToggledSignal
- While (ON == True)
  - If (CappingIsPressed == True)
    - Then
      - While (Empty == False)
          GetAssembly: BlackCap steps as AssemblyOrder
          TransportIn: AssemblyOrder as ProductIn
        - If (Angle == 0)
          - Then
              State: Blocked
              TransportOut: ProductIn
              Delay: 10s
          - Else
              Halt
    - Else
        <empty>
  - If (CappingIsPressed == False)
    - Then
      - While (Empty == False)
          GetAssembly: BlueCap steps as AssemblyOrder
          TransportIn: AssemblyOrder as ProductIn
        - If (Angle == 0)
          - Then
              State: Blocked
              TransportOut: ProductIn
              Delay: 10s
          - Else
              Halt
    - Else
        <empty>
```

Figure A.5: Programming in VC



KR22R1610_2

Coordinates ● World ○ Parent ○ Object

X 3535.254 Y -356.184 Z 0

Rx 0 Ry 0 Rz 0

Motion: Controller

Controller
Execution on the connected controller (Office Lite, Office or robot controller)

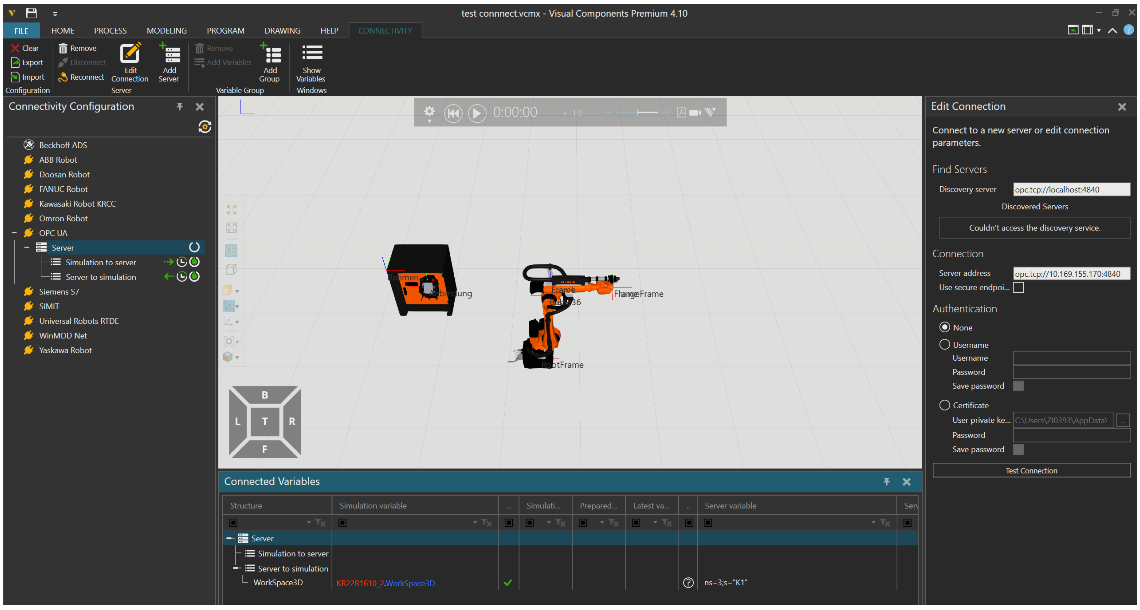
RCS
Motion execution with the Robot Controller Simulation (RCS)

Integrated
Motion and program execution with the built-in KRL interpreter

Step mode: Go

Simulation m...: Debugging

Figure A.6: Motion Execution menu



test connnect.vcmx - Visual Components Premium 4.10

Connect to a new server or edit connection parameters.

Discovery server: opc.tcp://localhost:4840

Couldn't access the discovery service.

Server address: opc.tcp://10.169.155.170:4840

Use secure endpoi... ☐

● None

○ Username

Username

Password

Save password

○ Certificate

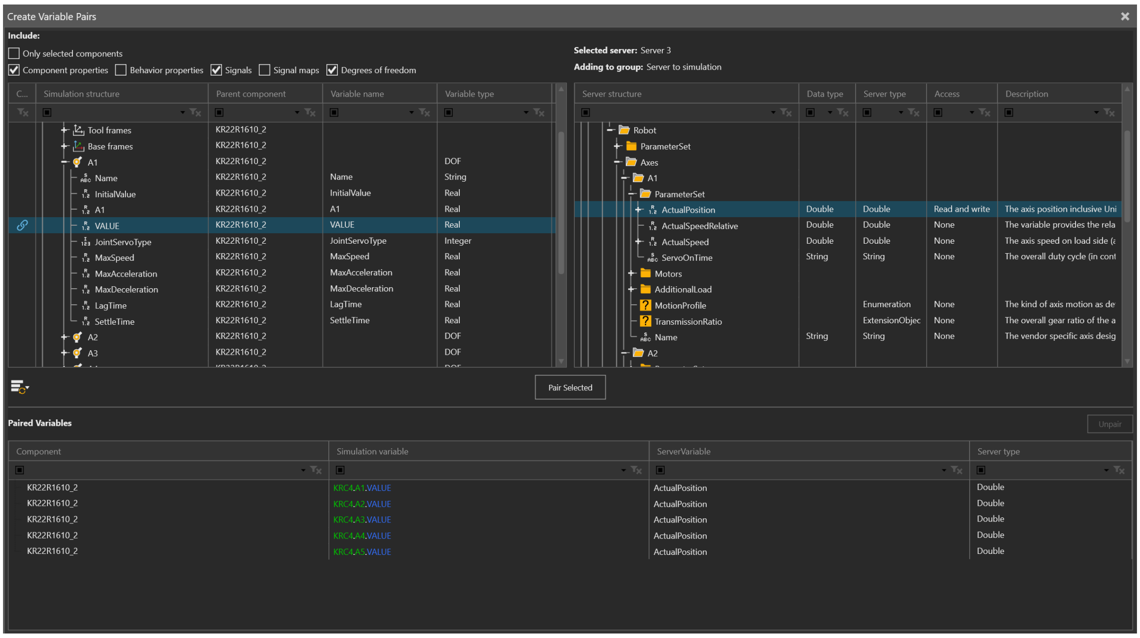
User private ke... C:\Users\ZI0393\AppData\

Password

Save password

Structure	Simulation variable	...	Simulati...	Prepared...	Latest va...	..	Server variable	Ser
Server								
Simulation to server								
Server to simulation								
WorkSpace3D	KR22R1610_2.WorkSpace3D	✓				?	ns=3;s="K1"	

Figure A.7: The Connectivity tab



Include:

☐ Only selected components

☑ Component properties ☐ Behavior properties ☑ Signals ☐ Signal maps ☑ Degrees of freedom

Selected server: Server 3
Adding to group: Server to simulation

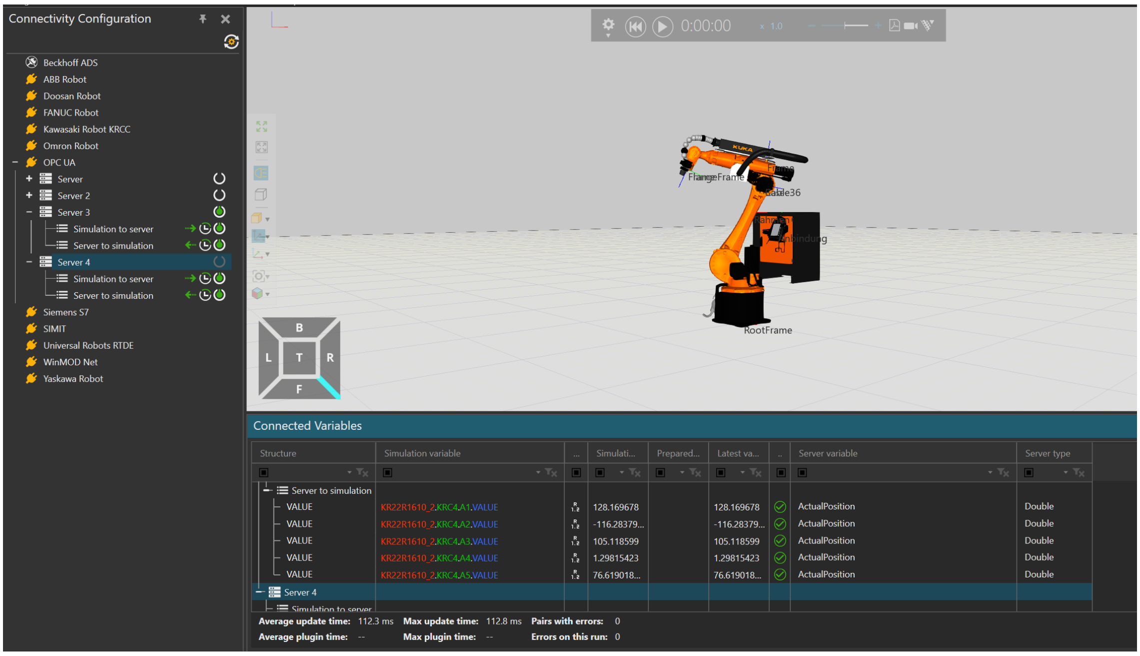
C...	Simulation structure	Parent component	Variable name	Variable type
	Tool frames	KR22R1610_2		
	Base frames	KR22R1610_2		
	A1	KR22R1610_2		DOF
	Name	KR22R1610_2	Name	String
	InitialValue	KR22R1610_2	InitialValue	Real
	A1	KR22R1610_2	A1	Real
	VALUE	KR22R1610_2	VALUE	Real
	JointServoType	KR22R1610_2	JointServoType	Integer
	MaxSpeed	KR22R1610_2	MaxSpeed	Real
	MaxAcceleration	KR22R1610_2	MaxAcceleration	Real
	MaxDeceleration	KR22R1610_2	MaxDeceleration	Real
	LagTime	KR22R1610_2	LagTime	Real
	SettleTime	KR22R1610_2	SettleTime	Real
	A2	KR22R1610_2		DOF
	A3	KR22R1610_2		DOF

Server structure	Data type	Server type	Access	Description
Robot				
ParameterSet				
Axes				
A1				
ParameterSet				
ActualPosition	Double	Double	Read and write	The axis position inclusive Uni
ActualSpeedRelative	Double	Double	None	The variable provides the rela
ActualSpeed	Double	Double	None	The axis speed on load side (a
ServoOnTime	String	String	None	The overall duty cycle (in cont
Motors				
AdditionalLoad				
MotionProfile		Enumeration	None	The kind of axis motion as de
TransmissionRatio		ExtensionObjec	None	The overall gear ratio of the a
Name	String	String	None	The vendor specific axis desig
A2				

Paired Variables

Component	Simulation variable	ServerVariable	Server type
KR22R1610_2	KRC4.A1.VALUE	ActualPosition	Double
KR22R1610_2	KRC4.A2.VALUE	ActualPosition	Double
KR22R1610_2	KRC4.A3.VALUE	ActualPosition	Double
KR22R1610_2	KRC4.A4.VALUE	ActualPosition	Double
KR22R1610_2	KRC4.A5.VALUE	ActualPosition	Double

Figure A.8: An example of how pairing variables works



Structure	Simulation variable	...	Simulati...	Prepared...	Latest va...	..	Server variable	Server type
Server to simulation								
VALUE	KR22R1610_2.KRC4.A1.VALUE		128.169678		128.169678	✓	ActualPosition	Double
VALUE	KR22R1610_2.KRC4.A2.VALUE		-116.28379...		-116.28379...	✓	ActualPosition	Double
VALUE	KR22R1610_2.KRC4.A3.VALUE		105.118599		105.118599	✓	ActualPosition	Double
VALUE	KR22R1610_2.KRC4.A4.VALUE		1.29815423		1.29815423	✓	ActualPosition	Double
VALUE	KR22R1610_2.KRC4.A5.VALUE		76.619018...		76.619018...	✓	ActualPosition	Double
Server 4								
Simulation to server								

Average update time: 112.3 ms **Max update time:** 112.8 ms **Pairs with errors:** 0
Average plugin time: -- **Max plugin time:** -- **Errors on this run:** 0

Figure A.9: Pairing sensors with a PLC (Visual Components, 2025a).

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY