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School of Innovation, Design, and Engineering

# Simulation as an Enabler for Production System Development within the Indoor Vertical Farming Industry

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# ABSTRACT

With the increase in food consumption, new ideas, and technologies began to be developed. In addition, the developments generated by Industry 4.0 technologies have started to be applied to the entire manufacturing sector and the indoor farming industry, which is currently trending. Many studies and articles have been prepared on this subject, and the main goal of each study is to produce quality products and to ensure continuity in production to cover the nonending increase in demand.

This paper discusses how simulation technology, which is one of the industry 4.0 technologies, can be used in the production system development of the indoor farming industry. According to many researchers, the biggest obstacle for the vertical farming industry is start-up cost, and simulation technologies can be the solution for this since it allows future production systems to be analyzed without any investment. To have a clear vision of how these technologies can be adapted in the indoor farming industry, this paper will find the answers to these questions, RQ1: How can simulation facilitate production system development and Industry 4.0 projects within the indoor farming industry? RQ2: What are the benefits and challenges when using simulation as a tool for production system development within the indoor farming industry? To reach the goal of this paper, the case study method was used, and an indoor farming company was selected to get more realistic data about the vertical farming system. BlueRedGold AB is a start-up company in the indoor farming industry, and it has a huge growth potential since they aim to transform its current production lines to be fully automated. Many articles and studies were used to approach the solution of the research questions from a more technical and academic point of view, and the analysis of these articles was carried out with the structured literature review method.

After conducting this research, answers have been obtained for the research questions. The authors' solution to the layout issue, one of the case company's main challenges as indicated in this study, was developed after extensive simulation model testing. As highlighted in this paper, it has been stated by many researchers, there are several simulation approaches to follow. However, the authors have developed a simulation modeling approach to be followed in the indoor vertical farming industry to overcome the complexity of these systems as well as the simulation program complexity. In addition, several challenges and benefits have been highlighted in this paper such as the lack of ready models of the equipment used in indoor farming which requires a knowledge of a programming language to overcome. Finally, despite challenges, simulation technology can provide an applicable solution for production system problems of vertical farming companies/organizations to obtain continuous improvement philosophy which is the main principle of Lean thinking. The generated simulation model in this thesis project was successfully implemented, demonstrating how this technology might be an effective solution for complex production systems as in the indoor farming sector.

**(Keywords: Indoor Vertical Farming, Production System Development, Industry 4.0, Facility Layout Design, and Simulation.)**

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## 1. INTRODUCTION

Overall, the introduction section of this thesis report sets the foundation for the report and establishes a clear focus for the study. This introduction starts with a background of the research area, followed by a problem formulation that addresses a particular research problem, and ends with the aim of this thesis report and its questions. The background subtitle provides the context for the research problem and underlines the significance of the study to set its relevance to the academic community. Where the problem formulation subtitle, the problem to be solved by this thesis report is clearly specified and finally the aim of this study is outlined, along with the research questions that will direct the research process.

### 1.1 Background

A UN report from 2019 estimates that by 2050, there will be 9.8 billion people on Earth, demanding a 70% increase in food production. Encouraging the concept of vertical farming, which utilizes indoor farming systems in a controlled environment where every ecological aspect can be monitored and managed, is one strategy to address this issue (Halgamuge et al., 2021). Indoor farming, frequently referred to as a vertical farming system or greenhouse is a relatively new technique to produce vegetables and other plants in a controlled environment (Stein, 2021). The benefits of adopting this farming system are enormous and discussed thoroughly by researchers. According to research, indoor vertical farming can use 70–95% less water than conventional farming methods (Kalntari et al., 2017) while yet producing up to 100 times greater yield per unit area (Kozai & Takagaki, 2015). Furthermore, indoor vertical farming is not affected by environmental factors such as extreme weather conditions, pests, and diseases and this ensures a stable and predictable yield throughout the year (Migliore et al., 2021). Therefore, it is a more common study subject in areas where the soil type is not suitable for agriculture. By moving food production closer to consumers, indoor vertical farming can reduce the carbon footprint associated with transportation (Khoshnevisan et al., 2021). However, the initial investment is considered to be the main obstacle to adopting this kind of farming. Kashiwagi et al. (2020) found that the high cost of indoor vertical farming systems can make it difficult for farmers to turn a profit, especially in the early years of operation. Similarly, Shang et al. (2020) found that small-scale farmers may be discouraged from adopting the technology due to the high start-up costs of indoor vertical farming systems. The term 'in-door' agriculture is seen as a new manufacturing industry, and it is also thought to be an easy and effective way to ensure the continuity of production which is a sustainable production system (Naranjani et al., 2022).

Simultaneously industrial production has changed a lot according to the new technologies and production/consumption volume. In this global market, where consumption is increasing and supply remains insufficient due to this increase, a more rational and sustainable production system is currently the most invested issue. The long-term production system in Toyota production principles has become the main policy of all large and medium-sized manufacturers. All these developments have made Industry 4.0, which is currently popular, an important production element (Santiteerakul et al., 2020). Industry 4.0 is a new and still trainable production phase by many researchers, authors, and companies, and industry 4.0 offers companies the information flow in an understandable way or language (Dalenogare et al., 2018). According to a systematic literature review done by Silvestri et al. (2020), when referring to the technologies associated with Industry 4.0, nine technological pillars are identified in several

studies and they include (1) Industrial Internet of Things (IIoT), (2) Big Data and Analytics, (3) Horizontal and vertical system integration, (4) Simulation, (5) Cloud computing, (6) Augmented Reality (AR), (7) Autonomous Robots, (8) Additive manufacturing (AM) and (9) Cyber Security. It is worth mentioning that two other technologies that are not included in these nine pillars but interact with them are Artificial Intelligence (AI) and Cyber-Physical Systems. According to many studies, industry 4.0 contributes to both a sustainable production system and the construction of a sustainable social structure (Brozzi et al., 2020). The effects of Industry 4.0 from different perspectives can be examined. For example, from the market side, companies can use the internet-based technique to provide better service and a good supply chain to their customers, and with these methods, customers can follow the supply chain more easily. From the production perspective, IoT and other digital techniques minimize setup time, labor, and similar expenses, thus helping the company always stay competitive in all areas (Dalenogare et al., 2018).

Industry 4.0 is anticipated to reshape the agriculture industry once more and promote the fourth agricultural revolution, much as the previous three industrial revolutions changed it from traditional farming to mechanized farming and, more recently, precision agriculture (Liu et al., 2020). Several technologies of Industry 4.0 are utilized in today's farming systems such as IoT, AI, and robotics. With any smart mobile device, IoT enables farmers to remotely monitor the conditions of their farms in real-time, from any location, at any time (Al-Kodmany, 2018). Furthermore, IoT data analytics finds patterns in data and draws unique understandings about crop growth, livestock health, and prospective process improvements and this reduces human error while promoting efficient problem-solving and decision-making (Sadiku et al., 2020). AI, on the other hand, can examine soil and water, as well as identify possible pests, weeds, and unhealthy plants, enabling timely application of fertilizers, pesticides, and irrigation to plants that require treatment (Yanes et al., 2020). On top of that, according to Veloo et al. (2019), AI can anticipate plant growth, assist with scheduling filtration and water supply, and automatically sort plants to reduce the need for manual nutrition grading and quality inspections (Tian, 2020). Robotics has a huge impact on farming systems, for instance, pre-programmed robots or drones can complete routine tasks like crop monitoring and watering, and they can precisely distribute the necessary fertilizer or pesticide to each plant (Sadiku et al., 2020). While taking advantage of its high maneuverability, robots are used to do inspection tasks at vertical grow towers, such as inspecting crops and grow beds, looking for signs of plant illnesses or insect pests, etc. (Salim, et al., 2019). However, not all of the Industry 4.0 technologies are sufficiently utilized in farming systems. According to a study conducted by Ng and Mahkeswaran (2021), they found that based on the literature from 2015 to 2021, IoT, automation, and AI are the top three technologies that are extensively implemented and documented while others are in their early adoption stages.

## **1.2 Problem Formulation**

As mentioned earlier, the indoor farming industry is rapidly expanding and becoming an important sector for sustainable food production, and it might be the solution for the required 70% increase in food production. However, the development of efficient production systems in indoor farming requires the integration of advanced technologies and complex systems, such as the technologies of Industry 4.0, which can be difficult to achieve without the use of simulation tools. Simulation tools can support system design optimization, identify potential problems, and improve efficiency (Banks, 1999). For indoor farming systems, different researchers have

pointed out the possibilities of technologies like AI, IoT, and robotics (de Abreu & Deventer, 2022; Kurni, 2021). Unfortunately, the use of simulation for production system development is not explored enough within indoor vertical farming (Ng & Mahkeswaran, 2021), leading to the necessity for this research.

### **1.3 Aim and Research Questions**

The research aims to explore the use of simulation as a tool in the early stages of production system development related to Industry 4.0 and smart manufacturing within the indoor farming industry. Furthermore, it aims to investigate the ability of simulation in producing several scenarios of the production system and choose the most appropriate model. Therefore, the following research questions have been developed:

RQ1: How can simulation facilitate production system development and Industry 4.0 projects within the indoor farming industry?

RQ2: What are the benefits and challenges when using simulation as a tool for production system development within the indoor farming industry?

## 2 THEORETICAL FRAMEWORK

Overall, the theoretic framework section of this thesis report presents the existing theoretical knowledge that serves as a frame of reference during this thesis work, and it contains four subsections. The first one discusses indoor vertical farming where the focus is to highlight the required criteria for indoor farming as well as the connection between industry 4.0 technologies and indoor vertical farming. While the second and third subsections cover production system development and facility layout design where brief introductions are presented as well as suggested approaches. Finally, the fourth subsection presents the simulation along with its benefits, challenges, and methods to follow are presented.

### 2.1 Indoor Vertical Farming

In this part of the theoretical framework, the aim is to provide the needed data on indoor vertical farming that is necessary to answer the research questions. It is divided into two subheadings where the first introduces the required criteria for indoor farming while the second explores the integration of Industry 4.0 technologies with indoor vertical farming. Furthermore, it covers soilless vertical farming models like hydroponics and aeroponics, highlighting their benefits as well as the six-layered architecture for efficient smart indoor farming systems.

#### 2.1.1 Required Criteria for Indoor Farming

To produce products within indoor farming, some environmental aspects are required such as light, water, and nutrients. Scientists working on the science of biotechnology in the past years have been publishing information and production technologies about vertical farming or soilless vertical farming. According to these publications, three different soilless crop-growing models were created. These are hydroponics and aeroponics which is more popular and, aquaponics (Hati & Singh, 2021). Plant cultivation technologies, for example, the hydroponic system, it is used to achieve high-value yields (for high-value crops). This provided alternatives to the soil environment for planting in extensive areas and minimizing the impact of increasing and reducing runs (environmental aspects). As mentioned in Figure 2.1, in a hydroponics growing system within vertical farming, plants are grown in an aqueous nutrient solution with or without an inert support substrate around the roots. The nutrient solution is usually recirculated through the system with the addition of fertilizer as required by monitoring results. (Halgamuge et al., 2021).

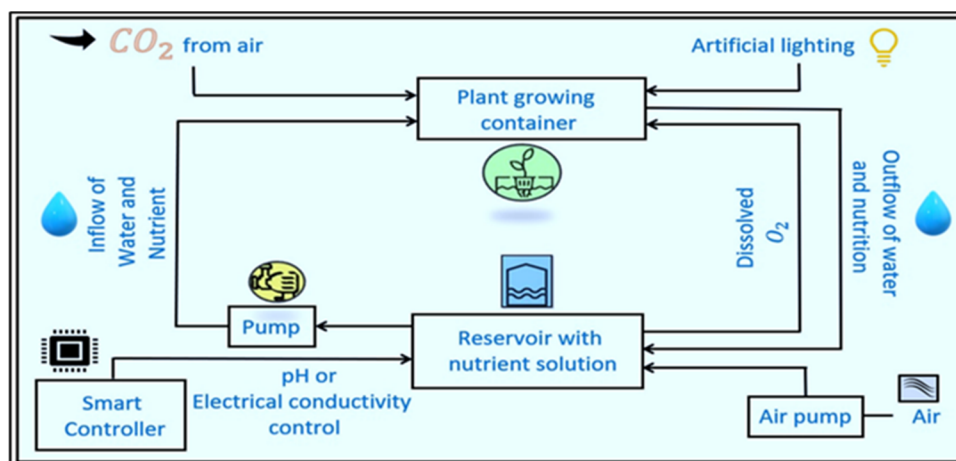
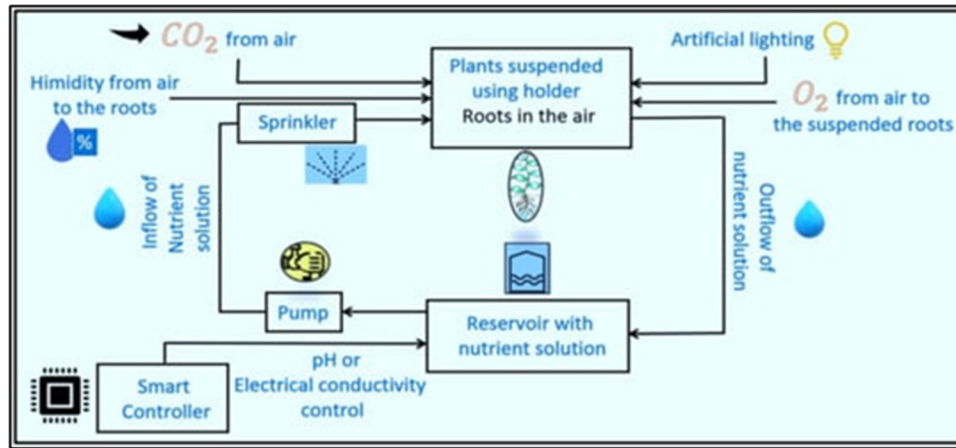


Figure 2.1 Hydroponics growing system principle (Hati & Singh, 2021)

If manufacturers require low cost and high growth rate within their indoor farming system, the Aeroponic system is one of the best choices in this area. An aeroponic system can provide low-cost and high amount of growth rates if environmental conditions such as nutrition value, water level, and temperature are controlled. It means that this system needs technology with a connection to the sensor to control all these conditions as a hydroponic system as seen in Figure 2.2 (Hati & Singh, 2021).



**Figure 2.2 Aeroponic growing system (Hati & Singh, 2021)**

Another important required aspect is lighting technologies. In the indoor farming environment, a source such as sunlight to support the growing process is a vital object. For this reason, many alternative solutions have been produced to sunlight, for example, artificial rays such as fluorescent lamps, high-intensity lamps (HID), and light-emitting diodes (LED) have been developed to control the photosynthesis event and rate of growth. LED stands out more in these solutions, the main reason for this is that this type of light is more suitable for photosynthetic phenomena (Hati & Singh, 2021). According to the research, a lighting system can increase efficiency by 28% for normal farming but this value is between 50% - 60% for indoor farming. Furthermore, induction lighting systems increase efficiency during the production the vegetables within indoor farming by using an electro-magnet to thrill argon gas as its light source (Al-Kodmany, 2018). As Stein (2021) mentioned, there are several benefits and challenges of the vertical farming system. These are shown in Table 2.1 below.

**Table 2.1 Vertical farming system – Benefits and Challenges.**

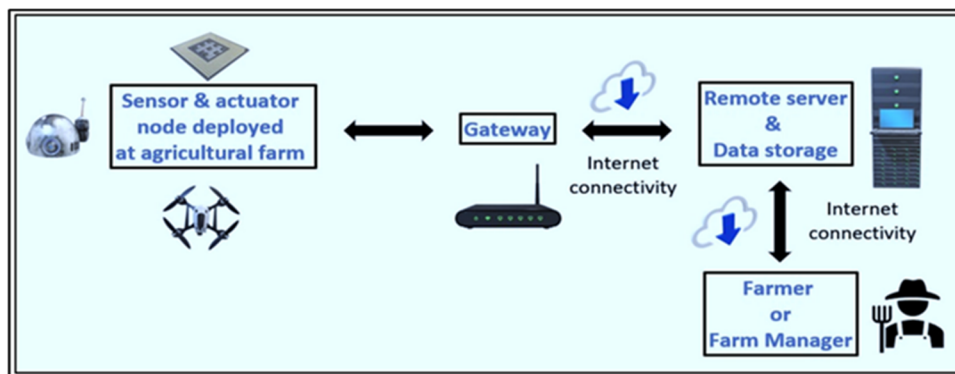
Benefits	Challenges
Uses much less water	Need to demonstrate the scale
Price stability	High capital start-up costs
Reduced labor possible	Prices of production are still higher than conventional
May be located closer to urban centers	Vertical farms require significant energy
Resilient to climate change, drought, etc.	The industry still seeking metrics and standards

### 2.1.2 Industry 4.0 Technologies & Indoor Vertical Farming

As mentioned before, the technologies developed in the current world are called the fourth industrial revolution, and this has also shown to the production world how necessary ICT- based production systems (information and communication technologies) with the integration of digital twins on the internet are (Bersani et al., 2022). As Kovacs and Husti (2018) mentioned, Industry 4.0 is still a new trend for manufacturers during the production improvement processes. In

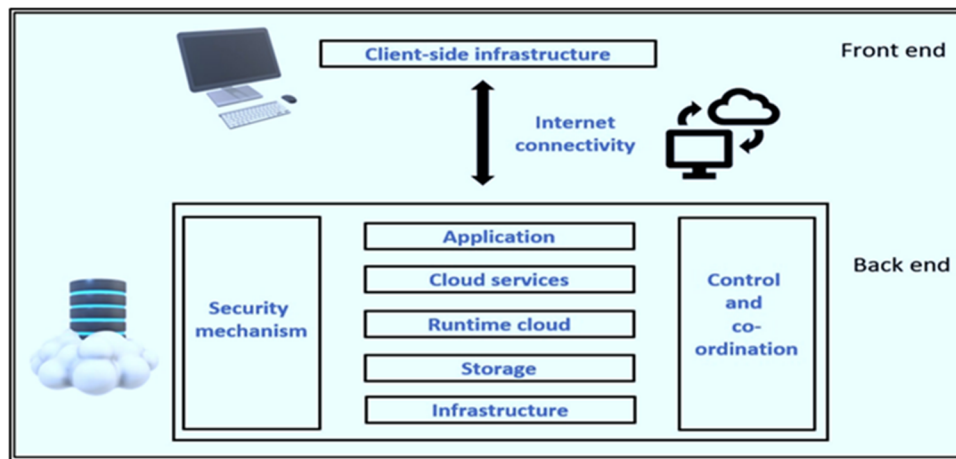
Industry 4.0 technologies, especially IoT, many manufacturers will push to establish new and real communication, as well as to provide intelligent decision-making and human-machine integration. They will use it by creating digital twins. In addition, IoT contributes to the production process of the producer by collecting data from the soil or crop in vertical farming and providing information about the quality of the crop, as well as facilitating production and sales planning (Bersani et al., 2022).

Depending on time and space, wireless sensor network (WSN) and remote sensing (RS) technologies and, accordingly, aircraft can be used in smart indoor farms to obtain information about some changes and characteristics in agriculture. In order to integrate the WSN system into smart farms, different sensor nodes must be placed in different parts of the farm to receive information, and actuators must be used to perform the control action. The mechanism we need to distribute or receive the information obtained from these nodes is called Radio Frequency (RF). And with this established information-sharing system, any device that owns the farm has the chance to follow all the situations happening in the indoor farm anytime and anywhere via tablet, phone, or computer (Hati & Singh, 2021). This situation can be seen as a human-system integration and this system is shown more deeply in Figure 2.3 below.



**Figure 2.3 Wireless sensor networks within smart indoor farming (Hati & Singh, 2021).**

Industry 4.0 technologies used vary according to the volume and importance of data. If the collected data is very large, which is called big data, the previously mentioned wireless sensor networks are just one of the sources at this stage, making it easy for big data producers to collect and analyze data. This technology is called the cloud-based data warehouse, which allows large volumes of important information on the farm to be stored in the data warehouses. The biggest reason why this technology is used by large-scale companies today is that this technology does not require the purchase of any physical equipment by the manager and has the ability to make decisions and analyze faster. Thanks to this system, the investor has the chance to see the information flow, analysis, and all available information through a website or software (Hati & Singh, 2021).



**Figure 2.4 Cloud computing architecture (Hati & Singh, 2021).**

There is no doubt that the new smart indoor farming production technologies mentioned above are used to increase efficiency. The term 'smart indoor farming' is a term coined to create a more efficient and more controllable production system. Hati and Singh (2021) noted that there are six layers to follow to implement an efficient smart indoor farming system and they are called six-layered architecture. These are:

*1. Agrisense Layer*

The Agrisense layer contains some devices such as sensors, actuators, and micro-controllers. Akkas and Sokullu (2017) mentioned that this sensor helps to get data about the condition such as humidity, temperature, water pressure, leaf area index, and water level of the farm.

*2. Connectivity Layer*

In this layer, the collected data is transferred to the main data store. This information is sent by smartphones or using wireless network devices such as Bluetooth.

*3. Intermediate Layer*

The intermediate layer allows establishing the communication about data of the Agrisense Layer. In this Layer, many types of communication protocols are used such as (CoAP) Constrained application protocol. The data which comes from the end of this communication is generally stored as short-term data storage. In addition, this layer is also called the bridge layer because data moves from the first layer to the next layer.

*4. Core Data Handling Layer*

In this layer, the management process and decision-making process are run. Huge data is transferred thanks to the connectivity layer to be stored and analyzed. In this layer, several Industry 4.0 technologies are used such as big data and analytics, machine learning, and cloud computing. Smart technologies are used to contribute more efficient work to the decision-making process and management module as well as the cloud-based action module. As mentioned before, IoT is a more powerful tool during the implementation of smart indoor farming because the cloud system software or platform integrated with IoT to provide/show web service.

*5. Farmer Experience Layer*

In this layer, all data analysis, collection, and connection processes are finished, and all data goes to the end users or farmers.

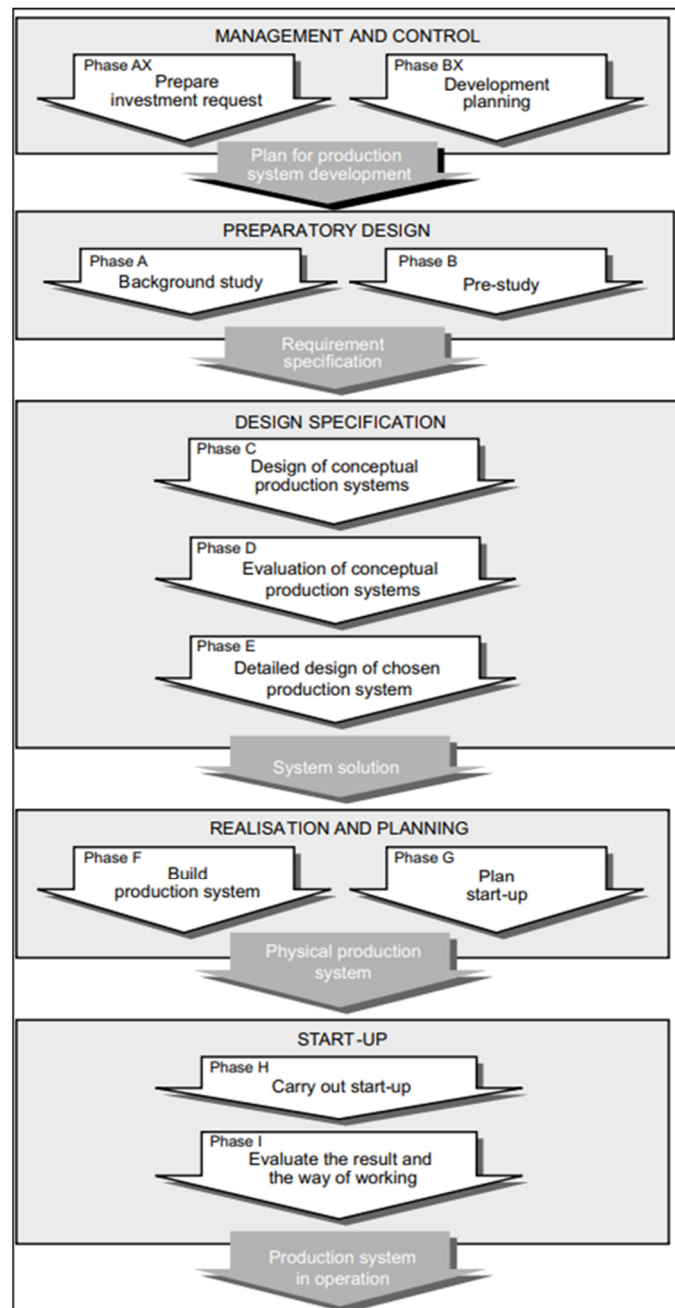
*6. Agri-Business Layer*

In this Layer, a conceptual model of profit is created for owners, and interconnections are established between stakeholders and farmers. To obtain a better understanding of the farming system, AgBIS Logic, and TOA-MD can be used in this layer.

## 2.2 Production System Development

Production system development means to improve an already existing production in operation and according to Bellgran and Säfteen (2010), there is a huge improvement potential for a production system that already exists, which means developing a new production system to obtain an efficient production system. One of the biggest reasons for the implementation of these production system development processes is the development of products with high customer demand. While providing the development of this product, of course, the production system should also be developed. According to Bellgran and Säfteen (2009), designing the new production system development process can be divided into two groups, these are minor and major development. Minor developments can be explained as small changes such as changing some equipment whereas major changing can be described as changing the whole current production system. Säfteen and Johansson (2005) noted that Product realization, that is, product development, is about all activities which are necessary to make customers satisfied with the demanded product, and some technological functions such as production engineering techniques and IT support can be used during the product development process.

Lean Philosophy is the production system that stands out in this regard. This system was developed by Toyota and is actively applied in almost all large and medium companies today. This production technique has a philosophical approach, and this is that the lean production philosophy includes seeing any process that does not add value to production or the total company economy as worthless and waste (MUDA) (Liker, 2004). The production development process consists of many factors, that is, many principles and management styles affect this process. For example, Toledo et al. (2019) mentioned that the Lean production system which is used in PSD (Production system development) practice not only adopts methods, but its success requires leaders at all organizations to change their working system and to systematically apply philosophy and tools with the organization's strategic goals, vision, and values. In this section management philosophy plays a crucial role during the PSD process. Moreover, Bellgran and Säfteen (2010) noted that There are 5 steps or processes during the implementation of the production development process to get rid of a chaotic situation from the beginning phase, and on the other hand this development structure can minimize the development process with the high understandable process. These five processes are Management and Control, Preparatory Design, Design Specifications, Realisation and Planning, and Start-up as seen in Figure 2.5. Phase AX has denoted the preparation of investment and Phase BX has denoted planning system development.



**Figure 2.5 Production System Development Design (Bellgran and Säftsen, 2010)**

Planning the production development process comes from the Management and Control process which is the first step. After the first stage, the system development project plan and draft are created in the second stage which is preparatory design within Phase A and Phase B. Of course, this draft has a scientific background. According to the requirements specification which comes from Phase A and Phase B, a conceptual model (Phase C) is created to be used in the evaluation of conceptual mode (Phase D). Until now, the result from the evaluation step was obtained and according to this result, a production development design can be created with detail. It also can be named as a starting point. The next step should be Phase F and Phase G. In this step, all evaluation and planning are collected in one point, and a plan for the start-up is created. Finally, after all these calculations and the structure created, all possible results are researched, and the production system development process is implemented after it is decided whether this system is suitable for the production process.

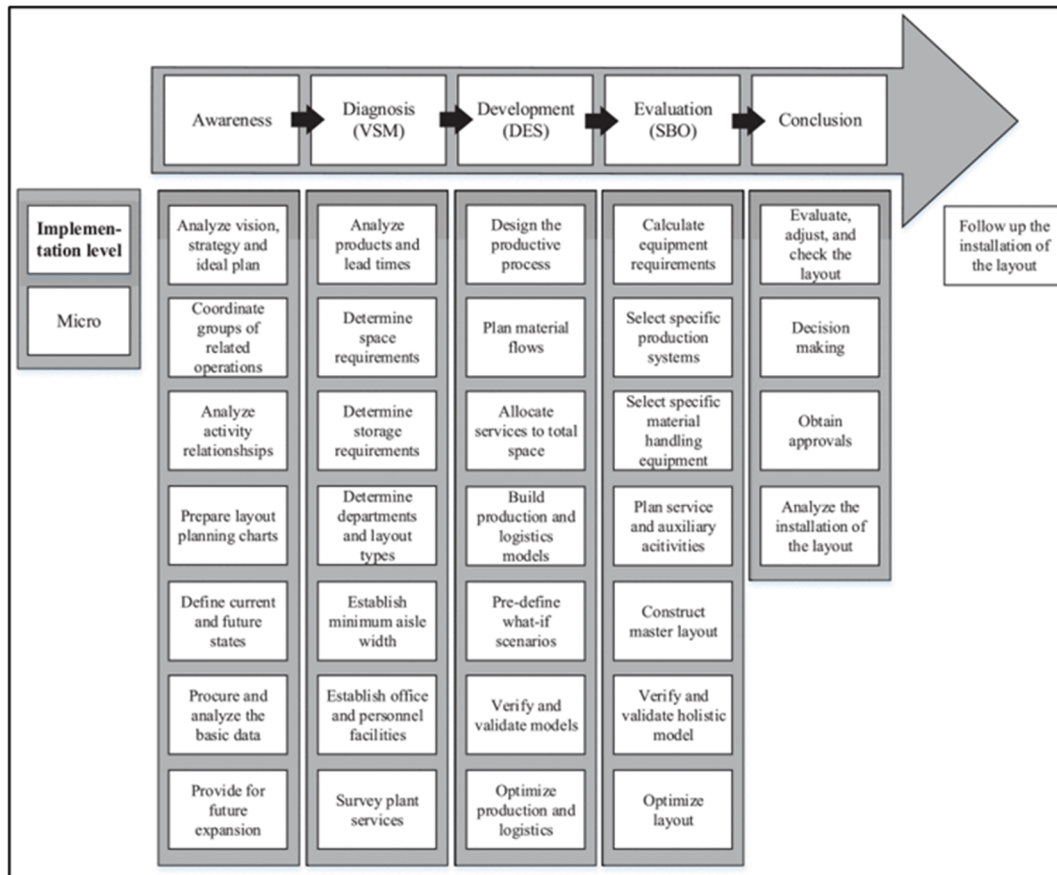
## 2.3 Facility Layout Design

Facility layout design is the process of identifying how to arrange the elements of industrial production systems in a given physical space (Pérez-Gosende et al., 2021). According to Tari and Neghabi (2015), the layout design is regarded as one of the key design decisions in terms of business operational strategies. It has a significant effect on the efficiency of production systems as well as on their productivity level (Ku et al., 2011). Monga and Khurana (2015) have pointed out that the main objective of the facility layout design is to organize the equipment and the working areas in the most efficient way considering the safety of the workers. Furthermore, they have listed four objectives of the facility layout design: (1) sense of unity, (2) minimum movement of people, material, and resources, (3) safety, and (4) flexibility. Security, accessibility, communication between different entities, efficiency, flexibility, clear flows of material and products, as well as fewer means of transport, less work-in-progress, less used space, and lower cost; all of these factors should be considered to develop a good facility layout (Belić et al., 2018). When designing a facility layout, the most significant challenges that the designer face include complexity, dynamicity, randomness, simultaneity, high cost, lack of integration and standard procedures, and safety (Ruiz Zúñiga et al., 2019). Nevertheless, to overcome the complexity of manufacturing facilities, the adaptation of computerized tools for system analysis and design, such as simulation and optimization can be the solution (Fathi et al., 2020). Likewise, Yang et al. (2019) have shown that simulation can offer complete, efficient, and accurate guidance for facility layout design.

The vast amount of literature on facility layout design, which spans several decades, is largely concerned with the methods and tools employed to facilitate space allocation in a manufacturing facility. However, in this report, the method suggested by Zúñiga et al. (2020) that uses a combination of simulation and optimization to design a facility layout in the best proper manner is adopted. According to them, this method is better than traditional methods if the system is complex and if simulation expertise and tools are available in the organization. Furthermore, they have developed two methods where the first is more oriented toward the management team and stakeholders, and the second is more toward the engineering team and simulation experts which is more suitable to be adopted in this report. This method consists of five stages and each stage also consists of several tasks. These stages can be summarized as follows:

1. *Awareness*: It focuses on defining the aim and objectives of the facility layout design concerning the vision, strategy, and ideal plan of the company.
2. *Diagnosis*: The definition of the current systems and future alternative production systems should be clear.
3. *Development*: A few alternative layout designs are reviewed together with the previously defined production solutions at this stage.
4. *Evaluation*: The validated simulation models are analyzed. A reduced number of solutions for the production and logistics systems and suitable layout designs should be selected at this stage.
5. *Conclusion*: At this stage, a workshop should be organized involving the entire project team, the people responsible for the different areas, and managers and stakeholders so that they can review and validate the final layout alternatives.

The following Figure 2.6 illustrates this method.



**Figure 2.6 Facility Layout Design Methodology (Zúñiga et al., 2020)**

## 2.4 Simulation

The dramatic evolution of technologies brought with it a rapid change in industrial requirements which led to the necessity of a quick investigation of the potential systems alternatives in order to develop a more efficient production system design (Mourtzis, 2020). According to Chung (2003), to better understand and investigate these complex systems before implementing them, simulation modeling and analysis are carried out. Simulation, as defined by Banks (1999), is the imitation of how a real-world process or system goes over time and it is a critical problem-solving tool for addressing a variety of real-world problems and is used to describe and analyze system behavior. The benefits and challenges of simulation are not a new topic and have been discussed thoroughly by researchers (Banks et al., 1996; Law & Kelton, 1991; Pegden et al., 1995; and Schriber, 1991). These benefits and challenges are shown in Table 2.2.

**Table 2.2 Simulation - Benefits and Challenges**

Benefits	Challenges
Choose correctly	Model building requires special training
Time compression and expansion	
Understand "why?"	
Explore possibilities	Simulation results may be difficult to interpret
Diagnose problems	
Identify constraints	
Develop understanding	

Visualize the plan	Simulation modeling and analysis can be time-consuming and expensive
Build consensus	
Prepare for change	
Wise investment	Simulation may be used inappropriately
Train the team	
Specify requirements	

Banks (1999) has identified a set of steps to guide a simulator through a simulation study. This guide consists of 12 steps as follows:

*1. Problem formulation:*

It represents the starting point and regardless of if it was formulated by the client or the simulation analyst, it should be clear and agreed to by the client.

*2. Setting of objectives and overall project plan:*

The objectives represent the questions that are to be answered by the simulation study while the project plan should include time, personnel, cost, and the used software.

*3. Model conceptualization:*

It represents a series of mathematical and logical relationships concerning the components and the structure of the system where it begins simply and grows until a model of appropriate complexity has been developed.

*4. Data collection:*

A list of needed data should be submitted to the client and the simulation analyst can readily construct the model while the data collection is progressing.

*5. Model translation:*

The conceptual model constructed in Step 3 is computerized.

*6. Verification:*

Verification concerns the operational model, and it is a continuing process.

*7. Validation:*

Validation is the determination that the conceptual model is an accurate representation of the real system and there are many methods for performing validation.

*8. Experimental design:*

For each scenario that is to be simulated, decisions need to be made concerning the length of the simulation run, the number of runs, and the manner of initialization, as required.

*9. Production runs and analysis:*

It is used to estimate measures of performance for the scenarios that are being simulated.

*10. More runs?*

It is about the decision made by the simulation analyst if additional runs are needed and if any additional scenarios need to be simulated.

*11. Documentation and reporting:*

It is needed If the simulation model is going to be used again and it will enable confidence in the simulation model so that the client can make decisions based on the analysis.

*12. Implementation:*

The simulation analyst acts as a reporter rather than an advocate. If the client has been involved throughout the study period, and the simulation analyst has followed all of the steps, then the likelihood of a successful implementation is increased. Furthermore, the following Figure 2.7 illustrates these steps as follows.

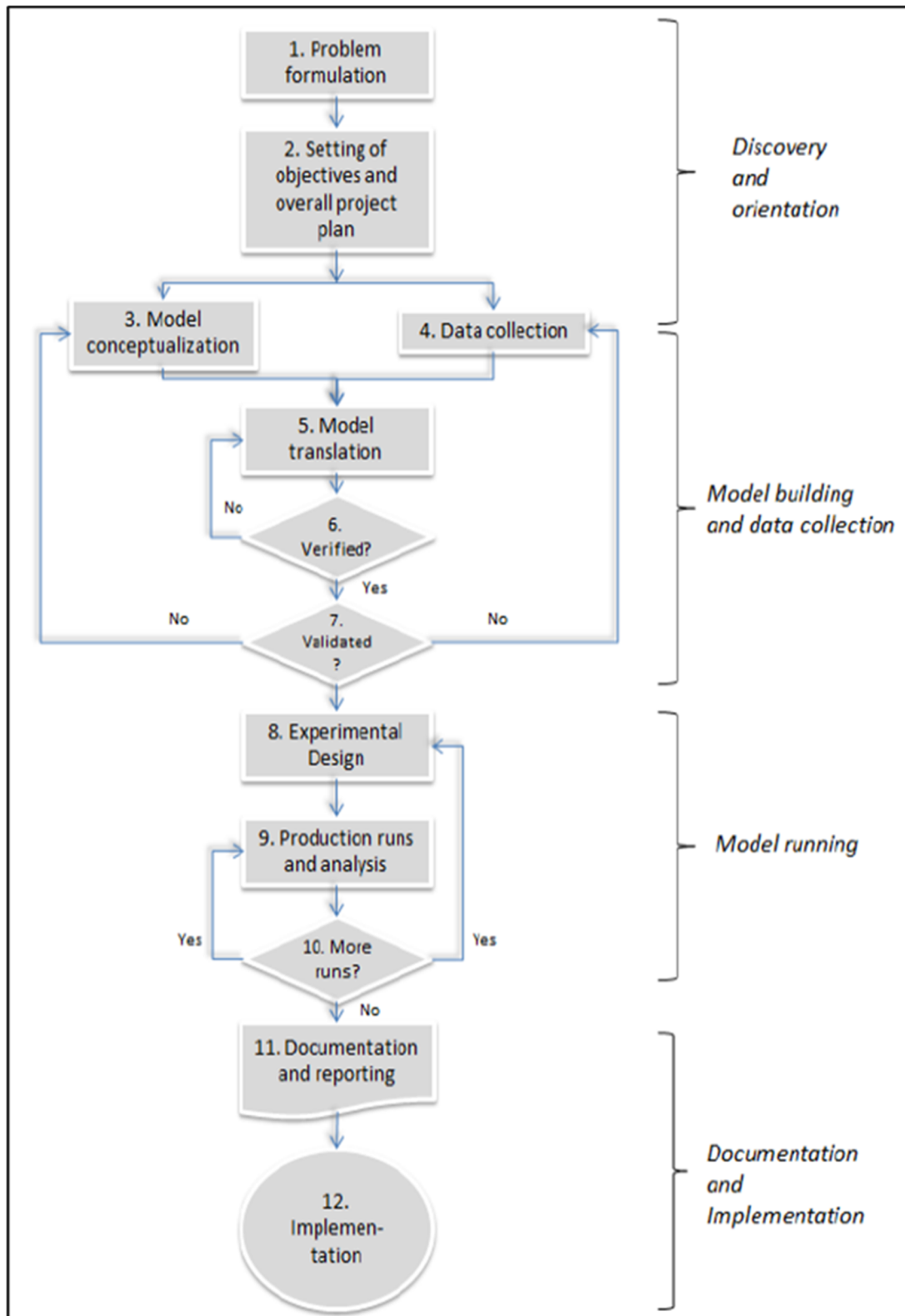


Figure 2.7 Simulation method (Banks, 1999)

### 3 RESEARCH METHODOLOGY

Overall, the research method section of this thesis report provides a detailed description of the research methodology used, that is how the research was conducted, along with the research method, data collection methods, data analysis techniques, and the limitations or challenges faced during the research process. Most importantly it includes how the simulation model was generated and the procedures the authors followed. By providing a clear description of the research methodology, the authors aim to establish a high level of credibility as well as to ensure that the research can be replicated by others which hopefully can contribute to the advancement of knowledge in this field.

#### 3.1 Research Approach and Method

The suitable approach to performing this research was by using a qualitative and deductive approach due to the fact that this research starting point was by collecting theoretical data from different reliable sources and then comparing these data with the collected empirical data. According to Gustavsson and Säfsten (2019), to ensure the accuracy of the theoretical assumptions of how something should be done and to achieve useful results, it has to be analyzed with collected empirical data. Furthermore, since the formulated research questions are basically an investigation of a real-world phenomenon in the indoor farming industry, the case study method was found to be the most appropriate and reliable to answer these questions. According to Yin (2018), a case study enables studying phenomena deeply in their natural environment. Flyvbjerg (2011) mentioned that case studies are generally based on real problems and real problems bring real solutions and deep data/information. In addition, some projects need more in-depth information or data which can be obtained from case companies and some kind of literature and in this case, the collection of data process can be more clearly by using the case study method (Stake, 1995). Moreover, Saftan and Gustafson (2019) have mentioned several advantages of this method, (1) it allows for a more comprehensive examination and evaluation of the results and analyses that will emerge from the project, (2) it allows comparison of previously written articles or studies, (3) it can yield results with descriptive or explanatory information that can contribute to the search for the optimum answer/result for a case study project.

#### 3.2 Theoretical Framework

The obtained data in this section of the research played a crucial role in developing or finding answers to the research questions. According to Säfsten and Gustavsson (2019), in order to contribute to the development of knowledge of a project, the first step should be to know existing articles or projects regarding the project subject. The theoretical framework covers four major topics that in their turn cover all angles of the research. These topics are, (1) Indoor Vertical Farming, (2) Production System Development, (3) Facility Layout Design, and (4) Simulation. The intended aim of these four topics was to determine the relationship between the research problem and the body of knowledge in this area, to broaden the researchers' knowledge, to bring clarity to the research problem, to improve the research methodology, and to put the findings in context (Kothari, 2004). Furthermore, to obtain and analyze these theoretical data, a structured literature review method was used. Säfsten and Gustavsson (2019) have defined literature review as mapping out and analyzing current and relevant literature; it involves the selection, reading,

and compilation of the literature and can be done in ten steps. These ten steps were followed in order to write the theoretical framework and are presented as follows:

- *Step 1*: is to specify the purpose of the research; which had been done in the introduction.
- *Step 2*: is to identify suitable keywords; in this paper “Indoor Vertical Farming”, “Production System Development”, “Industry 4.0”, “Facility Layout Design”, and “Simulation” were used as keywords.
- *Step 3*: is to formulate criteria for including and excluding literature; recent research papers published in the last ten years and books to a limited extent were mainly used in this research.
- *Step 4*: is to select search tools and databases; MDU Primo and Google Scholar search engines were used to find and collect literature.
- *Step 5*: is to formulate a search strategy and perform searches; the snowballing approach was used to find more relevant literature to the addressed topic in this research.
- *Steps 6, 7, and 8*: are about extracting the right data that fill the mentioned criteria above and summarizing it in a proper manner; which was done in the theoretical framework section.
- *Steps 9 and 10*: are about analyzing the contents and presenting the results; which was done in the theoretical framework section.

### **3.3 Empirical Findings**

The empirical data was collected through interviews, questionnaires, observations, and from the results of the generated simulation model. According to Hansson (2007), empirical science is generally based on the observation of the system of the case company by using our senses such as smell, taste, and sound. When you observe a certain process and participate and interact with it, a deeper understanding of the subject is developed (Safstan & Gustavsson, 2019). Three visits to the production facility of the case study had been done where the goal was not only to obtain a deeper understanding of the production process but to interact with the employees and take into consideration their point of view since they already obtain the needed knowledge that might help in this research process. Hansson (2007) mentioned that in the direct observation model, rather than understanding the production system, the research group interacts directly with the employees, and decisions are taken about what to observe and how to observe. Furthermore, Williamson and Johanson (2017) noted that observation can sometimes be described as basic human knowledge, not only based on scientific knowledge.

The second method for collecting the empirical data was interviews, questionnaires, and meetings. The authors have done four virtual meetings and two in-person meetings with several employees who are responsible for the production system in the addressed case study. The goal of these meetings was to understand the production system and collect all needed data in order to start and finalize the simulation model. According to Kvale and Brinkmann (2009), this method is generally powerful for researchers to describe and understand the current production situation from responsible people within the case company. Interviews on the other hand are a suitable data collection technique used when a researcher wants to gather information, in the form of perceptions and experiences, from one or more case studies about a phenomenon (Säfsen & Gustavsson, 2019). Therefore, one main interview and one questionnaire were done during this research and each one of them is connected to one of the research questions. The interview was a semi-structured interview, which contained both fixed questions/response alternatives in addition to some other open questions which involved some areas that will be discussed freely. This technique is a flexible technique that allows the researcher to adjust the questions during

the interview to fetch more clarifications/ information about the case study (Säfssten & Gustavsson, 2019). The interview was done with a simulation expert working at another company that is considered a benchmark for this research and it aims to collect more real-time data about the challenges and benefits of using simulation in the production system development context. It is worth mentioning that the interview was recorded after the approval of the participant and transcribed and attached as an appendix to this research. The questionnaire, on the other hand, was not the authors' first option but due to time constraints, it had been done. Questions were prepared and sent to the manager of the case study, where the aim is to establish an understanding of how production system development is approached in the case study. The findings of them both are covered in the empirical findings section.

### 3.4 Simulation

The simulation approach in this research followed the 12 steps stage-gate method proposed by Banks (1999), see Figure 2.7. It is worth mentioning that this method has some kind of flexibility that allows the simulator to go back to previous steps if needed. Furthermore, more specific details of these steps are described in the following:

- *Steps 1 & 2 (Problem formulation and Setting of objectives and overall project plan):*

Based on the data collected from the visits and the meetings, the authors were able to develop the following figure. Figure 3.1 illustrates the needed data for these two steps.

#### Framework for problem formulation

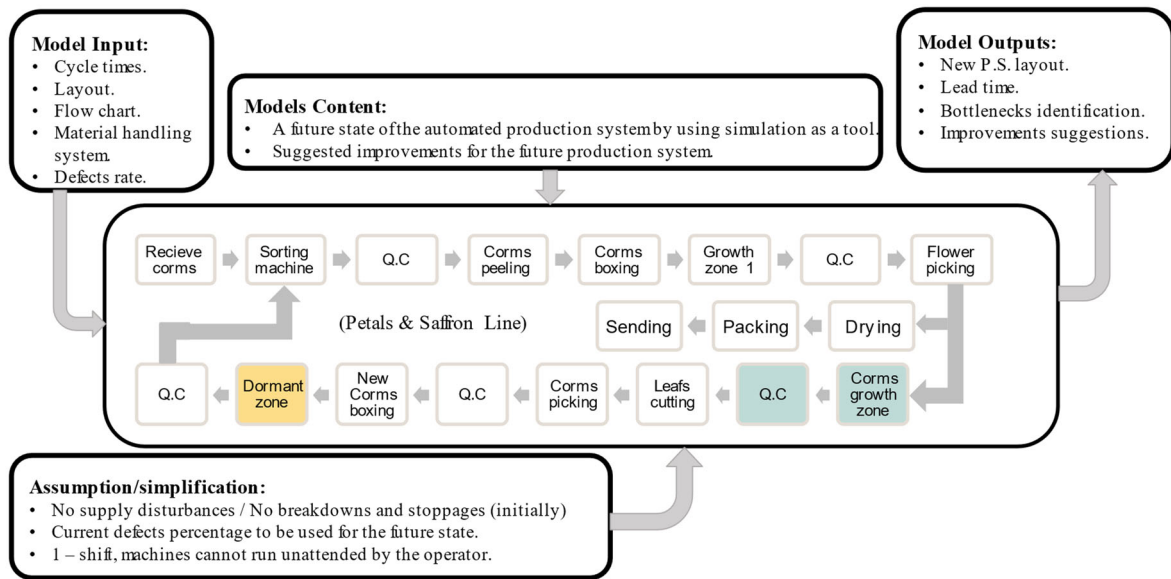
<b>Company Name:</b> BlueRedGold	<b>Data Collection:</b> <ul style="list-style-type: none"> <li>- Conceptual model of the future state.</li> <li>- Cycle times.</li> <li>- Available work hours.</li> <li>- Initial Layout (450 m<sup>2</sup> around 18*25) &amp; Flow chart.</li> <li>- Defects rate for the product for each quality control point.</li> </ul>
<b>Problem of Interest as Stated by Decision Maker:</b> Evaluate the new factory layout that includes a new semi-automated production system and validate the fulfillment of desired capacity.	<b>Model Assumptions</b> <ul style="list-style-type: none"> <li>- Unlimited raw material supply.</li> <li>- Current defects percentage to be used for the future state.</li> <li>- 1 – shift, machines cannot run unattended by the operator.</li> <li>- No breakdowns and stoppages (Initially).</li> </ul>
<b>Overall Objective of the Study:</b> <ul style="list-style-type: none"> <li>- To evaluate simulation tools for internal logistics and build a simulation model that can be used for future improvements.</li> <li>- To investigate the application of new automation technologies in the indoor farming industry</li> </ul>	<b>Vision of a solution:</b> <ul style="list-style-type: none"> <li>- A comparison of the current and future state.</li> <li>- Future state maximum output.</li> <li>- Identification of problems and suggestions for improvement.</li> <li>- Visualization of the new production system to support decision making.</li> <li>- Present suggestions for future next steps.</li> </ul>
<b>Specific Questions to be Answered:</b> <ol style="list-style-type: none"> <li>1- How many robots are to be used?</li> <li>2- What kind of storage systems are to be used?</li> <li>3- What method to use for the material handling?</li> <li>4- How much manpower?</li> <li>5- What is the future maximum output based on the answers to the previous questions?</li> </ol>	<b>Contact Person</b> Mikael Öhman Email: <a href="mailto:mikael.ohman@blueredgold.com">mikael.ohman@blueredgold.com</a> Telephone: +46 707295584 <b>MDU supervisor:</b> Anas Fattouh Email: <a href="mailto:anas.fattouh@mdu.se">anas.fattouh@mdu.se</a>
<b>Performance Measures for Evaluation:</b> <ul style="list-style-type: none"> <li>- The efficiency of the production system</li> <li>- Lead time for customers' orders.</li> <li>- Bottlenecks in production.</li> <li>- Maximum Throughput.</li> </ul>	

**Figure 3.1 Simulation – Problem formulation**

- *Step 3 (Model conceptualization):*

After understanding the production process, the authors were able to develop the following figure. Figure 3.2 illustrates the conceptual model, and it was confirmed and approved by the case study.

## Conceptual model



**Figure 3.2 Simulation – Conceptual model**

### - Step 4 (Data collection):

Needed data was obtained from the case study before generating the previous three steps. However, the need for more data from the case study was generated when constructing the model and was solved by several correspondences with the case study.

### - Step 5 (Model translation):

The process of the model building began with designing the facility layout using a 2d drawing program “AutoCAD”. By doing this, the authors ensured that the 3d model generated from the simulation program was accurate and at the same time it eased up the discussion with the case study in the sense that major decisions were discussed and taken directly on the 2d model instead of building the model in 3d and then adjusting it. The modeling program used is Visual Component, which is an animation-oriented simulation software that allows the users to actually see the process in a virtual environment. Furthermore, the model was continually tested throughout the building process and each modeling step was clearly described in the model. This will help the case study in using this model in the future for further development projects.

### - Steps 6 & 7 (Verification and Validation):

The problem faced at the verification step is that usually, the verification stage requires historical data of the real production system so that the simulator can compare the production rates of the simulation model with these historical data and verify the model, which is not the case here. The built model represents a new facility with new measurements, and it is not fair for it to be compared with the existing one. However, to overcome this obstacle, the chosen simulation software allows the user of real-time simulation where every movement done in the facility can be modeled and presented. This allowed the authors to continuously verify the model by showing it to the case study production engineers as well as verifying that the outcome of this model is near to the expected one by them. Furthermore, the validation of this simulation model was done parallel to its development. This was done by continually running the model and fixing any faced issues as well as continuous discussions of the simulation model.

- *Step 8 (Experimental design):*

For the first scenario, it was suggested that the new facility area will be around 450 m<sup>2</sup>. However, after moving forward in the simulation model, it was found definitively that this area is not sufficient enough to reach the desired production rate. This led to reconsidering this decision made by the case study management and increasing the area. The second option found by the case study was a new facility that has an area of around 900 m<sup>2</sup> divided into two floors. This forced the remodeling of the complete simulation model from the beginning but at this time the desired production rate was fulfilled.

- *Steps 9 & 10 (Production runs and analysis and More runs?):*

Runs for this simulation model have been done continually while modeling it and a final run that covers the complete production period (one year) was done at the end of modeling.

- *Step 11 (Documentation and reporting):*

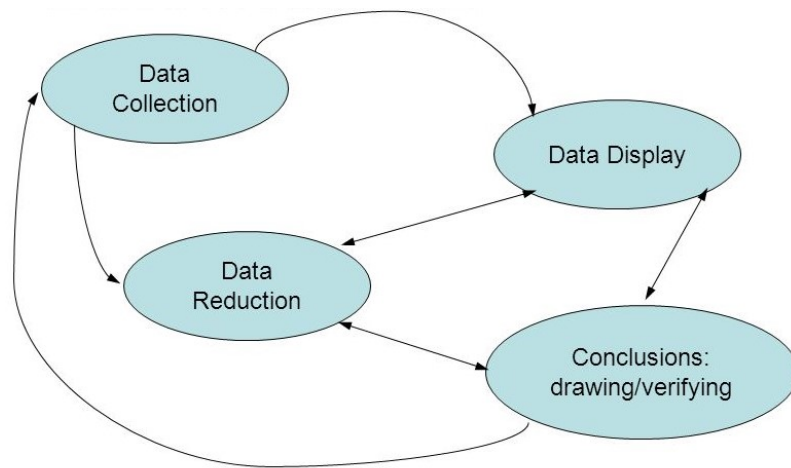
All generated reports and the developed simulation model have been shared with the case study as well as appendices to this report (if possible).

- *Step 12 (Implementation):*

It is expected to start the implementation soon (by autumn), and the authors have done all of Banks (1999) recommendations regarding following the steps and involving the case study throughout the study period to increase the likelihood of a successful implementation.

### **3.5 Data Analysis Method**

The data analysis was conducted based on the collected data from the case study, and the simulation model outcomes, along with the theoretical framework that is built to cover the research problem. The chosen analysis method strongly depends on the study's purpose and research questions as well as on the nature of the collected data. Therefore, the qualitative data analysis method, developed by Miles and Huberman (1994), was used in this research and this method consists of three concurrent flows of activities, data reduction, data display, and conclusion drawing and verification. The first one refers to the process of selecting, focusing, simplifying, abstracting, and transforming the collected data. While the second one, data display, is visualizing what is interesting in the collected qualitative data to enable an in-depth analysis, otherwise, the qualitative data tends to become very extensive and misleading from the main research question and the common format used for data display are matrices and networks (Säfssten & Gustavsson, 2019). The final step includes drawing conclusions based on the patterns, themes, and categories identified earlier and verifying these conclusions. Furthermore, Miles and Huberman (1994) have presented these three streams as shown in Figure 3.3. In this figure, the data collection activity and the three types of analysis activities work together to create an interactive, cyclical process that the researcher moves between during data collection before moving to reduction, display, and conclusion drawing/verification during the rest of the study.



**Figure 3.3 Qualitative Data Analysis Method (Miles & Huberman, 1994)**

### **3.6 Research Quality**

According to Säfsten and Gustavsson (2019), validity and reliability are the two most crucial scientific quality criteria and indicators of research quality, and they are interdependent. Validity means “*the extent to which what is measured/observed corresponds to what was intended to be studied (internal validity) and in which contexts the results are valid (external validity)*”, while reliability is to repeat an observation and get the same results” (Nyquist, 2017). To achieve a high level of validity and reliability, which was the aim that the authors strived to reach, two known methods were used, triangulation and careful documentation. According to Flick (2019), the use of triangulation and careful documentation is in line with best practices for enhancing the quality of research. By using these techniques, the authors aimed to minimize the risk of bias and errors in their study, which could compromise its validity and reliability. According to Leedy and Ormrod (2015), triangulation is a method used for enhancing validity and as defined by Yin (2018) it is the utilization of many data sources, methods, or researchers. Data triangulation was used in this research, which means that several methods of data collecting, such as interviews, observations, and from various trustworthy, relatively recent scientific articles, were used to complement one another. Furthermore, since this research was written by two different authors and involved the participation of each in data collection, analysis, and findings, researcher triangulation was also used. On the other hand, reliability was considered from the beginning in terms of well-documentation for all data used in this research, either theoretical or empirical. According to Johnson and Onwuegbuzie (2004), by documenting data sources and procedures researchers can report their methods in an accurate and transparent way, which will allow other researchers to evaluate and potentially replicate their findings.

### **3.7 Project Limitations**

The primary limitation of this thesis work is that it relies on empirical findings from a single case study, which might lead to other limitations for drawing generalizations in the study’s conclusions. Two factors contributed to this limitation, the first is time restrictions since this study was developed in a limited time frame (20 weeks) restricting the authors from conducting multiple case studies. The second is that the Indoor Vertical Farming industry, addressed in this study, is still a relatively small industry when compared to other industries in Sweden like the automobile industry, which led to further restricting the authors from considering more case

studies. However, by considering another company as a benchmark for this study, the authors tried to minimize this limitation. Furthermore, due to the novelty of the chosen topic, the authors were restricted from finding more similar studies to build the theoretical framework. On the other hand, the empirical findings from the simulation model are based on the assumptions outlined in the conceptual model, and therefore, may not reflect the actual situation. However, since these assumptions were made under the supervision and approval of the case study, the findings are considered reliable enough.

## 4 EMPIRICAL FINDINGS

Overall, the empirical data section of this thesis report presents the empirical findings that will serve as a base for answers to the research questions. It starts with a short description of the case company followed by an overview of the practical problem addressed at this company. Furthermore, the findings of a specific interview done with the case company discussing their production system development approach were presented. The final subsection presents the simulation-related empirical results that can be classified into two parts, the benchmark interview findings, and the simulation model findings.

### 4.1 Case Company

The addressed case company, BlueRedGold, is a local startup founded in 2021 and it is considered to be the first company in the world to grow saffron, indoors and commercially. Currently, they produce saffron from their pilot farm in Mariefred, and they have already started sales in small batches. Not only were they able to take the initiative to produce saffron indoors and commercially, in a short period, but according to the official EU testing lab “Eurofins”, their produced saffron is class 1 saffron with outstanding results. Three main factors led to the importance of BlueRedGold, (1) the fact that more than 90% of today-produced saffron comes from one country, which is considered to be high risk in itself, and (2) the never-ending increasing demand led to the fact that today’s global production is not enough for the demand, finally (3) their ability to produce in 4 cycles a year which is compared to the traditional farming an increase in 400%. Furthermore, their team consists of eight employees, seven advisors, and the ability to have more manpower when it is needed. BlueRedGold management has set several goals to be achieved by the end of 2026. They are looking forward to producing 15 kg in 2023 and by 2026 the production will reach one ton of saffron.

### 4.2 Case Description

To achieve the goals that the management of BlueRedGold has set, it has been decided to open a new production facility, “R&D Factory” as called by the management. The production rate of this factory will be at least 100 kg/year and the production in this factory will be a mix of standard procedures as well as new technologies that need to be adapted to fit the needs. The current production system is operated manually while in the new factory, the management is aiming to facilitate more automated operations. Several methods can be used in adapting new technologies, especially for material handling such as conveyor belts or moving robots and simulation can be used as a tool to verify the efficiency of these solutions. That being said, the objective at this point is to plan this new facility and investigate and evaluate the best practices from both a technical and commercial perspective that can be utilized by using a simulation as a tool.

### 4.3 Production System Development Process

To understand and clarify how the case company approaches its production system development process, which methods they follow, and how they implement them, questions regarding this topic were prepared by the authors and sent to the case company by email to be answered by the CEO. These questions are generally questions that aim to show how much the addressed case company knows about the production system development methods, and if they have this

knowledge, how much they follow. In addition to this, some questions cover how the company integrates the production system development process with industry 4.0 technologies and how the simulation model, an industry 4.0 technology, contributes to the production system development process. After answering the prepared questions, the CEO sent back these answers (see Appendix 1) and then it was summarized as follows. It is worth mentioning that these questions are 11 open questions that the CEO can answer freely without interference from the authors.

As mentioned earlier, there are two alternatives for growing systems within the indoor farming industry, and as understood from the case company answer, they generally prefer to implement the already existing ideas to their production system to develop the new production system, and he added that the reason that it is managed this way is that the case company is a newly established company and the company's inability to have many employees has made it difficult to enforce development ideas. For this reason, the case company chose to base itself on the previously intended ideas. Currently, they are developing a system for both the picking and sorting process by robots, and this project is considered by the CEO as a small PSD project. As seen in Appendix 1, when it was asked which types of challenges were faced during the PSD process, the CEO mentioned that they don't know how many saffron flowers they will get, and this unknown data makes it complicated during the implementation of the new production system. According to the CEO, the main aim of this project is to provide a proper simulation model for the case company, and solving the layout problem is one of the issues for the CEO to estimate how much free space they have for further improvements. According to the CEO, the simulation model can be used as a layout problem-solving method and he added that his company needs to utilize robots and autonomous systems in the beginning phase, and they see the simulation method as the ideal way to introduce these systems. In this way, one of the most important factors that the case company expects from the simulation model is solving the layout problem, and another factor is which robot to use as well as which material handling systems are suitable for the new production system. Finally, questions related to smart manufacturing were asked, and for the case company and according to the CEO's answers, the smart manufacturing system means IoT, IA, and data analytics to get more quality products by monitoring the production system. According to the case company, a smart manufacturing model can minimize saffron handling time because, according to them, the picking process for the saffron is one of the big issues to solve to get a more stable production system. In addition, as previously mentioned there are 2 different popular growing systems for the indoor farming industry and based on their answer, they are currently using hydroponic growing systems in their production process and this system must be monitored frequently to get a better production rate. According to the CEO, implementing smart manufacturing systems is one of the good opportunities to get the necessary data from product and production environmental conditions.

#### **4.4 Simulation**

In this part of the empirical findings, the aim is to present the simulation-related empirical findings. Since these findings come from two different resources, which are the simulation expert interview and the simulation models, it is divided into two subheadings. The first of which discusses the interview findings where all outcome of this interview is summarized and presented. The second of which presents the findings of the two generated simulation models with all related details.

#### 4.4.1 Methods, Challenges, and Benefits of Simulation for Production System Development

As mentioned earlier an interview was done with a simulation expert who is working at Mälardalen Industrial technology center (MITC). This center is built on a collaboration between Mälardalen University with the manufacturing industry in Sweden and their head-quartered is in Eskilstuna. They have been operating since 2011 and their scope of work is building needs-driven cooperation for manufacturing companies' development, training, research, and technical projects. They describe themselves as a physical location for future competence, technology, innovation, and development. Nevertheless, this interview (see Appendix 2) was done to get a deeper understanding and holistic view of the current use of simulation in the industry in general. Furthermore, the interview took place at MITC offices in Eskilstuna, and it was divided into four parts or subtitles. In the first part, a brief introduction about the topic was given to the expert as well as several questions about his educational background and current responsibilities and projects he is responsible for. The second part is about simulation in general, approaches, programs, and verification and validation methods. The third and fourth parts were about the benefits and challenges of simulation and these two parts contained seven questions.

Our expert is a master's degree holder in industrial engineering and has a mechanical engineering degree as well. His current job title is simulation engineer and currently, he is a part of a team that is building a smart factory. When a question was asked about the approach they use to simulate and if they follow the Banks method, the reply was "Normally we just don't exactly follow it". According to him, each project has its own approach, and it is the simulator's job to decide the approach from the beginning of any project. Furthermore, the used program at MITC is Visual Component and the expert highlighted the enormous features that this program has when he was asked if companies decide which software to use, he replied "They were fine with visual components because they were aware of its capabilities". In his reply on verification and validation, the expert said that each project has its approach, and it depends on the historical data that the company has but the great feature that Visual Component has is the ability to visualize and see the production line working and, in this case, it is easier to validate based on this feature. Nevertheless, the expert insists that the main thing a simulator must do is to "go and see for yourself" to get a better understanding of the production flow and he highlighted the importance of the collected data as well. On the other hand, the following table, Table 4.1, summarizes the benefits and challenges of using simulation in production system development according to the expert opinion.

**Table 4.1 Simulation - Benefits and Challenges**

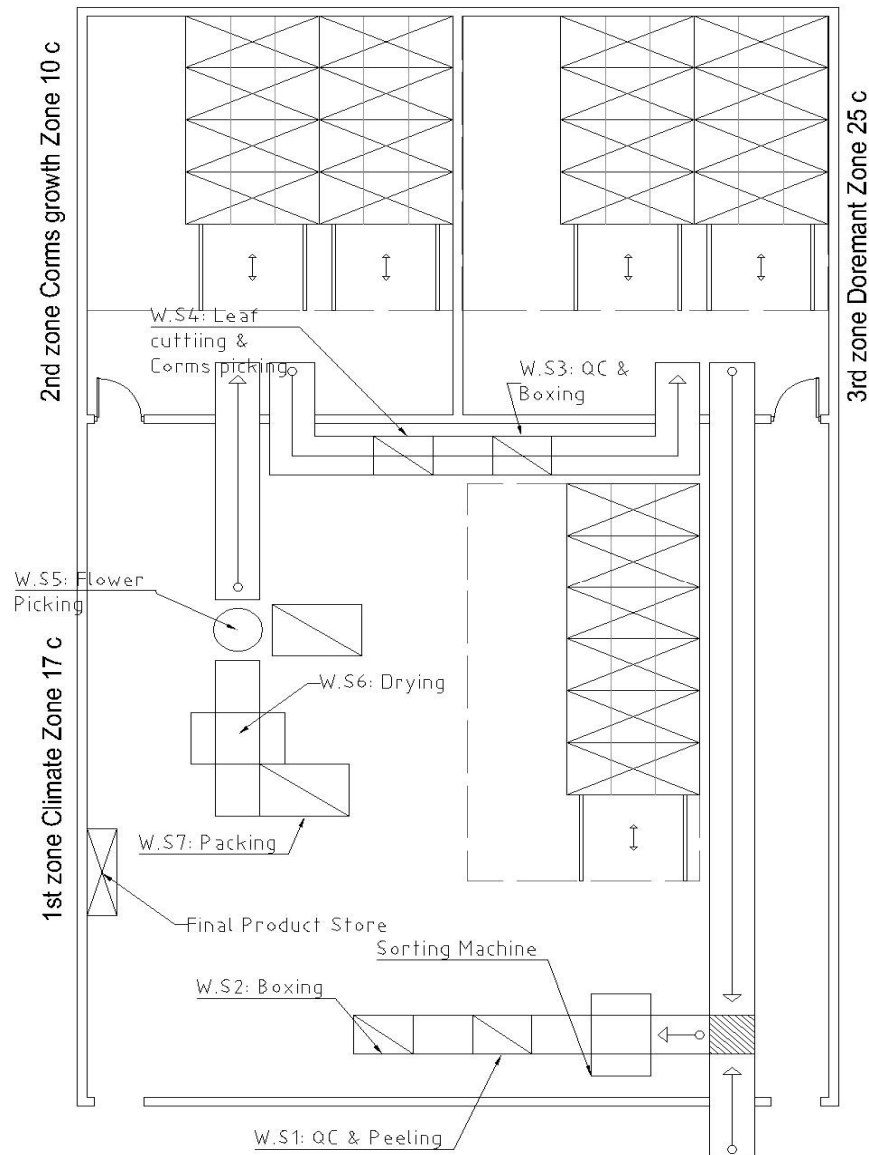
Benefits	Challenges
Visualization	Data Collection
Validation of encountered problems solutions	Unavailable components model in Visual Component
Identifying constraints, especially regarding the safety of the workers	
Development suggestions	The need to learn special programming languages.
A better understanding of the existing production lines will lead to a better future system	

#### 4.4.2 The Simulation Model

The following two scenarios represent the two generated simulation models where each scenario represents a different facility that the case company considered as their future production facility.

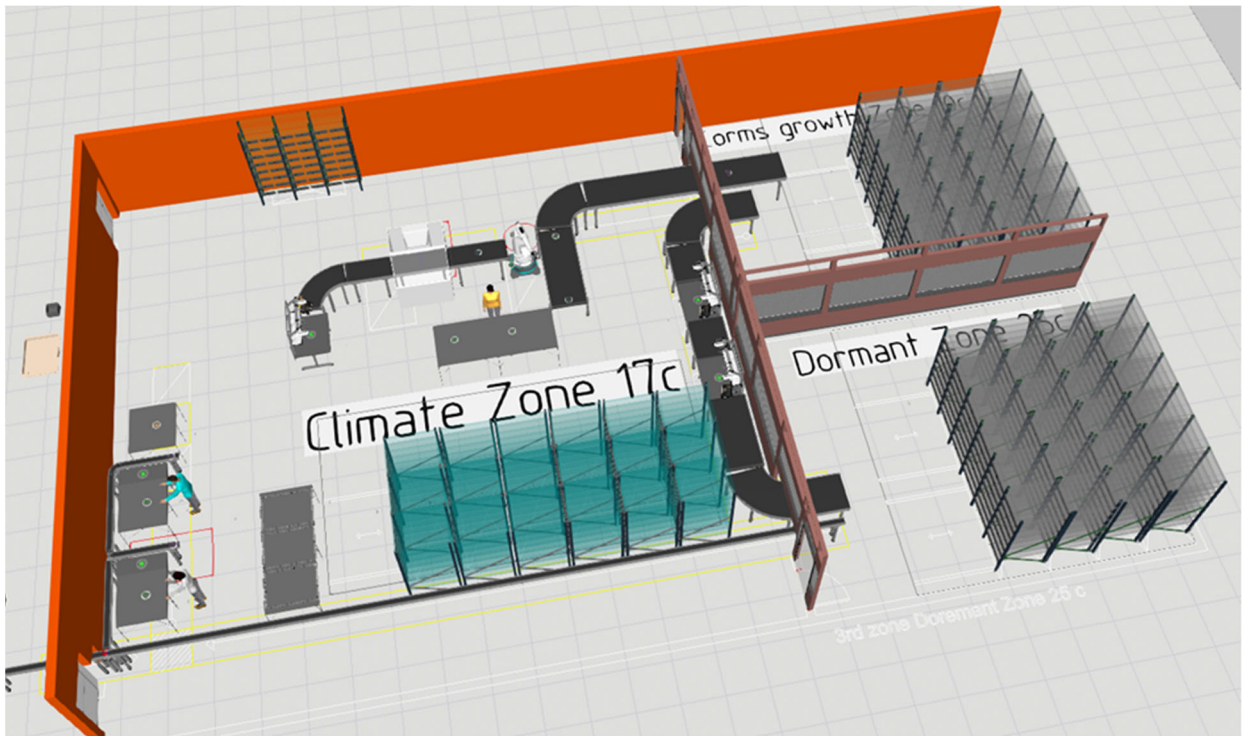
##### First Scenario:

The first step at this stage was to develop a 2d model (see Figure 4.1) where an initial design for the facility layout was generated with the help of the company's expertise. As seen in Figure 4.1, the facility area is divided into several departments, and it covers the production and storage area.



**Figure 4.1 Facility Layout 2d Model**

This 2d model was then transferred to the 3d world and the work on developing suggestions started directly after modeling the departments. The authors applied a number of technologies to convert the fully manual production system to some kind of automated production system at the request of the case company. As seen in Figure 4.2, the previously manual picking system has been automated thanks to a smart robot, and the manual material handling system was changed to include conveyors.



**Figure 4.2 First Simulation Model**

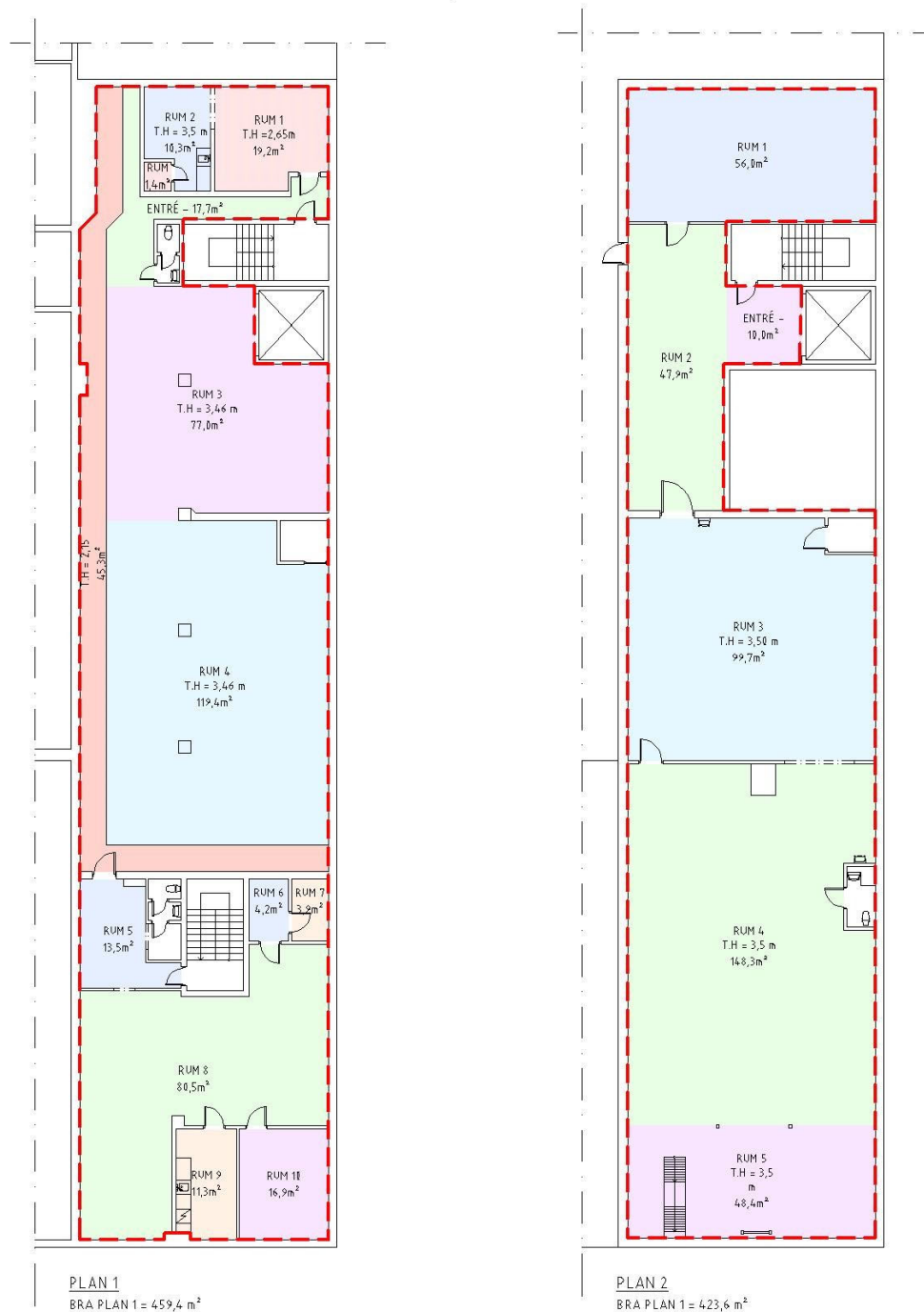
In addition, currently, the case company uses non-moving vertical farming shelves, in line with the company's recommendation, this system was replaced with rail vertical farming shelves as seen in Figure 4.3. Although these shelves save a huge amount of area due to their flexibility in moving in one direction when partially running the model, it has been found that these shelves would never cover the needed production rate and more storage area is needed (further explanation will be mentioned in the analysis chapter). This was taken to the case company which confirmed their expectations that the area of this facility is not enough and that led to a decision to move forward to other available options.



**Figure 4.3 Vertical Farming Shelves**

### Second Scenario:

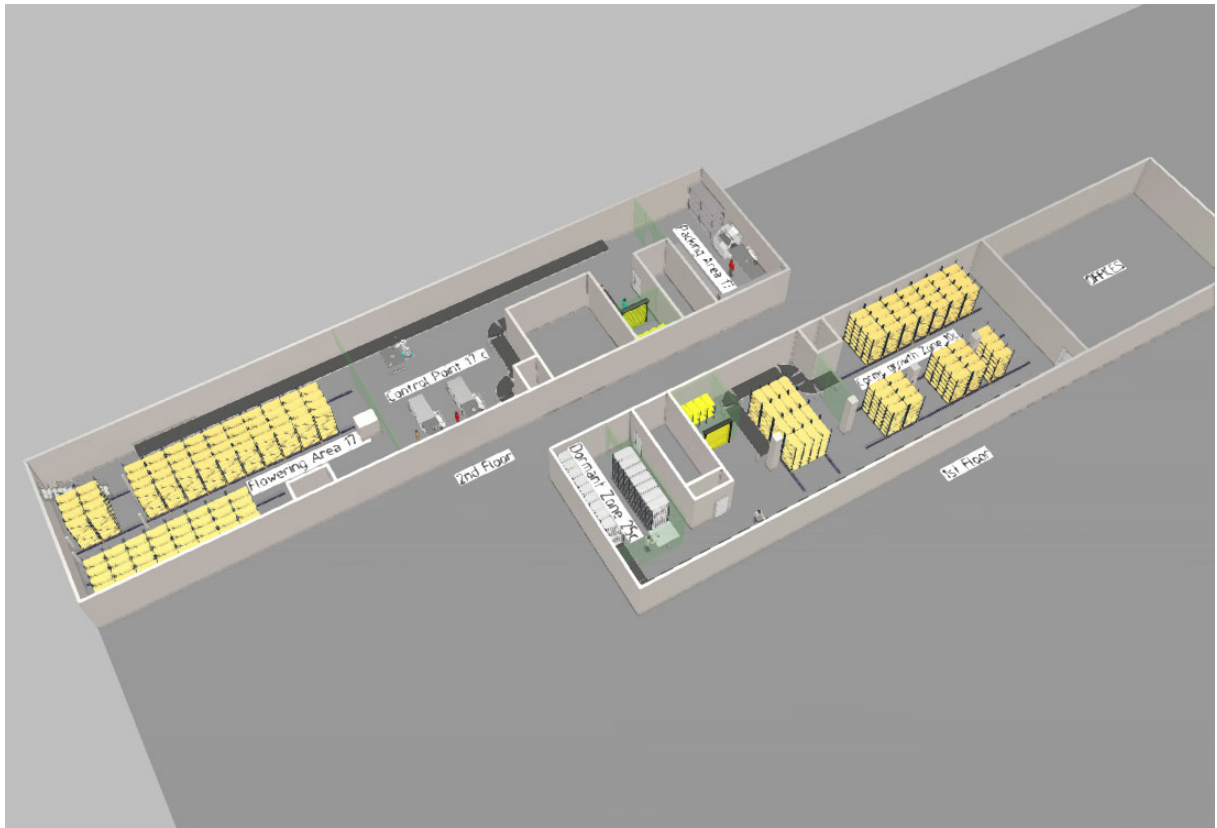
At this stage, the case company found another facility with a total area of around 950 square meters (about twice the area of a basketball court) divided into two floors. This division eased up the area issue but made it harder to design the material handling. Furthermore, in this model, Banks' (1999) designing method, mentioned earlier, was used to clarify the model during the simulation model development process. As in the first scenario, a 2d model was developed as seen in the following figure, Figure 4.4, but at this time, fewer details were included.



**Figure 4.4 Facility Layout 2d Model**

Furthermore, the same types of vertical farming shelves and robot for the picking process were used in the second simulation model. The major change that can be understood from the comparison of the second model with the first model is that more conveyors are used in the

second model. However, the positioning of the production equipment has also changed in the second model as seen in Figure 4.5. After running the model this time, the needed production rate was covered.



**Figure 4.5 Second Simulation Model**

## 5 ANALYSIS

Overall, the analysis part of this paper provides a clear link between the analyzed empirical findings and theoretical findings which were found from different reliable articles and resources. In this chapter, two main questions which were mentioned in the problem formulation part will be answered by analyzing the obtained data, and then the final simulation result, interview, and observation will be used to support the analysis output.

### **5.1 How can simulation facilitate production system development and Industry 4.0 projects within the indoor farming industry?**

The need for change is playing a crucial role in the addressed company to develop their production system to stay in computation. For this reason, utilizing Industry 4.0 technologies and using them as a development solution is generally widely used by all companies/organizations as well as for BlueRedGold AB, as Kovacs and Husti (2018) mentioned that Industry 4.0 is still popular for solving production systems problems. Simulation technology is a powerful tool to estimate future production layouts/systems for the manufacturing industry. As mentioned before, the case company has taken a decision to move to another facility to obtain more space for storage and production area. As defined by Banks (1999), simulation can be described as a tool to implement a real-case production system into the visual world before making actual investments. Many simulation models were prepared by the authors to find the most proper solutions for production flow and facility layout.

The first model was prepared on the 450 m<sup>2</sup> area as seen in Figure 4.2. In this simulation model, three working areas, which are manual, that is, a human-powered and one robot for the picking process were used. In addition, rail vertical farming shelves were used in the model as seen in Figure 4.3. The reason behind this is that the use of rail shelves can provide more area for the storage of corms during the growing period. However, when the model was run for months, it was realized that the storage area was insufficient to cover the production rate. One of the major reasons for this is, as was emphasized before, three storage areas have different waiting times during the corms' growing period, for example, 40 days are required for the growth of the corms in the climate zone, while this period is 120 days for the dormant zone. Also, as mentioned before, the first model did not give any positive response to the company's desire to produce 100 kg of product annually. A larger storage space was needed for these long standby times for the growth process. This issue was shared with the case company. After the cooperation with the CEO of BlueRedGold AB, the company confirmed the conclusion reached by the authors and it was decided to move to a new production area for a larger production and storage area. The issue of insufficient storage volume was realized by using the Visual Component simulation program. As Chung (2003) mentioned, the simulation model is an Industry 4.0 technology that helps to better understand the production system in cases where the product flow or production system is complex and irregular, as well as to observe and solve any storage problem or problem that occurs in any of the production processes. To implement all changes which were decided during the cooperation with the case company into the simulation program to get more storage and process area, Banks' (1999) simulation method was used to identify and clarify the new simulation model.

This situation once again revealed how vital it is to design the facility layout. The design of the factory plan allows the implementation of the most appropriate plan, which decides exactly how the machines, materials, and product carriers (conveyors) are to be used in the factory, and all this equipment is to be located in the limited space given (Pérez-Gosende et al., 2021). In the fifth step of Banks' (1999) method (the model translation), a 2d drawing software (AutoCAD) was referenced by the authors as a solution method to the problem of facility layout, and of course, the next step would be implementing the 2d model into the 3d program (Visual Component 4.5 simulation software). After the first simulation scenario and the AutoCAD 2d model, it was decided to move forward to a two-floor area of 900 square meters facility, and the second simulation model was designed by the authors as seen in Figure 4.5. In the second model, the authors decided to use the same robot for the picking process and the same idea for production flow. The biggest change in the second model is that the production building has two floors, and the final quality control area is located on the second floor. By this, the material handling became more complicated and the need to use more conveyors was presented. There is a large elevator in the building that the case company has decided to use for material handling, that is, the product flow between the floors will be carried out by this elevator. With this in mind, the authors placed a warehouse shelf in the elevator to store enough items in the simulation program. In this case, more products could be transported at once. Furthermore, the model shows positive signs while running it partially which was a big motivator for the authors to finalize this model. After finalizing the model, and running it for a complete year, which is the test period, the model shows that the case company can reach the desired production rate which made the authors recommend putting this facility in consideration.

## **5.2 Production System Development Process for BlueRedGold AB**

The most important reason for the case company to change its production system is to obtain a more modern and automated production system and high-quality product. Bellgran and Säfssten (2010) pointed out that the important reason behind the changing production system is to obtain a more sustainable and modern production system to always open way for the further improvements. The role of production system development in the existing production system was discussed in this paper and lean philosophy was mentioned as an effective production process development technique to solve production systems' problems. The authors Bellgran and Säfssten noted the five steps to follow during the implementation of the production system development process which include Management and Control, Preparatory Design, Design Specification, Realization and Planning, and Start-up. All these steps provide a better understanding of ways of thinking based on the development process. There are two important changes behind designing the production system to get better production flow. According to Bellgran and Säfssten (2010), there are minor and major changes during the PSD process as mentioned before in the paper. In this case, the company made a major change in the implementation of the new production system and decided to change the production line and all of the equipment used. As previously mentioned, the interview method and questionnaire were used by the authors as a method of obtaining data to compare the company's production development process with the information from the theoretical framework. As Kvale and Brinkmann (2009) mentioned, the interview technique is done directly with someone who is authorized in production, and this is a very short and definitive solution to gathering information. In addition, this method plays an important role in finding differences between the company production development process and the existing knowledge about the same topic.

The CEO of BlueRedGold AB provided many different answers to the questions on how his company is currently working within the production system development process and how the simulation model can be used as a development tool. According to the answer, the case company generally prefer to use already existing idea during the production system development process because he mentioned that the case company is a start-up company and there is not enough worker to follow production development processes another reason is that they have limited resources to implement new ideas, so they don't want to risk budget of the company. In this stage, Bellgran and Säftsen' (2010) five steps of the production system development process are not used by the company during the development processes. Currently, the company is developing a new robot for the picking and sorting process to get a faster production process because the case company thinks that picking and sorting of the saffron process takes a lot of time when it is done manually. This process development trial by the company can be seen as proof of how the wasted time in the lean production system is costly for companies, as mentioned in the theoretical data section before. As Liker (2004) mentioned, Lean philosophy thinking generally aims to eliminate non-value-adding processes to get a more sustainable production system. Moreover, this improvement action of the case company can be regarded as an indirect production development technique.

One of the most important aims of this project is to present an applicable simulation model to the company. According to the answers received by the authors from the CEO, the company sees the simulation model as a solution to solve the layout problem of the new production system. At the same time, the case company thinks that the issue of positioning the robots and conveyors to partially convert the production system towards automation, and which robot is suitable for this production process can be answered by the use of simulation. This is understandable because according to Chung (2003), the simulation model is used for solving layout problems, as well as for organizing the production flow and creating a more understandable production process with the visualization of some production lines, which is in the positive features of the simulation program. The indoor farming industry has some unique environmental conditions as stated before, for instance, since the product is produced without soil, it is an important parameter that the environmental conditions of the product grown are suitable and constantly under control. Hati and Singh (2021) mentioned that indoor farming has two important methods of growing products, and these are, Hydroponics growing system and the Aeroponic growing system. According to the information received from the case company, which can be accessed in Appendix 1, the company uses the hydroponic growing system. According to Hati and Sight (2021), this system has given the opportunity to obtain high-value yields and it facilitates less water consumption and more efficient crops. The CEO of the company emphasized that it is necessary to use several Industry 4.0 technologies to take this system under control. As the authors mentioned earlier, the IoT and computing cloud are powerful methods for this monitoring and controlling process. Hati and Sight (2021) also noted that establishing the information-sharing system as seen in Figure 4 by using sensors which is directly connected to the farmer's phone or computer is one of the best monitoring systems and this system is called a smart indoor farming system.

### **5.3 Benefits, Challenges, and Approach of Using Simulation for Production System Development**

The advancement of technologies provides a quick investigation of potential system development alternatives. Simulation modeling was identified as a problem-solving tool for real-case problems as mentioned before. As Law and Kelton (1991) mentioned that simulation model can help problem solvers to get new improvement ideas during solving production system problems. In this analysis section, Banks' (1999) 12 simulation model designing steps can be used as a modeling guide to avoiding potential problems. According to the interview findings with an expert from MITC, each simulation model has its own approach. With this aspect, Banks' (1999) 12-step simulation model development technique is not always used by the expert. The expert also mentioned the importance of visualization of the production line which is one of the advantages of the simulation model and the ability of the multipurpose software Visual Component to provide this feature and also noted that each industry has its own rules to follow to create the production line as authors did. As mentioned before, the authors followed Banks' (1999) 12 steps to develop the new production system but some criteria such as long waiting time forced the authors to use different ways of designing the model, as explained by the MITC expert. For example, taking advantage of some models that have been used before and are available in the simulation program as a guide for the desired model.

The visualization of the production system is one of the most significant benefits of employing the simulation model. As Chung (2003) mentioned, to solve complex production systems and develop them, simulation methods can be a good solution by using visualization features. Using the production stages in any two-dimensional program that the authors use as a step in designing the simulation model only helps to solve the layout problem. However, the simulation model provides a preview of the flow chart of the product in the production process. This ensures that any potential problems that occur are recognized and solved. Considering that the simulation of the indoor farming production system is one of the purposes of this paper, this feature of the simulation model is of great importance to the authors. To mention another positive advantage of the simulation, a limited area was determined by the case company for the indoor farming production process, in this case, the activity of the workers in limited areas may cause some safety problems. This situation was also stated by the expert at MITC. In the production layout, the correct positioning of the equipment is vital to avoid safety problems. One of the most vital elements in the simulation model designed by the authors was that the ability of the workers to move comfortably was not hindered. The authors made many model trials before designing the current simulation model and each model inspired a new solution method. As the simulation expert from MITC emphasizes, each new model leads to new, better, and solution-oriented models. If all features are taken into consideration, it is understandable why the simulation technique is an important point for companies and why there is a huge investment in it. Banks (1999) mentioned that simulation models let companies stay in the computations thanks to the inspiration of new ideas of each simulation model, and in this way, companies can obtain continuous improvement which is one of the main philosophies of lean production systems.

One of the major challenges faced by the authors while designing the simulation model is that some equipment models belonging to the indoor farming industry are not included in the program. This situation forced the authors to use other types of equipment similar to those used in the indoor farming industry in the simulation model. This is confirmed by the simulation

program expert in the interview with MITC. The Visual component program is a program that focuses on automation in general, and this situation can be defined as a negative factor for the indoor farming industry where automation has been utilized recently. In general, observation and meeting methods were used to collect data about the production line. The first input of data is a very important element for a newly designed simulation model. As Säfsten and Gustavsson (2019) also emphasize on this issue, since the interview technique is done with an expert from the case company, the changes that the company wants to make in the production line or some problems in the production line can be noticed more easily and even a solution can be produced. Based on the interview with MITC, the incorrect first input of data into the simulation brings with it some new problems that are difficult to solve later on. One of the difficulties faced by the authors is the sudden stop of the entire product flow with the application of some changes made according to the request of the company to the simulation software. The fact that solution to this problem sometimes takes hours or even days, and this situation shows that simulation requires a huge knowledge possessed by the simulator and training which consist of the theoretical framework.

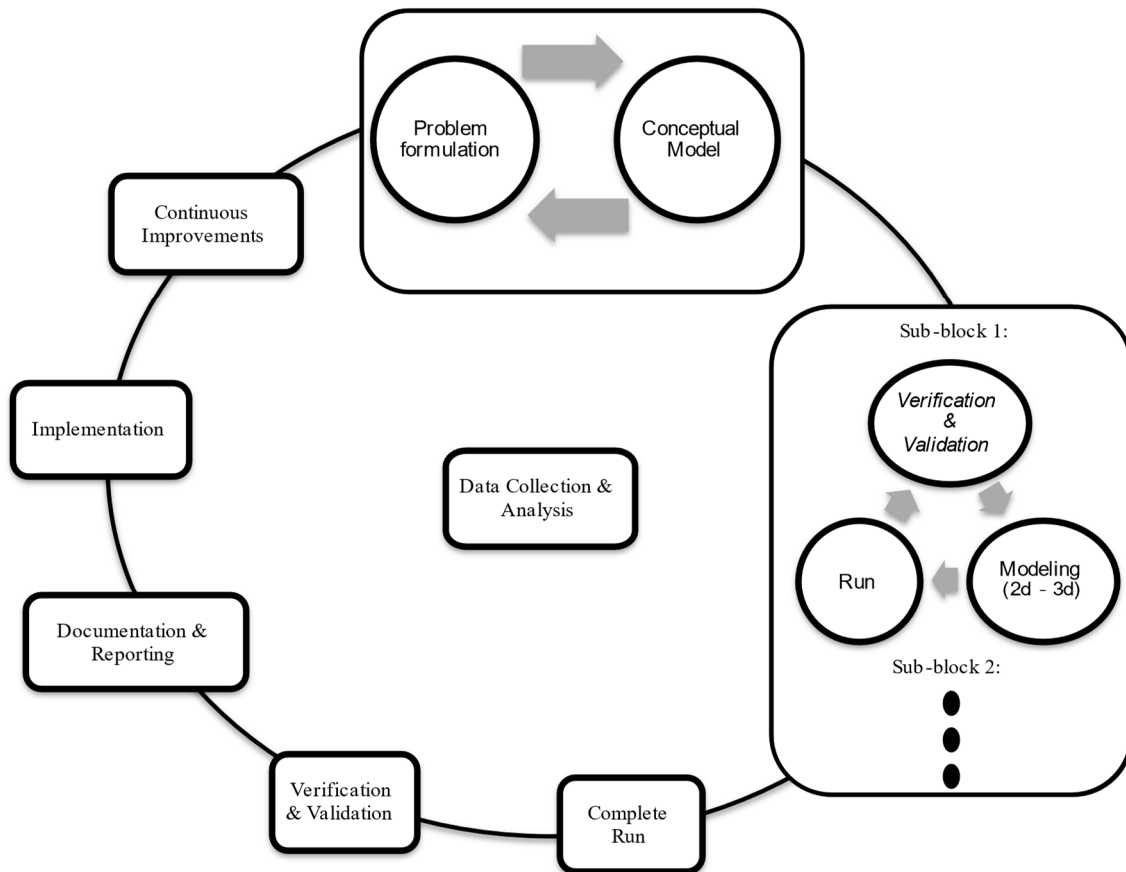
## 6 RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

The significance of indoor vertical farming as a possible solution to the never-ending increasing demand for food production, which is estimated to rise by 70% by 2050, has been highlighted. Indoor vertical farming offers various benefits, including water savings of 90% compared to regular farming methods, 100 times higher yield per unit area, a reduced carbon footprint associated with transportation, and much more. Meanwhile, Industry 4.0 has emerged as an important element that reshapes the agriculture industry and supplies the fourth agricultural revolution with many technologies such as Artificial Intelligence and the Internet of Things, and much more that are used currently. We can secure sustainable food production systems that will cover the increasing demand and at the same time save the environment, by combining the advantages of vertical farming and the potential of Industry 4.0 technologies. However, the major obstacle to adopting this type of farming is the high initial cost. By answering the research questions, a valuable insight into the potential of simulation in minimizing the major obstacle of the initial high cost generated by facilitating Industry 4.0 technologies in the indoor vertical farming industry. Furthermore, the research questions that will guide this study are:

RQ1: How can simulation facilitate production system development and Industry 4.0 projects within the indoor farming industry?

RQ2: What are the benefits and challenges when using simulation as a tool for production system development within the indoor farming industry?

A case study approach was used in order to answer the first question. This case study is a start-up company which implies that they have limited resources and at the same time that are taking steps towards developing a new production system where they want to invest in new technologies. Therefore, the use of simulation is seen as a suitable solution to solve their facility layout problem and a way to confirm that new technologies can be adapted to their production system and at the same time reach the desired production rate and all of that before doing the real investment. Based on this, this company was considered to be a suitable case study to answer the first research question and the authors were able to fulfill the company's need by developing a simulation model that simulates the future facility based on the data given by the case study and the data generated from the simulation model. However, in order to develop this model, Banks' (1999) simulation method was used as an initial approach or guide and then adapted accordingly while the project is advancing. To overcome the problems raised by the long period of the simulation model, the authors recommend that the modeling is done in stages or subblocks each one of which represents a major event in the production flow. Furthermore, the method should have an agile approach where the simulator can always revise earlier steps which will give him or her more flexibility. The data collection and analysis are considered to be the center of this approach since they are involved in each step of it from beginning to end. After finishing all subblocks, the complete model should be run as a whole and further validation and verification should be done. After all documentation and reporting of the model with all related issues are done, the implementation phase should start after the approval of the management. Data collection and analysis of the implemented production system will guide the way of continuous improvement which is the heart of lean philosophy. Nevertheless, Figure 6.1 summarizes and illustrates the method the authors used in this project.



**Figure 6.1 Simulation Approach**

The outcome from the mentioned earlier case study and a benchmark company were used in order to formulate an answer to the second question. The addressed case study demonstrates how beneficial simulation is in confirming a new production system and identifying problems before making an actual investment. Storage area and material handling options can be verified by the use of simulation. With simulation help, the facility layout problem that the case study had was solved. Furthermore, simulation is a powerful tool for the development of production systems, generating quick investigation of potential options and helping companies to generate new improvement ideas and verify them. A key advantage of simulation is the visualization of the production system, as it allows potential problems to be found and solved before investing. The complexity of production systems can be simplified by using the enormous features of simulation. When it comes to challenges, the main encountered is the availability of indoor vertical farming equipment such as vertical rail shelves inside the simulation software (Visual Component). Two ways to overcome this challenge, the first is to use similar equipment that fulfills the original needs, and the second way is to reprogram this equipment using a special programming language. Furthermore, as with all simulation models, the collected data plays a major role in the model and therefore it is considered to be a challenge. Updating the model with new inputs is in itself a challenge because of the complexity of the simulation program itself.

Finally, despite challenges, simulation technology can provide an applicable solution for production system problems of the companies/organizations to obtain continuous improvement philosophy which is the main principle of Lean thinking. The generated simulation model in this thesis project was successfully implemented, demonstrating how this technology might be an effective solution for complex production systems as in the indoor farming sector. As a result, it

is recommended that other companies in this sector consider utilizing simulation technology to enhance their manufacturing processes and reach their desired production rates. Furthermore, due to the increase in the utilization of the automation in indoor vertical farming industry, it is highly recommended that simulation programs be adapted and provide features in this regard. Nevertheless, due to the nature of this research, as it is built on one case study, the results might be limited in applicability in other situations, therefore further research is recommended to validate the outcomes of this thesis.

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## 8 APPENDICES

### 8.1 Appendix 1

Questionnaire for BlueRedGold AB

The person for the questionnaire: Mikael Öhman- CEO

Production system development/Smart Manufacturing

These first questions are about how you are currently working with production system development in terms of radical and bigger changes for the plant, e.g., major production line changes/impacts. But also incremental, smaller changes such as continuous improvement or process adjustments.

**1. Tell us about how your company works with production system development.**

Answer: We generally work with sprints when it comes to new development. We have been doing 2week sprints but it may differ depending on the partner we work with. We prefer to buy as much ready to use rather than developing new things as we are forced to develop new robotic systems for picking and sorting among other things. Adding on top of that with things like rack systems would harm our speed for scale up.

As we are a startup, we have only a very few people to manage everything. Now when we are scaling up I will drop a lot of tasks and focus on keeping the R&D plus Operations going. That includes new production development. We have a few different partners we work with, where the majority of the time is for robotics and automation but also ag-tech and general food quality/safety. We also have partners for packaging and all those basic needs you have including 3PL.

Some, like 3PL-integration, are easy. It's only configuration needed so no need to work with sprints or looking at some agile method.

For our R&D team in Holland we work with a "when needed" approach. We have a certain amount of hours and we use them over a time. Not like in sprints as it's mainly help with looking at research papers and such bit the output they have is needed when we select what system we should get such as growing racks, nutrition mix and similar.

We will have multiple parties involved in our "R&D Factory" that we are starting up now. First installation is our own team, our robotics partner and a partner for power/aircon. But after that there will be a lot more people involved as the building will be renovated to our needs. So, a lot of standard planning during this autumn and we will work with the system for construction that our landlord is using.

When it comes to quality control and testing I can take example on how we work with robotics/automation in the farm as this is the major bulk of work. We work in two week sprints. We will have more than one robot in the production line so one gets the new config/change as a failsafe if it's not delivering as planned. We also have parts where we use humans to mimic robotic arms to test the new gripper.

Once we have a working system we will go for continuous improvement where we also work with two week sprints. Basically just like before, but more focus on getting faster rather than correct.

For integration we use ROS2 as a basic platform for our robotics applications. Both our partner here in Sweden and the one we have in Denmark use ROS2. It's a lot easier with integrations as it's more of a configuration matter rather than new code when you integrate. On top of this we will need to get data from multiple devices like temperature, humidity sensors etc. All events from this sort of device will go into Monday.com where we will work with events and incidents.

**a. Can you think of a specific smaller project that you can tell us about?**

Answer: We are developing a system to pick and sort saffron automatically. This whole chain has not been done before and it's very high precision with both the picking and sorting. It will be very interesting to get this into live action in September!

**b. Can you think of a specific larger project that you can tell us about?**

Answer: Apart from the picking and sorting we will have an autonomous skylift driving around the farm. In the day it will move trays and when staff go home it will switch "tool" to drive around and collect data about the plants health and look for issues in the system so we can have a fresh dataset when we come the next morning.

## **2. What are the main challenges in developing and implementing production system development?**

Answer: It's very hard for us to know the exact amount of flowers etc. as we are in an early stage. We aim to get at least four rotations per year. That, compared to two, is a major shift is how much each climate zone needs to handle at what time. Basically we get a lot of bottleneck issues when we manage to improve our system and as we are pioneers in this, there is no-one we can look at to see what may happen. We can only look at standard ways of working with bottlenecks in general terms.

### **a. According to you, how could simulation help in solving the main challenges within the indoor farming industry?**

Answer: Understanding how much free space is good to have during the first two years would be great. Getting general "worst vs best case". Also general info on how we should think when we scale up next year. How much space is needed for staff, robots etc. to not make up ques. Also to understand how much time we may need to add to the next shift if we have people home sick and need to catch up with production.

## **3. How do you currently identify a problem or a new opportunity in the production process?**

Answer: A lot of coffee and Miro+Monday.com when kids are asleep in the night. :)

### **a. According to you, how can simulation help to detect a problem or a new opportunity?**

Answer: In multiple ways. First off, to plan for the setup. We need just a few robots at the start. How do we plan so it's easy to add the rest we will need over the coming 2-3years? Once we get more real data, then we want to run the simulation again to verify if we have missed something and can make improvements in a way that makes us less likely to lose productionspeed. Also to check if we have the data needed to do good calculations etc.

## **4. After identifying a problem or a new opportunity, how do you currently develop a new solution?**

Answer: Depending on the size of the issue. If it's smaller parts we will simply add them to a two-week sprint. If it's something bigger, like moving a wall or similar, then it's a bigger project with the landlord.

### **a. What type of activities does it include?**

Answer: One example could be if we figure out a better way to stack robots. This would first be a matter of deciding on the new setup and running the simulation a couple of times with different sets of production info. Once we have decided what needs to be done we will divide it into sprints where we need to keep the delivery times in mind.

### **b. According to you, how can simulation facilitate the development of new production processes?**

Answer: It can be anything from looking at only the sorting process and changing the grippers or using different robots to the factory floor plan, but at the end of the day a simulation is just as good as the data you have. This company is a startup so we don't have much data yet. We will start with the first parts we have, mainly for our pick and sort. We will need to get more data on how our racks should be set up so that our autonomous skylife will have the fastest way of working, for example. I think working with a simulation will show us when we have the correct sort of data and when we need to do a better job at planning.

## **5. How do you implement new solutions in production processes (e.g., defining new routines or a new way of working)?**

Answer: First it's done with two-week sprints. That is for installation and configuration. When it comes to handling events and daily routines we use Monday.com. Each ticket is linked to a routine. If there is some sort of new event that we didn't work with before then we will create a new routine document for this after handling the event for the first time. We then update the routine when needed in the future. Some events are triggered by another system, such as power outage, temperature levels that are too high or low. Some are standard routines such as cleaning, changing filters, maintenance checks for the robots.

### **a. According to you, how may simulation help to implement these new solutions?**

Answer: If it's maintenance checks or a general list of points to do it may help by giving a good idea of what order to do them in to save time. Or, to move around things so that power switches and other basic things are in a better alignment.

## **6. From your perspective, what are the key enablers for using simulation to develop and implement new production processes?**

Answer: Accurate data. The basic shit in, shit out. That is where we are right now with the facility, but we do have pretty good data for our picking and sorting. After that it's the part out data from the facility and things like the amount of wind created when the robots move. When we start to get more of this in place it will be a lot easier to work with vendors and use decision-making tools.

## **7. We think it would be interesting to hear what smart manufacturing means for your company.**

Answer: That's one of the major keys for use. We will have a mix of IoT, automation, Data Analytics and AI. Saffron is extremely time consuming to handle by hand so we need to do this automatically and to get the automation to

work well, we need the other parts I named there as well. The staff in Iran are paid around 6SEK/Hour so that is what we are up against if we want to be able to scale up and not only stay in the high end market.

**8. What potential do you think smart manufacturing has for your company?**

Answer: If we don't manage with it, then we won't make it. Simple as that.

**a. What current challenges do you think smart manufacturing could solve?**

Answer: In our case, less staff. The goal we have right now is to get to over 1000kg production within three years. If we don't do that automatically, then it's the difference between a work force of 20 people and ca 300. And this is why Saffron is so expensive, even with low cost labor. Add the current climate change to that...

**9. How is your company currently working with simulation studies?**

Answer: We have only done this with our pick and sort project. And now, with you guys as well. :)

**10. What is your saffron growing system method? (Hydroponics growing system or Aeroponic growing system)**

Answer: We use a hydroponic system. We won't use aeroponics. Not sure what to call it actually. It's kind of a mix of two types of hydroponic setups. I may come up with some new fancy name for it later on.

**11. Are you using IoT technology to monitor your indoor farming environment (temperature, water pressure, humidity...)?**

Answer: Yes, we use different types of sensors. Will most likely switch to new sensors later on this year for the indoor climate.

## 8.2 Appendix 2

00:00:01

**Authors:** Okay, now it started recording. Great. So, a little bit in the beginning about the background information. I told you, our topic. We have two research questions: How can simulation facilitate production system development and thus the 4.0 projects within the indoor farming industry? And what are the benefits and challenges when using simulation as a tool for production system development within indoor farming? I need your help on these, especially these benefits and challenges. So let's start with a little bit of information about you. Actually, the name. Yeah.

00:00:35

**Expert:** And I work as a simulation engineer, you could say, at the MITC.

00:00:47

**Authors:** ITC education and work experience. I know that.

00:00:54

**Expert:** My background is in mechanical engineering, but yeah, I did my master's here at MDU within product development, product and process development with production and logistics.

00:01:07

**Authors:** It's a long name. I have the same problem I have still this problem. How can I introduce myself or ask if should I tell them all of the name or so cool current responsibilities and projects? Maybe the responsibilities as you said. Simulation?

00:01:21

**Expert:** Yeah. Simulation. Then we are building a smart factory as well. The simulation of a lot of partner companies that we have with MITC. We have a lot of like Volvo, GEICO and Robot Island, Alfa Laval. So, working on projects with all these.

00:01:48

**Authors:** Companies, what kind of a smart factory is it?

00:01:52

**Expert:** Well, after this interview we have the display, so we will you can attend that. Okay, cool.

00:01:58

**Authors:** Yeah, cool. Okay. So yeah, our interview will be divided into three topics the simulation method and the benefits and the challenges. So we are writing our master thesis, as I said, and we found a lot of researchers using the Banks method, the one that we have already done in the course we were with you. And I want to ask the following. Tell us about how you address the simulation project. I mean, do you follow Banks' method or.

00:02:32

**Expert:** Normally we just don't follow. Like it's hard to say which method we follow because every project is different. In my experience, I've worked with almost 20 projects up till now. So, um, and every project has its own

requirements or its own goals. So in order to meet them, how are we going to meet them? And so that kind of analysis we do, Um, then we go over taking in data which um, CAD files or, you know, production flow or the shop floor area, how does it look like? And we start somewhere over there. Okay, cool.

00:03:20

**Authors:** Yeah. So, I mean, you don't follow the steps exactly as it is. It's flexible. More on real life.

00:03:26

**Expert:** It depends really on the project.

00:03:28

**Authors:** Yes. Okay. This is. Yeah. Uh, what computer programs do you use?

00:03:33

**Expert:** Computer programs? Like for what is it?

00:03:36

**Authors:** The visual component?

00:03:37

**Expert:** Uh, visual components. You can say for simulation.

00:03:41

**Authors:** Yeah. I mean, the program you use for simulation.

00:03:44

**Expert:** Simulation? Yeah. Visual components. That's what I'm using right now.

00:03:48

**Authors:** Okay. Uh, follow-up question. Does the client demand a program? A special program, or it's up to you to decide which program?

00:03:57

**Expert:** The client keeps it to us but it also depends.

00:04:04

**Authors:** I mean, some clients say that for us, for example, at the beginning of our master thesis, the case study told us we want this program. We told them we can't do this program, we can't do the visual component. And it's almost the same. So we try to convince them with a visual component. But does the client know which program? Or sometimes they decide.

00:04:27

**Expert:** And most of the cases they were fine with visual components because they were aware of its capabilities. Because. Viewing them in 3D is made possible by visual components. So that is a really good thing. But other than that, no, we they didn't they never none of the companies, they never came to us. They don't they wanted to do it in some other software. But everything that can be done on this software can be done on visual components. So because of that, we never had any problems.

00:05:08

**Authors:** Don't you face this problem that maybe some robots or methods are not programmed to the visual component? I mean, for example, we are trying to use a crane and there are no cranes there. The scissor crane, for example, is the one that we want. And yeah, we will just place it with the bird effect. I mean.

00:05:31

**Expert:** Yeah, for that individual component, they also have the ability for you to put in more animations using Python scripting. Okay, So you'll have to go a bit deeper with the modeling tab and the other functionalities.

00:05:50

**Authors:** More experts.

00:05:51

**Expert:** Yeah, exactly. Yeah. In that you have to define, okay, here is my crane and these are the different joints in the crane, and I want them to move it in this particular direction or speed. You define it.

00:06:05

**Authors:** I got you. I got you. So, uh, you already answered my question about this one. The third one. Does the size of the project decide the method you proceed with? Depending on the project? Yes. Oh, yes. Can you think of a specific, smaller project that you can tell us about?

00:06:22

**Expert:** Smaller project? Yeah. Like, uh. Well, there was this one project with visual lift. Where they just wanted

to visualize their whole industry in a 3D world. So we just got the machine's CAD files and placed them all together and then showed them in VR. So that was really small.

00:06:53

**Authors:** Okay. It's all about visualization.

00:06:56

**Expert:** Yeah, it was only about visualization because they wanted, you know, to think a bit more about how they can free up some space because things were almost everywhere in there. Yeah. Yeah, I got you. Yeah.

00:07:11

**Authors:** Uh, the same question, but for a larger project, I think the Smart Factory can work here. Maybe it's like I have.

00:07:18

**Expert:** We have had larger projects than that, but I guess they are still ongoing. But I can't really classify them because they move in stages. Like we finished one stage and then we go depending on what requirements are there.

00:07:34

**Authors:** So yeah. Okay. Yeah. Uh, does the type of industry, I mean, the industry type size, and location of the client affect it in any way? I mean, the method.

00:07:48

**Expert:** Obviously for now, since we at MIT are only focusing on, you know, companies here in Sweden. So it's just easy for us to just travel and it's within this region. So yeah.

00:08:02

**Authors:** And the industry that the clients you have, most of them are in the automotive industry or I mean for us it's agriculture in this case.

00:08:12

**Expert:** So some of them are, some of them are not. It's a bit difficult to say because in some companies some part of their automation is not all. So it's a bit difficult to say, okay, this particular company is fully automated. No, we can never or we can. It's a bit difficult for us to classify it on a practical level.

00:08:36

**Authors:** Exactly. Um, the last question on this topic. Any recommendation for us as a method, do we follow the things that we got in the course problem formulation, conceptual model, then modeling validation and like that.

00:08:50

**Expert:** My accommodation will be a bit more nontheoretically, to begin with. Go to their factory, and analyze. Okay. What, how does the industry floor look like? And then gather all the information about different resources. Then make a process flow. The process flow should have all the different processes you have. For example, in the beginning, you're packaging. Then as I'm sorry, then you're processing maybe on a lathe machine or drilling or those operations processes make a value stream map of the whole production flow. Yeah. Look at how things are they look like then once that is ready, then you go to the visual components and try putting in, okay, do we have all the resources gathered? Resources could be CAD files, process machines, and the 2D layout of the whole shop floor. Then we import them all in the. The simulation model that we are creating and then do an analysis. Okay. Have they been placed where we want to place them? And if it's correct, then proceed to further simulation with the timings and whatnot.

00:10:22

**Authors:** One small question about the validation of the model. For example, for instance, in our case, we are doing a new layout which we don't have any way to validate. I mean, if it's a development for something that exists, we just model the existing one and see the results if it's a real-life scenario. Okay, it's validated. Good, we change. But in our case, it's like we are beginning from scratch and there's nothing to compare with how to validate. In this case.

00:10:53

**Expert:** Again, it depends on which different machines you are using. For example, if you have a robot, then validation would go inside, you know, programming the robot, seeing whether the coding that we have done is actually working properly or not, depending on the gripper dimensions or if you want to be more specific. So validation could it's a really broad term when you mention that because it could mean so many things. What are you trying to validate the whole production, the model that you have created or validate only the simulation model? Because if you want just validate, like trying to validate the simulation model, then it's all visual. For example, you

want the robot to pick something and place it here and it's doing that. You can just see it so it's automatically validated.

00:11:47

**Authors:** Okay. Yeah, yeah, that's it.

00:11:50

**Expert:** Thank you. But validating it in terms of real life could mean something different altogether. For example, that same robot, you have it in real life and you want to do the same task, but then you have to look at the robot's coding and see, okay, how can we simulate the exact thing that we have done in our program? Yeah.

00:12:16

**Authors:** One small question. I had always this question, about the timing that the robot need to do a process. Like if I if I model it and visual component, it will I can get the time by just modeling it without changing anything. But does this time reflect the real life scenario? I mean, when they program it inside the visual component, the robot.

00:12:41

**Expert:** Okay, so the thing is, in the visual components, in the course which I taught you, I taught you using the transport controller in that when you just connect it, plug and play, it automatically does it. Okay. So it's there is also a programming tab in visual components. If you click on it and click on the robot, then you can actually go inside and specify which motion sequence you want to put in and how at which speed this joint arm should move and in which linear motion. So all these in detail things you can like play around with. So over there, I think I could answer your question. Okay. Okay.

00:13:23

**Authors:** So we go to the second part. It's about the benefits of simulation, the benefits of simulation. I mentioned a lot by researchers and it's not a new topic. However, within the Swedish market, it needs to be updated due to the fast changes in technologies that led to the need for a quicker way to adapt to new production systems. Our questions on this topic are as follows. Based on your experience, what are the main goals that the clients are searching for? I mean, when the client comes to you, he wants simulation. Why?

00:13:54

**Expert:** Mainly now it's not like that. In most of the cases, the clients are in the actual hardcore engineering problem and some of the requirements were like, can we how can we solve it? Like without, you know, actually making actual changes in their production flow. So they wanted to visualize what are we thinking for like, you know, the future state? Is it even possible? And if it's possible, yes. Then is it safe or is it, you know, easy to how much new costs will it add up to make those changes, those kind of calculations? We have to like, uh, like, yeah, yeah. Usually those kind of things. Yeah.

00:14:48

**Authors:** Okay. Uh, do all of your clients know the benefits of simulation, or do you always need to make your case? I mean, do you look for a job or job come to you as a simulator? Um, I mean, it depends on the existing. Companies have the real data about simulation. Do they know what simulation?

00:15:08

**Expert:** Some of them, yes. Some of them? No. It depends on different companies, actually. And it's really subjective to different companies, actually. In most cases, some companies do have them, but they don't know how to utilize them. You know the data that they have. Um, so, yeah.

00:15:32

**Authors:** So in your opinion, finally in this chapter, what are the main benefits of simulation?

00:15:39

**Expert:** Um, you can do optimization, and visualize the future state. Then you can do a cost analysis. The future state, then visualization. Yeah.

00:16:00

**Authors:** Can we consider visualization as a benefit for it? I mean, yes. Is it that important? Because we discussed that with the teacher at Malardalen. He said that, yeah, it's all about visualization here. It's like I got this feeling that it's nothing, but it's a big deal, in my opinion.

00:16:21

**Expert:** I can give you a practical example. For example, I created a new layout where I placed a lot of machines. Okay? And there we have two, three operators working as well. So they have their own desks, benches alongside with the machines. Now, I created this in my model and now I want to analyze is it safe for the operator to work? Is

the space for the operator to move sufficient enough? Is there a space for, for example, in case the machine goes under maintenance or it needs repairing? Can the serviceman go and is it accessible to the repairman or not? So those kind of things are a bit more easy to visualize once we put it in the our model into the VR. So we can actually visualize in like same aspect ratio as the viewer in real-time as well. At the same time to just map out. Okay, Yeah. This looks okay to walk in.

00:17:34

**Authors:** Yeah. So, so it's not all about optimization of time or cost. Also the safety factor play a big role in this one. Thank you. About the challenges when it came to the challenges, the existing literature does not discuss them as thoroughly as the benefits and we were able to identify four challenges model building require special training. Simulation results may be difficult to interpret. Simulation modeling and analysis can be time consuming and expensive simulation may be used inappropriately. So our questions on this topic are as follows. In your opinion, what are the main challenges you face? I mean, obviously you face challenges when you do simulation, but what are what are they challenges?

00:18:22

**Expert:** They first of all vary project to project. Yeah.

00:18:26

**Authors:** But what's the thing that annoy you a lot when you do a simulation? Is it the data collecting? Is it the client? Is it the job itself? Is it visual component, the program itself?

00:18:41

**Expert:** Up till now, it was not really that challenging in terms of the challenges that you mentioned, because if the client is not really ready with their CAD models, so we would just search for them somewhere else on which are available on the Internet, on some sources, and then we would just import it and just kind of give a rough estimate visualization, Okay, that is there or if some things are not available. So we would try the other things the other way around. So somehow the other challenges don't really think like it's more about knowing how you can overcome those challenges actually. Like because not everything is available at all times. Yeah. And given that, you have to know, okay, is that really important for our simulation model? If it's not, in most cases it wasn't that important. So we could we substituted it for something like which looks similar to that product and we did the simulation using that. Okay. Because yeah.

00:19:59

**Authors:** So yeah, in our case, for example, we are facing a big problem in data collection. The clients he have data but it's, I mean the process timing, the machine timing, the manpower handling system timing most of it about time because he's doing manual work now and he wants to shift to automation, kind of automation all the conveyors. And he will buy like two robots and still they will be manual work. So it will be like semi-automated. So mostly it's about the timing of process. Timing. They don't have it Now.

00:20:38

**Expert:** This you can do it like, you know, just go to their shop floor, see their workers working. Just you just stand there, record the times. Okay. To assemble this product they took when you were just standing, they took five minutes and then they moved to the next product and it took seven minutes and gather all the data. These kind of data, you'll have to just go in their shop floor and gather them like, yeah, like hardcore. So those kind of mapping, like how the Kaizen practices that people in Japan, how they started doing it, they actually went in their shop floor, stood there the whole day observing every actions of the shop floor, the operators, everything they wrote, okay, from this second to this second, they pick a bolt, then they place it. And then from this second, this second, they screw it. So right down to each and every sequence of motion sequence of the operator, they noted it down. So it depends like, Yeah, so doing it new takes a lot of time. Yeah. Okay.

00:22:00

**Authors:** This one you have answered me. This one you have answered me. Uh, can you give me an example for a challenge you faced and overcome? Example Um.

00:22:18

**Expert:** There was this company. It was not important to visualize the conveyor. Sorry, the overhead conveyor. And it was a bit like difficult. The documentation was not available on the visual components, but I did. I did look up for on the Visual Components forum. I just asked the question if someone has previously done it and then someone had actually done it. So. So he modified that file which I had uploaded, sent me back and then it was

working. So I kind of made some more changes according to what I wanted because it was really basic and that's how I put it in my simulation model.

00:23:13

**Authors:** It was a robot. I mean, it was a machine. It was it.

00:23:16

**Expert:** Was an overhead conveyor. Like, you know, those when you go for skiing, you see those that take you up. So it's like an overhead conveyor. So those kind of big cranes were there, sorry, conveyors with hangers instead of seats. You had fixtures? Yeah.

00:23:40

**Authors:** Cool, cool, cool. So we are done for today. Okay. Thank you so much for this. No worries. It will be beneficial for us because. Yeah, as I told you, we are still. We are modeling now. And that's why I'm looking for the videos. I need to close this one.