An Integrated Self-Assessment and Maturity Model for the Urban Smart Factory

Master thesis submitted to Delft University of Technology in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE
in **Management of Technology**

Faculty of Technology, Policy and Management
by

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To be defended in public on 30 June 2023

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Preface

I would like to thank my academic supervisors, Paola Ibarra Gonzalez and Anneke Zuiderwijk, who guided me throughout my thesis and provided me with the opportunity to engage with a unique interdisciplinary subject. Their mentorship and encouragement have been instrumental in shaping my research and fostering a deeper understanding of the subject at hand.

I would also like to express my sincerest appreciation to my company supervisor, Frank van Cappellen, whose assistance, insights, and industry experience have significantly contributed to the success of my thesis. I am deeply grateful for Frank's invaluable contributions and the mentorship I received throughout this process.

I am also indebted to my beloved family and friends for their unwavering support and encouragement throughout my academic journey. To my parents, Christina and Spiros, I am forever grateful for their unconditional love and constant belief in my abilities. To my sister, Marialena, I express my heartfelt thanks for her continuous presence, understanding, and motivation. Lastly, I want to express my profound gratitude to Manto, for her support and encouragement throughout the demanding process of completing this thesis.

K.D.

Executive Summary

Background: Recently, the concept of the Urban Smart Factory (USF), which combines urban manufacturing with Industry 4.0 technologies, has emerged as a promising solution that can create numerous value-added opportunities. Such factories have the potential to enhance customer involvement, enable a higher degree of personalization, and improve the overall efficiency of the supply chain. To this date, however, no model for assessing the maturity of a company in relation to the USF has been developed. This is a problem as companies struggle to evaluate their current capabilities accurately and identify areas for improvement. To address this issue, two useful tools have been identified: maturity models and self-assessment tools. These tools can assist companies in evaluating and enhancing their readiness for the USF. These models are generally developed in a disconnected manner, even though their true potential can be achieved if they are developed simultaneously.

Purpose: The purpose of this research was to develop an integrated maturity and self-assessment model for companies operating within the urban environment, enabling them to evaluate their maturity level in implementing Industry 4.0 concepts and technologies. By addressing the gaps in existing models, this research contributes to a better understanding of the concept of urban smart factories and its maturity levels. Through a combination of literature review, expert input, and validation through an implementation example, the developed tool serves as a valuable resource for companies seeking to assess and enhance their readiness in the context of Industry 4.0.

Methodology: A literature review was conducted to understand how to develop such models, by investigating relevant maturity models, and to map the relevant features and characteristics of urban smart factories. Moreover, a series of interviews with 14 experts (7 individual interviews and one group interview with 7 participants) from urban factories, smart factories and an Industry 4.0 consulting firm were conducted to enrich the understanding of the USF concept. The individual interviews were conducted with experts closely aligned with the concept of the urban smart factory, providing in-depth insights into the integration of smart technologies, urban considerations, and operational aspects, thus ensuring the model's relevance to the target context. The group interview aimed to foster dynamic interactions among participants and simultaneously capture a wide range of perspectives. By engaging multiple experts in a collaborative discussion, the group interview facilitated the identification of common themes, emerging trends, and collective insights, which further enriched the understanding of urban smart factories and informed the development of the maturity model. After developing the maturity model, it was validated with a company that can be considered an urban smart factory. Based on the validation process, it was possible to not only ensure its accuracy and reliability in assessing organizational capabilities, but to also showcase areas that the model could be improved.

Results: Based on the information that was collected through the literature review and the expert interviews, the Urban Smart Factory Maturity Model (USFMM) was created with 4 maturity levels (pilot actions, partial implementation, advanced implementation, exemplary implementation), 5 core dimensions (technology, workforce, strategy and organization, process products and services, urban integration) and 25 sub-dimensions. To assess the level of maturity, a self-assessment in the form of a questionnaire was created, where each sub-dimension is measured by one or more questions. In the model validation, the company achieved a maturity score of 3.52 out of 5, signifying an "Advanced Implementation" level. The dimensions *technology*, *urban integration*, and *process, products, and services* scored exceptionally well. However, the *workforce* dimension scored low and required improvement. To address this, the maturity model revealed that by implementing an employee satisfaction monitoring system and establishing comprehensive metrics and KPIs would facilitate the innovation process. Overall, the assessment identified key areas for improvement, providing valuable insights for the operations of the company. The validation process played a crucial role in enhancing the model, leading to important improvements such as the recognition that non-technical innovation should be included as an essential component.

Conclusions: In conclusion, the model successfully identified issues and areas for improvement in an urban smart factory, and provided a personalized strategic roadmap. This demonstrates the effectiveness of the model in evaluating company capabilities. Furthermore, the development of the integrated maturity model with the assessment enhanced its usability and applicability. The concept of the urban smart factory was enriched through a comprehensive incorporation of literature and expert input, resulting in a well-structured set of dimensions and sub-dimensions that fully cover the concept without overlap. Through the validation of the model, it was identified that the leadership sub-dimension could be strengthened. While the model enables an initial evaluation of a company's maturity, its true value becomes apparent after the assessment takes place, particularly during the transformation journey. Overall, the model proves to be a valuable tool for assessing and advancing urban smart factories.

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1 Background

1.1 Introduction

In the past decades, two mega-trends related to manufacturing have emerged that affect the global affairs and have thus become research topics of high interest. The first one is the development and implementation of innovative and disruptive technologies in manufacturing settings. This has led to the introduction of the fourth industrial revolution, also known as Industry 4.0 or the smart factory (Hughes, Dwivedi, Rana, Williams, & Raghavan, 2022). The smart factory aims to integrate the processes in the setting of the cyber-physical factory, by employing technologies such as big data analytics, autonomous robotics, additive manufacturing and industrial IoT (Jamwal et al., 2021, p. 430). By utilizing these, and many other technologies, the smart factory unlocks several opportunities. For instance, it allows improved productivity and efficiency, improved customer satisfaction, personalized products and increased profitability. The second mega-trend is urban manufacturing, which is often also mentioned as the urban factory. The term urban factory literally describes a factory that is located within the urban environment and value is created from it, by transforming inputs into outputs (Juraschek et al., 2018, p. 74). More specifically, the material, information and energy inputs are transformed into products, by-products, waste and emissions through its operations (Burggräf, Dannapfel, Uelpenich, & Kasalo, 2019). Due to its proximity to customers, suppliers and employees, as well as its urban-industrial symbiosis potential, the USF unlocks several opportunities for added value. Examples of such opportunities include increased customer involvement, a higher degree of personalization, shortened lead time and improved supply chain (Herrmann et al., 2020).

The combination of the smart factory and the urban factory is called the Urban Smart Factory (USF). Literature has focused on these topics individually in the past decade, however, only one paper was found that delves into the urban smart factory concept (Sajadieh et al., 2022). As mentioned by the authors, this new production paradigm is unique as it combines three major characteristics. It is human-centric, sustainable, and resilient. It is human-centric because customers are highly involved in the design process and close collaboration with local communities is a high priority. Secondly, the USF supports the three pillars of sustainability: the economy, society, and the environment. It supports economic growth, as it is centered around value creation and new business model development. It considers social aspects, as it is aimed at improving human well-being and environmental aspects, by maximizing resource and energy efficiency. Finally, the USF is resilient as it anticipates potential adversities and is able to adapt to changing circumstances, by utilizing smart meters, big data analytics and industrial AI. The adversities can be internal, such as problems that stem from the operations of the factory, or external such as events that might negatively impact production and distribution. Overall, the USF presents an opportunity for companies, as it can combine the benefits of both the urban factory and the smart factory, and thus can unlock opportunities that would otherwise not be possible.

The challenge for the companies that want to adopt this type of manufacturing paradigm, is that constructing a strategic roadmap for their actions can be difficult (Akdil, Ustundag, & Cevikcan, 2018). That is because there are numerous considerations, that need to be accounted for. For instance, Hizam-Hanafiah et. al. (2020) in their systematic literature for Industry 4.0 readiness models, they found 158 unique dimensions related to smart manufacturing. Even though the authors managed to group them into six core dimensions (Technology, People, Strategy, Leadership, Process and Innovation), each one of those has relevant sub-dimensions that need to be accounted for. The complexity increases even more for the USF, which also includes the urban manufacturing aspect. As such, companies that want to embark on a transformation journey towards achieving their goals often utilize maturity models (Akdil et al., 2018).

Maturity models have been defined as “a sequence of stages used to assess situations, and guide potential improvements" (Wagire et al., 2020, p. 605). They can be used to measure the current state, and to plan the future desired state, by identifying which transformational capabilities should be developed (Santos & Martinho, 2020, p. 1023). Maturity models are also frequently mentioned as readiness models (Akdil et al., 2018, p. 62). To add to that, in the literature similar models appear under terminology such as 'roadmaps', 'maturity models', 'frameworks', and 'readiness assessment' have been used widely in the literature. Even though these terms seem similar, they have distinct differences:

Maturity Models "are models that help an individual or entity to reach a more sophisticated maturity level (i.e., ability) in people/culture, processes/structures and/or objects/technologies following a step-by-step continuous improvement process" (Mittal, Khan, Romero, & Wuest, 2018, p. 199).

Readiness Assessments "are evaluation tools to analyze and determine the level of preparedness of the conditions, attitudes, and resources, at all levels of a system, needed for achieving its goal(s)" (Mittal et al., 2018, p. 199).

Another core difference between those tools is the moment at which they are used. Readiness assessments are usually done before a company embarks on the transformation process (Yoo, Kim, & Choi, 2018). That is because it is important to understand where does a company stand, what capabilities it has and what are its strategic goals. This assessment is usually done in the form of a questionnaire. Self-assessment tools have been suggested to be especially useful as they allow companies to understand their position without the need of an external party (Hizam-Hanafiah et al., 2020). The second tool on the other hand, the maturity model, is used in the process of transformation to help individuals or entities reach a higher level of maturity (Santos & Martinho, 2020). The maturity models typically have four to five maturity levels, and each of which has a specific roadmap to guide a company into a higher level (Mittal et al., 2018). These models typically have dimensions and sub-dimensions that assist in making a multi-level analysis. These dimensions vary significantly between different applications, and even for the same applications based on the research teams that developed them (Elibal & Özceylan, 2021).

1.2 Knowledge gaps

By reviewing the state-of-the-art in the current literature, it was possible to identify key knowledge gaps that still need to be filled.

1) *The dimensions and characteristics surrounding the urban smart factory are not fully understood yet.*

To the best of the authors' knowledge, the urban smart factory is a novel concept that has only been coined by one research team (Sajadieh et al., 2022). Even though these researchers have made a significant effort to contribute to the understanding of this concept, there is still much more that needs to be investigated and explored. The authors only focused on three key characteristics of the USF (human-centric, sustainable, resilient). However, maturity models require a much deeper analysis of such concepts. For instance, Wagire et al. (2020) included 7 dimensions and 38 sub-dimensions when they developed their maturity model for Industry 4.0. It is therefore clear that a more in-depth analysis of the dimensions and the characteristics of the urban smart factory is required.

2) *Neither a self-assessment model nor a maturity model exist for the urban smart factory.*

Sajadiej et al. (2022) in their paper about the urban smart factory they highlighted the need to develop both an assessment model and maturity model. The state-of-the-art literature review did not return any results regarding the development of such models in the context of the USF. On the other hand, over the past few years, academics throughout the world have taken a great interest in maturity models for the smart factory. For instance, the systematic literature review by Elibal et. al. (2021) revealed 90 relevant publications, which were later taxonomized. As such, the need to develop such models for the USF still remains. The underlying problem of this gap is that existing urban smart factories do not have the necessary tools to understand the areas that they need to work on to improve. This is not the case, for instance, for smart factories, where literature has provided enough maturity models. Moreover, Mittal et al. (2018, p. 12) noted that self-assessment tools can be especially valuable for companies, as they can perform the assessment without the need for an external party. For this reason a self-administered questionnaire with the aim of assessing the readiness level of USF is crucial.

3) *There is a disconnection between the self-assessment and maturity models.*

As mentioned by Mittal et al. (2018, p. 210), there is a disconnection between readiness assessment models and maturity models. This means that it is still the case that these models are not developed together, but separately, and in many cases by different research teams. However, these models should be developed simultaneously, as when used together they are a complete tool that a manager could utilize.

1.3 Research objective

The purpose of the research is to develop an integrated maturity and self-assessment model that can help urban smart factories increase their maturity level. Since no such model exists to this date, information regarding how to develop this type of model will be gathered from the literature, input from experts will be included to make it more grounded for practical reasons, and validation through an implementation example will be done to improve the model.

Practical Implications
The developed tool holds significant practical implications for companies operating within the urban environment and seeking to embrace Industry 4.0 concepts and technologies. By utilizing this tool, companies can benefit in two crucial ways.

Firstly, they can conduct self-assessments to accurately gauge their current level of readiness across all dimensions of the urban smart factory (Hizam-Hanafiah et al., 2020). This assessment enables companies to identify their strengths, weaknesses, and areas for improvement, providing valuable insights into their overall maturity in adopting Industry 4.0 practices. By understanding their current state, companies can develop a clear understanding of where they stand in relation to their desired future state.

Secondly, the tool assists companies in formulating an actionable roadmap to navigate their transformational journey towards the desired state (Santos & Martinho, 2020). It helps in pinpointing the specific capabilities and strategies that need to be cultivated and enhanced to achieve higher maturity levels in implementing Industry 4.0 technologies. This guidance enables companies to plan and prioritize their initiatives, allocate resources effectively, and make informed decisions to drive their growth and competitiveness within the urban smart factory context.

These practical implications are particularly valuable as they empower companies to enhance their profitability, sustainability, and resilience (Fraser, Moultrie, & Gregory, 2002; Correia, Carvalho, Azevedo, & Govindan, 2017; Hernantes, Maraña, Gimenez, Sarriegi, & Labaka, 2019) By leveraging the insights and recommendations provided by the tool, companies can proactively adapt to the dynamic business landscape, seize value-added opportunities, optimize their operations, and establish a strong foundation for future success within the urban smart factory paradigm. Moreover, this research has broader managerial relevance, as it contributes to the advancement of knowledge in the field of urban smart factories. By building upon the novel concept and investigating the maturity levels within this manufacturing paradigm, researchers can gain a deeper understanding of the underlying dynamics, challenges, and opportunities. This enhanced knowledge facilitates further research and exploration of strategies, policies, and frameworks to foster the successful integration of urban manufacturing and Industry 4.0 technologies, ultimately benefiting both academia and industry.

Academic Value

This work holds significant academic value, offering valuable contributions to the understanding of the urban smart factory concept and its maturity levels. Researchers in the fields of urban factory and smart factory domains stand to benefit from this study, as it represents one of the few research endeavors that effectively combines these two concepts. By conducting a comprehensive literature review and expert interviews, a model has been developed that encompasses the key dimensions of urban smart factories: technology, workforce, strategy and organization, process products, and services, and urban integration. These dimensions are further divided into five mutually exclusive and collectively exhaustive sub-dimensions, providing a comprehensive understanding of each dimension. Moreover, the expert interviews have yielded insights into the challenges faced by urban smart factories, enriching the understanding of this manufacturing paradigm. Additionally, this research offers a novel and improved methodology for developing maturity models, benefiting the broader body of literature dedicated to maturity model development for various applications.

1.4 Link with Management of Technology

The thesis aligns closely with the requirements of the Management of Technology (MoT) program, which emphasizes the exploration of technology's role in corporate settings. Specifically, this thesis focuses on the development of a maturity model for urban smart factories. Through this research, a deep understanding of the interconnection between technology and various aspects of corporate operations, such as strategy, leadership, innovation processes, and societal integration, can be established.

To achieve this, the study employs rigorous scientific methods and techniques, including systematic literature review and semi-structured interviews, which adhere to established research methodologies. These approaches enable the analysis of complex technological problems and the proposal of effective solutions. By delving into these perspectives, the thesis aims to showcase a comprehensive understanding of technology as a valuable corporate resource from a corporate perspective, as emphasized in the MoT curriculum. It is important to note that while the significance of these perspectives is recognized in the current discussion, subsequent sections of the thesis will provide more explicit and detailed explanations of how each perspective contributes to the overall research framework.

2 Research Approach

The review of the state-of-the-art revealed that there is currently no maturity model for urban smart factories. As such, there is a need for developing such a model, so that companies can increase their profitability, sustainability and resilience. To do that, it is necessary to review existing maturity models from the literature, to enrich the understanding of the urban smart factory concept and finally to validate the developed maturity model. As such, it is now possible to formulate the research questions.

Research Questions

Main RQ	**What integrated maturity and self-assessment model can be developed for urban smart factories to increase their profitability, sustainability and resilience?**
RQ1	What are the key dimensions and sub-dimensions of the current maturity models, from the literature, that can be adapted to support the urban smart factory concept?
RQ2	What are the relevant features and characteristics of the urban smart factory that should be included in the maturity model?
RQ3	How can the proposed integrated maturity and self-assessment model be validated?

To answer the research questions and to fill the research gaps, the following methodology is followed. In order to develop the integrated model, a systematic step-wise approach (Figure 1) was developed based on the guidelines suggested by two research teams.

Firstly, De Bruin et. al. (2005) proposed a process to develop maturity models, which is flexible, applicable to diverse fields, and not restricted the Industry 4.0 sector. For instance, it has been used by Donavan et. al. (2018) in the field of business process support through human and IT factors. In addition, it was more recently used by Santos et. al. (2020) specifically for Industry 4.0, where they developed a model with five key dimensions (organizational strategy, structure and culture; workforce; smart factories; smart processes; smart products and services). A more detailed analysis on their model will follow on section 3. The methodology by De Bruin et. al. (2005) consists of 6 steps (scope; design; populate; test; deploy; maintain). The first step starts by defining the model and setting boundaries as well as the target audience. Next, the needs for the model design by the target audience are explained. Step 3 includes the model composition, through the contemplation of the concept and the population of its content. Literature review to clearly understand and explain the relevant concepts is included at this stage. Next, a model pilot test is applied to validate the model. The final stages relate to the final deployment of the model after it has been validated and its maintenance to ensure that it is properly updated. These two stages are not an objective of this research and will therefore be ommited. Overall, this structured methodology is the central building block for the research approach that will be followed in this work. In addition, however a second method approach is also considered.

The second is the methodology that was proposed by Hevner et. al. (2004). They proposed a framework for design science research, which provides guidance on how to develop and evaluate artifacts in the context of information systems and computer science. More specifically, the 7 step method (design as an artifact, problem relevance, design evaluation, research contributions, research rigor, design as a search process, communication of research) highlighted the need to incorporate applicable knowledge as well as the business needs within the development phase. Even though this method was initially developed for design research, it has also been used in the past by researchers to develop maturity models for Industry 4.0. For instance Schumacher et. al (2016) developed a maturity model for manufacturing enterprises in the field of Industry 4.0 with 9 core dimensions. The dimensions “Products”, “Customers”, “Operations” and “Technology” were created to assess basic enablers and the dimensions “Strategy”, "Leadership", Governance, "Culture" and "People" allowed the inclusion of organizational aspects into the assessment. More recently, Wagire et. al. (2020) utilized a multi-methodological approach that included the method by Schumacher et. al (2016). Their method included literature review, comparison of existing maturity models, expert's interview, creating the model, testing and validation. This approach allowed the creation of a model that is grounded based on theory and previous works, but also includes more practical considerations from experts in the field.

As such, based on the methodologies that where presented, the following systematic research approach with three core phases is followed to answer the research questions.

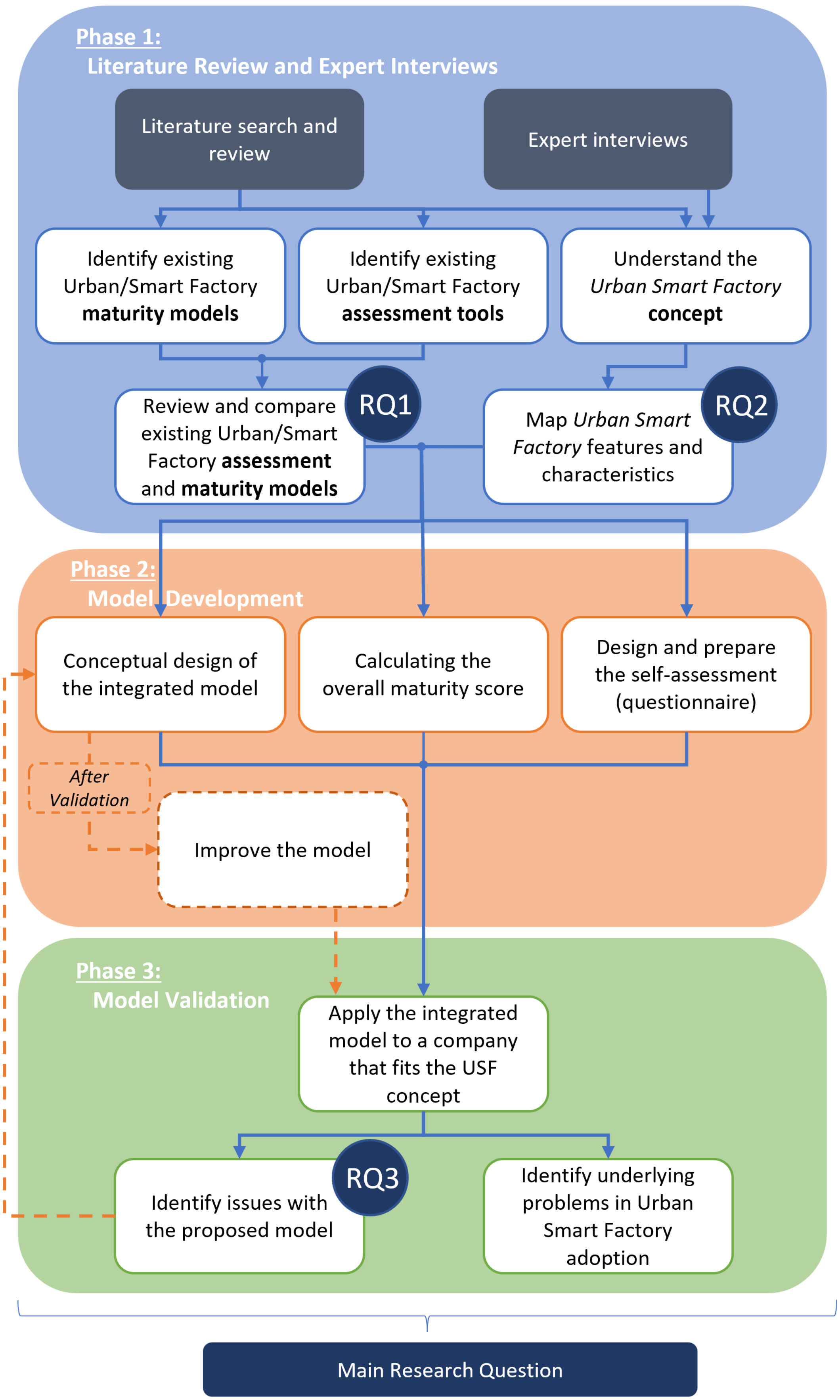

Figure 1: Research Methodology

Phase 1

Companies that want to thrive in the urban smart factory concept, first need to understand which capabilities are needed. Currently, even for the Industry 4.0 there is no consensus among practitioners as to which are the critical characteristics and features that need to be accounted for in terms of maturity models (Akdil et al., 2018; Wagire et al., 2020). Systematic literature reviews on the topic have attempted to solve this issue by grouping previous works (Mittal et al., 2018; Elibal & Özceylan, 2021). For this reason, the first step is to conduct a detailed literature review on previous works to assess the state-of-the-art assessment tools and maturity models that are close to the urban smart factory concept. The main purpose of this initial research is to identify the work that has been done in this field.

The maturity models and the assessment tools that are identified are explored, reviewed and compared thoroughly. By doing that, the methodologies that are used to develop the maturity models and assessment tools can be understood. By learning how these models are developed by different sources and assessing their fit to the USF concept, the process of developing the proposed integrated tool is better understood. Secondly, the dimensions and sub-dimensions of the models in the literature are categorized and mapped. Previous works by researchers in close fields such as the urban manufacturing and the smart factory are the starting points to develop the proposed integrated tool. A cross comparison of the models and their characteristics is made and a discussion of their advantages and disadvantages as well as their suitability for this study is done. Based on the information from the previous steps, it is be possible to understand what information regarding the USF is useful for the development of the tools. As such, the key features and characteristics of the USF are gathered based on similar works and expanded based on the requirements that were found.

Furthermore, it became evident during the literature review that there was a lack of comprehensive information on the topics of urban factories, smart factories, and urban smart factories. While the existing literature provided some foundational understanding of these concepts, it did not delve deeply into their complexities or practical aspects. Therefore, to address this knowledge gap and gain a more nuanced understanding, it was decided to conduct expert interviews with practitioners from the field. These interviews were deemed necessary to obtain practical viewpoints, identify underlying problems, and explore the emerging manufacturing paradigm of Urban Smart Factories (USF) more thoroughly. The chosen method for these qualitative semi-structured interviews was based on the work of A. Tong et al.(2007), which provides a checklist for detailed reporting of qualitative research, specifically in-depth interviews and focus groups. By engaging with industry experts, this research aims to bridge the gap between existing literature and practical insights, ultimately contributing to a more comprehensive understanding of USFs.

Phase 2

The second phase includes the development of the integrated model. Based on the information that is attained by the previous steps, it is possible to construct the integrated self-assessment and maturity model specifically for the USF. This has three key and interconnected steps. The first one is the development of the model's structure, including dimensions and measurement items. The maturity model has core dimensions, along with sub-dimensions as well as the maturity levels. At this step, each sub-dimension is explained in detail in the context of maturity models for companies. Based on this information it is also possible to develop a generalized strategic companies with each increasing level having increased implementations for each dimension. For each company, the importance level of the maturity items might be different. As such, the next step is to devise a method to flexibly adjust the importance weight of the items based on the needs and vision of each company. For this reason, a detailed explanation of how to measure the total maturity score is presented. Finally, based on the previous steps it is possible to design and prepare the self-assessment questionnaire. In order to simplify the process, the questionnaire is integrated with a spreadsheet software (Microsoft Excel). After the answers from the respondents are inserted into the spreadsheet, the numerical calculations are done automatically and the resulting graphs are displayed. This can help perform the self-assessment without the need of an external party.

Phase 3

The proposed integrated model is then validated through an implementation example in a company that fits the USF criteria and feedback from a representative from the company is received to improve the model and assess its practicability. Specifically, an expert from the company who has a holistic view of its operations is approached, explained of the purpose of the research and is asked to participate. After performing the assessment, the results are then sent back to the responsible researcher, for analysis. The analysis and conclusions of the assessment are then sent back to the expert and discussed during a feedback session. Based on their feedback, appropriate changes can be made to the model to improve its form and content. The focus is to evaluate the comprehension of the utilized concepts and terms as well as the questions that were asked in the questionnaire. The representative from the company is asked about the structure and flow of the evaluation instrument, its usability, and the assessment process. Finally, based on the results from the implementation example and the input from the respondents it is possible to answer the main research question in the discussion. Based on the analysis, conclusions are presented and future directives are proposed.

3 Phase 1: Literature Review and Expert Interviews

This section presents the findings of the literature review as well as the results from the expert interviews.

In the literature review sub-section, the methodology of searching and selecting research papers is explained. Then the urban smart factory concept and its characteristics are explained in detail. To do that the urban factory concept is analyzed first, and is followed by the smart factory concept analysis. Next, the definitions of maturity models as well as the assessment tools are explained, and examples from the literature are given. Key models that are relevant to this research are analyzed in more detail and their dimensions and sub-dimensions are presented. Moreover, the benefits of maturity modelling for companies is explained in detail. The concepts from the literature review are then summarized, and based on those a preliminary maturity model is created. In the expert interview sub-section, the method of conducting this qualitative research is explained and the selection of the interviewees is presented. Then, the questions that are asked in the interviews are presented thematically and a summary of the interviews is presented.

3.1 Literature review

3.1.1 Search and selection methodology

In order to conduct every stage of this research, a specific selection methodology is identified and used throughout this phase. This is based on the methodology that is followed by researchers that have done similar systematic literature reviews on topics close to this one (Elibal & Özceylan, 2021; Mittal et al., 2018). Firstly, the search was done in Scopus and the Web of Science. These two paper searching platforms are the leaders in their field were both used. In most cases the results were similar, and thus only one source was sufficient. Secondly, the search was based on certain selection criteria, which were used as a starting point for the search. The search terms that were used can be found on the Appendix (subsection A.1). These were then supplemented by the search terms presented in each step. The general selection criteria are the following:

Relevance: The results from the search should be relevant to the intended topic. In many cases the results also include papers that have the search terms inside, however the context is not the desired.
Year: From 2018. Since the search was done to identify the state-of-the-art, the latest papers are the most desired in this case. Key literature was used to retrieve useful information regarding the original definitions, however the current research gaps can only be identified by the latest papers. Papers close to the present day are therefore preferred. After that, by utilizing a waterfall approach it was possible to identify other key papers from an earlier date.
Number of citations: The results are then sorted based on the number of their citations. A paper with zero citations that was released several years ago might not be the best to use compared to similar with many citations.
Main research platforms: *Scopus* and *Web of Science*

This search methodology is meant to initially provide the state of the art in the relevant field. This starting point is then utilized to reveal other useful papers. Two methods are used to achieve that. First, key papers that are cited within those papers are taken into consideration and are studied even if they were published before 2018. Secondly, to confirm whether or not the research gaps have been filled by other authors, the "cited by" section in Scopus was used. By consulting this method other key, and even more recent publications can be derived. A detailed search history, that includes the process that led to the final research topic can be found in the Appendix (subsection A.1). In summary, the total number of identified papers as well as the number of the included papers in the literature review, grouped into the core themes, is presented below.

Table 1: Number of identified and included papers in the literature review

	Number of identified papers	Number of included papers
Urban factory	1.603	10
Smart factory	36.825	9
Urban smart factory	1	1
Maturity models and assessment frameworks	1.472	20

3.1.2 Urban Smart Factory

Urban Factory

The term urban factory describes a factory that is located in the urban environment. A factory is a place where value is created and has inputs that are transformed into outputs. The inputs are materials, energy and information, and the outputs are products, by-products, waste and emissions (Herrmann et al., 2020). The difference and the potential of the urban factory, when compared to a conventional factory, is the impact of these flows on the urban surrounding. In other words, the inputs and the outputs can come from, or be directed to the city, and thus promoting a more sustainable circular economy model. Moreover, due to its proximity to the potential customers, the urban factory unlocks the possibility of a high degree of customer involvement in all the stages of production. Some other benefits of the USF include the the ability to provide more customizable products, with lower lead time, improved supply chain and reduced production time and cost (Herrmann et al., 2020, p. 783). Recently, numerous authors have utilized this concept of urban production due to its potential contribution to the sustainable development of cities (Herrmann et al., 2020; Juraschek et al., 2018; Kreuz et al., 2020). Key research contributions present different perspectives on the urban factory, which can together build a more comprehensive picture.

Herrmann et al. (2020) presented the state of the art, as well as, the future trends for the urban factory. In the paper, they explored in detail the key technologies and methods that enable urban production. Moreover, they presented various case studies showcasing the concept of such a factory. Overall, this paper combined a lot of the work that has been done to develop and refine the urban factory concept, and managed to present an overall picture of the latest developments. The authors presented the idea that the urban factory can be thought of as a city-factory-product nexus, as it can be seen on Figure 2. This intertwined relationship between the three, often results in contradicting needs. For instance, they mentioned that there is a “contradictory degree of interest between a factory system and the surrounding urban neighborhood” (2020, p. 767). This is obviously the case and should be considered when designing such a system. This and several other conflicts, were then presented and understood in order to build a holistic framework. The key takeaway of the paper, however, is the clustering of the requirements and the key action areas that were identified. These are the following: technology, factory operation, site and construction, economy and business strategy, environment, society as well as logistics and mobility.

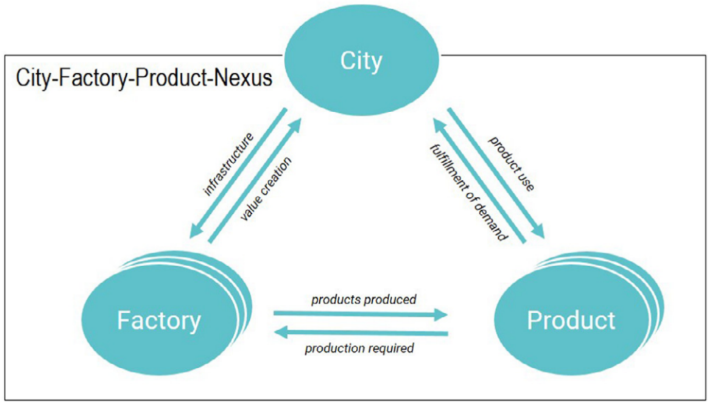

Figure 2: City-factory-product nexus as common reference system for urban production (Herrmann et al., 2020)

A completely different approach to identify key action areas regarding the urban factory was taken by Juraschek et al. (2018). Since a main problem of the urban factory concept is the perception of the negative environmental impact of industrial areas, the authors aimed at identifying the potential contribution of urban factories in relation to the Sustainable Development Goals (SDG). To achieve that they identified and categorized the characteristics of the urban production systems and they matched them to the SDGs and their corresponding targets. Based on this methodology, key action areas were able to be identified, through which these production systems can support cities and mutually benefit. More specifically, the sustainability development goals 8, 9 and 12 (decent work and economic growth, industry innovation and infrastructure, responsible consumption and production) where singled out as the urban factory could have a high contribution potential to them (Juraschek et al., 2018, p. 75). For instance, for SDG 8, they mentioned that these factories can enable a high quality of working conditions, if they are properly integrated with the urban environment. What is interesting to note here is that the intended result was similar in the previous two cases, however the methodologies that were utilized were different, resulting in a more comprehensive picture.

Kreuz et al. (2020) presented a different design approach for the urban factories . They argued that research on urban factories mainly has two objectives. Firstly the negative impacts of the factories must be minimized and secondly the potentials of the urban areas must be utilized for the factory. To achieve these objectives, an interdisciplinary approach of examining the city-factory system is needed, as argued by the authors. Based on this notion, the disciplines of production engineering, industrial building and architecture, logistics and transport, energy design, and urban planning and development, were singled out, as they play a critical role in these objectives. Interestingly, however, the authors focused on the city-factory system, and not on the city-factory-product nexus, which was presented by Herrmann et al. (2020). It could be possible that by including the product in their analysis, a more complete outlook could be derived. This could possibly also be an opportunity for future research.

Another interesting study tried to assess whether agglomeration of urban producer services promote carbon efficiency of the manufacturing industry (Liu, Zhang, & Sun, 2022). The results revealed that in this case carbon efficiency is improved, through scale, technology spillover and competition effects. As such, moving industrial complexes closer together and within cities can also have various positive side-effects, which could improve the production, leading to even more economic benefits for the city.

There are drawbacks though, when trying to make or unmake space for urban manufacturing as stated by Bonello et al. (2022). Through their research, it was revealed that various conflicts concerning co-habitation of residential and productive functions can arise. Another drawback, as explained by the authors, is that there is a potential exclusion of the lower skilled workforce from the development processes, as the innovative industries are replacing the traditional manufacturing activities. Based on those, the authors propose policy action that can help mitigate and deal with those issues. Co-creation initiatives and micro-zoning, where highlighted as strong solutions to deal with those drawbacks. By basing the development on action research, that can blend a top-down with a bottom-up approach and is focused on local actors it is possible to create co-development opportunities, which are mutually beneficial. This paper provides some interesting insight on the problems integrating manufacturing to the urban environment and help enrich the understanding of the urban factory concept and characteristics.

Overall, the literature on the urban factory concept, in its recent interpretation, has managed to create a comprehensive understanding of the characteristics, the technologies, the benefits as well as the issues involved. A combination of these information provides value in developing both maturity and assessment models. Since this concept is relatively recent, a lot is still left to be researched regarding the topic. Specifically, the actual transition of factories towards the urban context has not yet been studied in real case studies. The current static assessments lack the transitional effects and impacts, which could prove invaluable for a more complete understanding of the urban factory.

Mapping Urban Factory Characteristics

The following table presents the key characteristics from the literature regarding the urban factory concept. This information will be utilized to enrich the key features and characteristics of the urban smart factory and from that a relevant dimension will be created for the maturity model.

Table 2: Urban factory key features and characteristics based on literature

No	Paper Name	Author	UF Key Characteristics
1	A Conceptual Definition and Future Directions of Urban Smart Factory for Sustainable Manufacturing	(Sajadieh et al., 2022)	Human-Centric (customer, employee, communities) Sustainable (Environmental, social, economy) Resilient (Internal external adversity)
2	Urban production: State of the art and future trends for urban factories	(Herrmann et al., 2020)	Customizable products Lower environmental impact Shorter lead times
3	Urban production – A socially sustainable factory concept to overcome shortcomings of qualified workers in smart SMEs	(Matt, Orzes, Rauch, & Dallasega, 2020)	Integration of market and customer Constant production of new ideas Flexible working hours Working close to home Age-appropriate work in the city of tomorrow
4	Urban factories: Industry insights and empirical evidence within manufacturing companies in German-speaking countries	(Burggräf et al., 2019)	Integration of working and living Proximity to local employees Local Integration
5	Urban Factories and Their Potential Contribution to the Sustainable Development of Cities	(Juraschek et al., 2018)	Sustainable Industrialization Active components of the city Promoting responsible consumption patterns Build resilient infrastructure Allows high quality working conditions

Smart Factory and Industry 4.0

In the past decades, the manufacturing industry has been affected by the latest technological trends of digitization and automation. This has lead to a transition often called Industry 4.0, which is closely related to the factory of the future and the smart factory. This transition offers the manufacturing industry transformational opportunities and challenges, impacting various organizational aspects (Hughes et al., 2022). Usually cited technologies associated with the smart factory include cyber-physical systems (CPS), digital twins, big data analysis, industrial internet of things (IoT), mixed reality (MR), autonomous robotics and additive manufacturing. These, and many more technologies, enhance the abilities of the factories enabling opportunities that were previously not possible. Some design principles of the smart factory that have been mentioned by the literature are interoperability, modularity, virtualization and decentralization (Hughes et al., 2022). Lately, Industry 4.0 has become a topic of interest for dozens of researchers. For the purpose of this literature study, the focus is given more on the papers aimed on sustainable manufacturing opportunities within the Industry 4.0.

Garetti & Taisch (2012) highlight that the behavioural models in all sectors of the society must be changed to adhere to the finite re-generational capabilities of the environment. Manufacturing especially, being a central pillar in today's society, which is strongly tied to the older paradigms, should be carefully adjusted to more sustainable production processes. In the paper, which was published in 2012, the role of Information and communications technologies (ICT) is already being stated as a key enabler. Numerous papers have stepped upon this concept, in an attempt to strengthen the relationship between Industry 4.0 and sustainability. The paper by Stock et al. (2016) aimed at giving a comprehensive understanding of this connection by presenting a micro and a macro perspective of the Industry 4.0. They suggested that the macro perspective covers the horizontal integration as well as the end-to-end engineering dimension of Industry 4.0. On the other hand, the micro dimension covers the horizontal integration as well as the vertical integration within smart factories. In their work, they presented in-depth visual representations of these perspectives. Even though the opportunities that resulted from this research were a solid basis for understanding the new production paradigm, it still missed the critical role of success factors.

This gap was filled later on by Jabbour et al. (2018) who presented an integrated framework that help understand the synergetic effects between Industry 4.0 and sustainable manufacturing. The framework includes twelve research propositions, which can be seen on Figure 3. The framework in this work is a key stepping stone in understanding how emerging industrial trends, can work in a collaborative manner, and how the critical success factors can become either opportunities or risks. This concept can also be applied on the synergy between the urban and the smart factory, to create the urban smart factory. Their research followed a qualitative assessment of previous works on the subject, a discussion on the critical success factors and the development of a framework capable of systematising previous debate on the topic. This was one crucial first step of integrating the fields of Industry 4.0 and sustainable production.

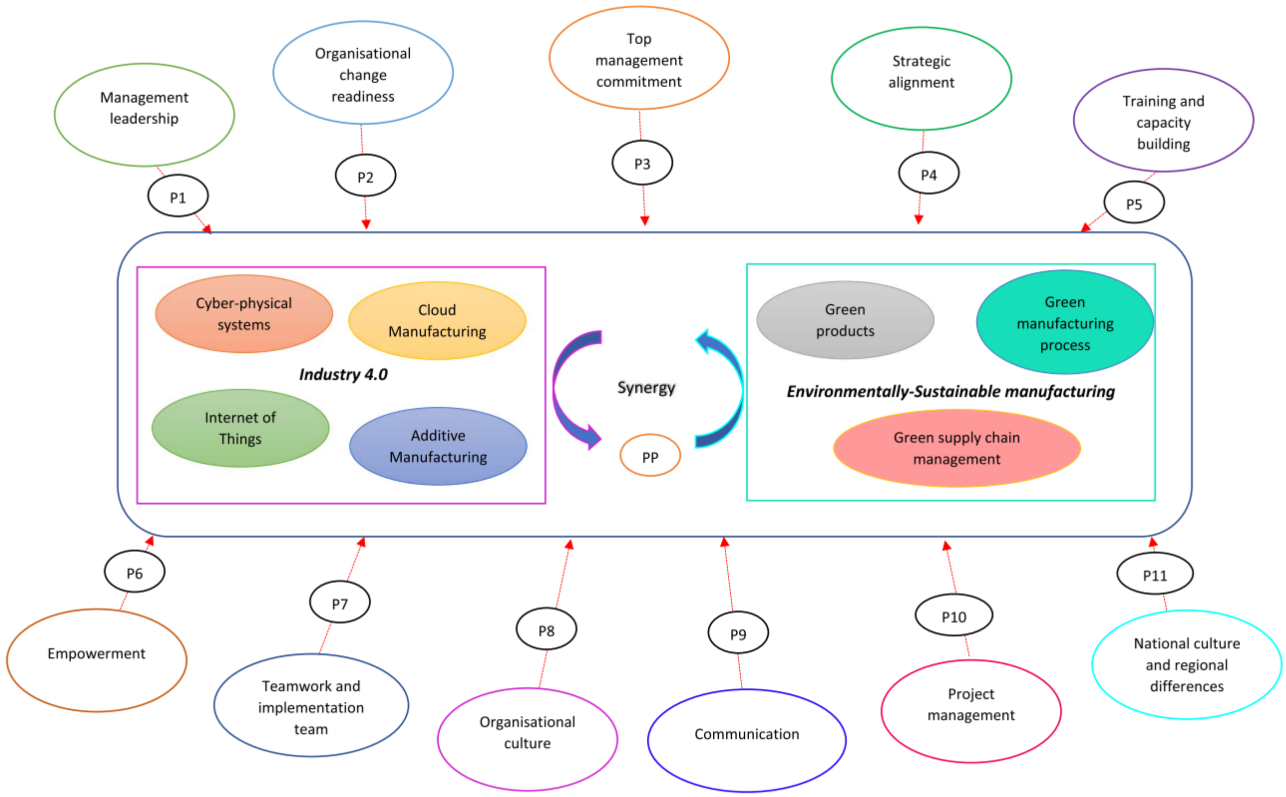

Figure 3: Framework for understanding the synergy between Industry 4.0 and environmentally-sustainable manufacturing. To achieve this synergy the authors proposed 11 critical success factors (outer bubbles), and for each one they created a research proposition (P1-P11), as an agenda for future studies (de Sousa Jabbour et al., 2018)

More practical papers have also been published in the past decade. For instance Jamwal et al. (2021) developed a framework for Micro Small Medium enterprises, that explained the key enablers to sustainability in Industry 4.0, as well as their relationship. In this study key enablers were identified and validated through a case study analysis. The these enablers include economic, supply chain, information and technology, environmental, as well as organization and social. The effect that each enabler has on the others can be seen on Figure 4. As it can be seen from the diagram, information and technology play a central role in the relationship with the other enablers. By focusing on this aspect it, is possible to improve the other enablers as well. The understanding of this field can be enriched by the research of Hughes et al. (2022) that study the barriers and challenges to the implementation of smart technologies in the manufacturing area. Three key challenges that were highlighted, are the uncertainty due to the emerging markets, the challenges which stem from the attemp to alighn Industry 4.0 with the SDGs and the difficulties that emerge in the transition to Industry 4.0. More interestingly, however, the authors also attempted to align their framework with the UN Sustainability goals, as was done in a similar manner by Juraschek et al. (2018) in a different setting. The research done by these, and many more authors, is crucial in understanding interconnection of Sustainable Manufacturing and Industry 4.0, however they have not considered the untapped potential of coupling it with urban manufacturing. To fill this gap, a new manufacturing paradigm called the "Urban Smart Factory" was proposed by Sajadieh et. al. (2022), which will be analyzed in the following sub-section.

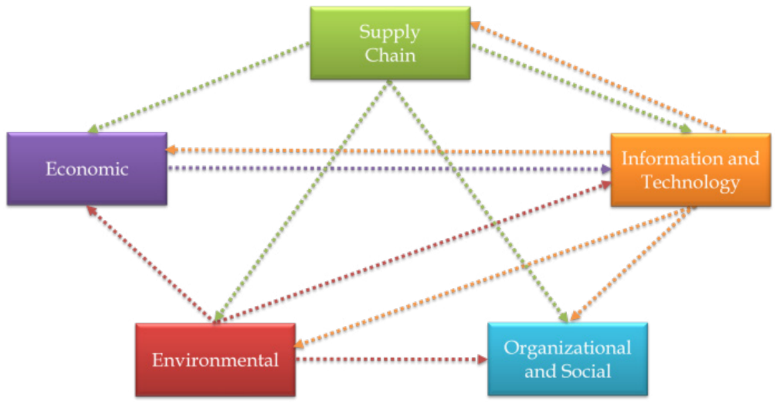

Figure 4: Casual relationship diagram for the main enablers criteria (Jamwal et al., 2021)

A new manufacturing paradigm: The Urban Smart Factory

The paper titled *"A Conceptual Definition and Future Directions of Urban Smart Factory for Sustainable Manufacturing"*, presents a new production paradigm that integrates the smart factory and urban manufacturing (Sajadieh et al., 2022). In the study, it is proposed that the use of smart manufacturing technologies in urban factories can reap greater benefits while dealing with its challenges. The authors define the Urban Smart Factory (USF) based on four main pillars: personalization, sustainability, resilience, and smart factory. These pillars encapsulate the key characteristics of the USF and are crucial in understanding its value within the context of Industry 4.0 technologies. Moreover, they present the key characteristics of the USF and explain their benefits in detail. A table summarising and explaining these characteristics can be found in Figure 5.

Characteristic	**Category**	**Description**
Human-Centric	Customer	Personalization of product/service through co-creation
	Employee	Workplace well-being, lifelong education, etc.
	Communities	Close collaboration, education, open innovation, etc.
Sustainable	Environmental	Minimizing emissions/pollutions, Resource and energy efficiency
	Social	Customer/employee/citizen well-being
	Economy	Value creation, new business model development
Resilient	Internal adversity	Wrong decision-making, equipment failure, strike, etc.
	External adversity	Political issues, natural disasters, regulations, etc.

Figure 5: USF Characteristics (Sajadieh et al., 2022)

Even though the introduction of this novel concept was achieved in this paper, still, much is left to be accomplished to get a well rounded understanding. This should be done similarly to what was presented related to the smart factory and the urban factory in the previous sections. To that end, the authors presented various recommendations for future research in this novel field. One of them was to develop a maturity model for its step-by-step continuous realization. Additionally, especially crucial, as noted by the authors, was that a customizable assessment model should be developed. Following the proposal by the authors, the development of the models will be attempted.

3.1.3 Maturity models

Maturity models are tools that businesses use to achieve their strategic goals. Specifically, they are used to measure the current starting state, and to plan the future desired state, by identifying which transformational capabilities should be developed (Santos & Martinho, 2020, p. 1023). The maturity of a company can be measured qualitatively or quantitatively, in a continuous or a discrete manner (Wagire et al., 2020). For instance, Sari et al. (2020) utilized a mixed-method approach, which combined several qualitative and quantitative methods. These methods included interview, systematic literature review, content analysis and questionnaires. The results of which are then used to create domains, sub-domains and maturity levels to help assess the position of the company. Normally, the higher the maturity level, the closer the company is to its specified objectives. The final step of the maturity model is to include a roadmap that can guide a company specific directions, based on its maturity level. Usually, after the development of the model, a validation process takes place through case studies of relevant companies (Çınar et al., 2021).

A variety of maturity models has been developed in the past years in the context of smart manufacturing and Industry 4.0. Sjödin et. al. (2018) presented a maturity model for the implementation of the smart factory, which was built around three core principles: cultivating digital people, introducing agile processes, and configuring modular technologies . These principles were used to distinguish between four maturity levels. A graphical representation of the model can be found in Figure 6. This maturity model has 3 dimensions (People, Process, Technology) and four maturity levels (1-4). By implementing the three smart factory principles (dimensions) it is possible to improve the maturity level, and reap the potential benefits, as it can be seen on the figure. Even though the model can provide a good insight related to the implementation of smart factory technologies, it lacks the depth of distinguishing between the different core principles. Specifically, similar maturity models for smart factories tend to have around 30 sub-dimensions so that a comprehensive assessment of the factory can be made.

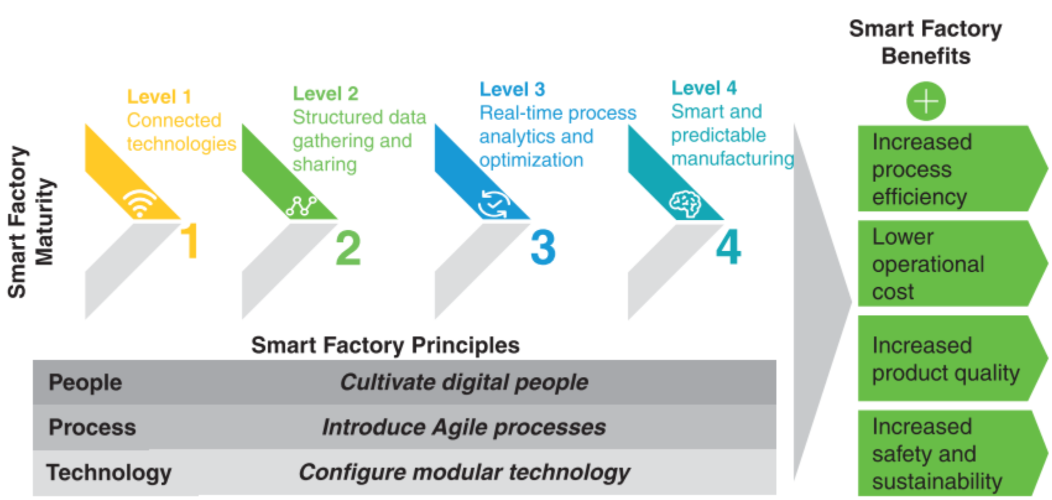

Figure 6: Key principles of smart factory implementation. (Sjödin et al., 2018)

For instance, Santos et. al. (2020) presented a model for Industry 4.0 maturity with 41 variables and 5 core dimensions (organizational strategy, structure and culture; workforce; smart factories; smart processes; smart products and services). It is evident that even though the two models have some similarities in the higher level of dimensions, in reality they have key differences. They both consider people, process and technology key principles (even though they use slighlty different terminology), however the model by Santos et. al. (2020) provides much more depth by having sub-dimensions, allowing for a more precise measurement of the high level dimensions. This highlights that there is yet to be a consensus regarding how these models should be developed. Lastly, the model of Gökalp introduced two main dimensions (process, capability) to measure maturity for digital transformation (Gökalp & Martinez, 2021). The process dimension is split into 26 processes defined under 4 process dimensions: strategic governance, digital process transformation, workforce management, and information and technology management. These can be seen on Figure 7. The capability dimension, has six levels (incomplete, performed, managed, established, predictable, innovating) and six maturity levels (from 0 to 5). This highly complex model also includes a roadmap of actions that need to be made based on the maturity level achieved.

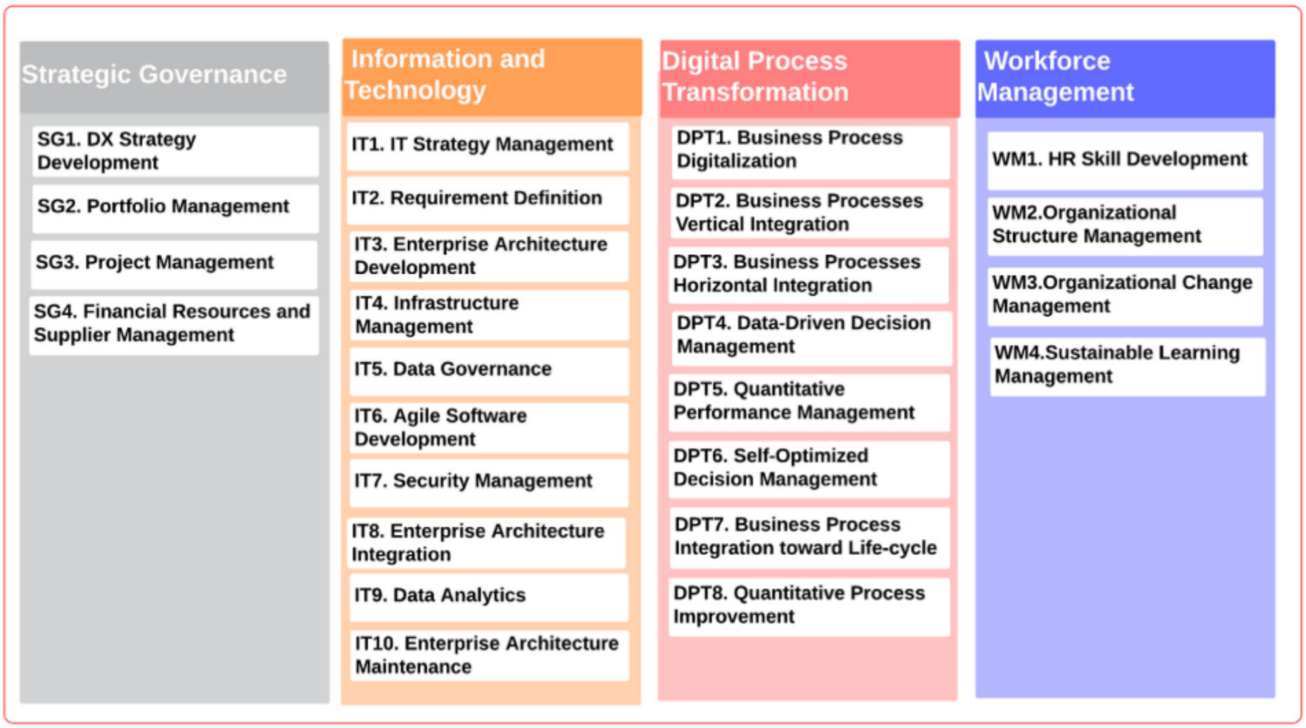

Figure 7: Process Categories from the maturity model proposed by Gokalp et. al. (2021)

Out of this analysis, it is evident that based on the specific implementation goal of its model, the dimensions are adapted accordingly. In that sense, the differences between smart factory, Industry 4.0 and digital transformation, even though they are subtle, they are enough to warrant differences in the maturity models. As such the importance of understanding the topic of application in depth is exemplified.

Another useful work is the one by Hizam-Hanafiah, who explored 158 model dimensions out of the existing literature on Industry 4.0 maturity modelling (Hizam-Hanafiah et al., 2020). From these, six dimensions were suggested to be the most important: Technology, People, Strategy, Leadership, Process and Innovation. These can, and have been, used for maturity modelling in related fields, and can be a starting point for the urban smart factory. Lastly, Mittal et al. (2018) revealed a crucial research gap that is commonly found in this field. The authors noted that "there is a disconnection between maturity models and self-assessment readiness-tools" (2018, p. 210). Specifically, they mentioned that these models are generally developed separately and that there is not direct connection between the two, which could be highly beneficial for the intended users. In other words, the maturity and self-assessment models should be developed together and be directly connected in order to maximize their utility.

Finally, to develop a maturity model the sub-dimensions must fully encompass the respective dimension and must be separate from each other. This principle is known as Mutually Exclusive and Collectively Exhaustive (MECE) (MBA Crystal Ball, 2018). It can help structure information in a way that is clear, comprehensive, complete, and covers every element in an non-overlapping manner. This framework is generally used by consulting companies to structure large sets of information, but it can also be used in this case. By categorizing the sub-dimensions in a MECE manner it is possible to incorporate every aspect of the urban smart factory into a maturity framework in a way that the concepts are overlapping. That is especially useful when creating the assessment in a form of a questionnaire, as the assessment questions should be structured clearly and concisely.

Comparison of Existing Maturity Models

The first step was to map the information from the literature that could help develop and design the maturity model. To achieve that the most relevant maturity models were selected that resulted from the literature review. The selected maturity models were as close as possible with the urban smart factory concept and they were highly cited. To add to that older models that have already been improved by other authors were not included. The relevant information that was collected were the maturity levels, dimensions and sub-dimensions. The key points that each model is doing well or requires improvement are also explained. This is important as this information will be utilized in the development of the proposed maturity model. The result were the eight models that are presented below.

Table 3: Existing maturity models dimensions, maturity levels and key points mapping

Model Name	Number of Maturity Levels	[Dim, Sub-dim]	Dimensions	Key points
Smart Manufacturing Readiness-Maturity Model for Small and Medium Enterprise (Rahamaddulla, Leman, Baharudin, & Ahmad, 2021)	5	[4,0]	• Machine • Management • Man • Method	By incorporating the external factory, a more complete understanding is allowed. This model is too simple to be used in a detailed maturity assessment, as it lacks the depth of the sub-dimensions.
Maturity model for smart factory implementation (Sjödin et al., 2018)	4	[3,0]	• People • Process • Technology	The proposed 3 dimensions are indeed central to many maturity models. However, this model is too simple to be used in a detailed maturity assessment.
Maturity model for assessing the implementation of Industry 4.0 (Wagire et al., 2020)	4	[7,47]	• People and culture • Industry 4.0 awareness • Organisational strategy • Value chain and processes • Smart manufacturing technology • Product and services oriented technology • Industry 4.0 base technology	The model incorporates the ability to give weights to the sub-dimensions, which is important since different companies have different strategic goals. The assessment framework has a good correlation between the sub-dimensions and the measurement items for the questionnaire. Some of the proposed dimensions have overlap.
Digital transformation capability maturity model (Gökalp & Martinez, 2021)	6	[4,25]	• Strategic Governance • Information and Technology • Digital Process Transformation • Workforce Management	The dimensions are diverse, do not overlap, and their sub-dimensions offer a sufficient depth for assessment. It lacks, however, a self-assessment tool for companies to use on their own.
Industry 4.0 maturity model (Santos & Martinho, 2020)	6	[4,25]	• Organizational strategy, structure and culture • Workforce • Smart factories • Smart processes • Smart products and services	The dimensions are diverse, do not overlap, and their sub-dimensions offer a sufficient depth for assessment. It also includes a self-assessment for companies.
Maturity and Readiness Model for Industry 4.0 Strategy (Akdil et al., 2018)	4	[3,31]	• Smart products and services • Smart business processes • Strategy and organization	Workforce/people dimension, which is key to the other models, is not focused. The technology dimension is analysed thoroughly in the model.
Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises (Çınar et al., 2021)	5	[4,30]	• Factory 4.0 • Logistics 4.0 • Operator 4.0 • Management 4.0	The dimensions are diverse, do not overlap, and their sub-dimensions offer a sufficient depth for assessment. The proposed hierarchy level for the maturity level distinction allows for a more detailed analysis.
Corporate sustainability maturity model for readiness assessment (Sari et al., 2020)	5	[5,29]	• CS driver (external) • CS driver (internal) • CS strategy • CS action • CS performance	The model focuses on the corporate strategy and not on Industry 4.0. The dimensions are diverse, do not overlap, and their sub-dimensions offer a sufficient depth for assessment.

From the research and the mapping of the dimensions a few conclusions can already be derived. Firstly, there are numerous maturity models for the Industry 4.0, however none for the urban factory. This highlights the need to utilize the input of an expert that is knowledgeable regarding the urban factory and is preferably working within one. The number of maturity levels varies between 4-6, but is mostly around 5. The number of maturity dimensions fluctuates between 3-7, but is mostly close to 4. As for the number of sub-dimensions, it is around 25-47, however it is mostly less than 30. Regarding the key dimensions that are used by the different research teams, it is evident that Technology, Workforce, Strategy and Products/Services are the most relevant, even if they are cited by a different name. For instance, an example of such a similarity are the following dimensions: Strategic Governance, Organizational strategy, structure and culture, Organisational strategy. On the other hand, in some cases researchers split dimensions in a way that there is an overlap between them, which is something that should be avoided. For instance the model by Cunar et al. (2021) uses the dimensions Smart factories, Smart processes, Smart products and services, which have overlap in their sub-dimensions. A table with the sub-dimensions can be found in the Appendix subsection A.2.

Based on the information that was collected, it was possible to map the dimensions by grouping them based on their relevance. This can help understand which are the dimensions that most researchers are using in their models, even if they give slightly different names for them. In addition it is possible to assess which dimensions have overlap, especially if their sub-dimensions are assessed, in order to avoid it in the development of the proposed model. Based on that, the Table 4 was constructed.

Table 4: Grouping and comparison of key dimensions of existing maturity models

Technology	**Strategy and organization**	**Workforce**	**Process**	**Smart products and services**	**Other**
Machine	Strategic Governance	Man	Smart processes	Product and services oriented technology	Industry 4.0 awareness
Smart manufacturing technology	Organizational strategy, structure and culture	People and culture	Smart business processes	Smart products and services	Method
Industry 4.0 base technology	Organisational strategy	Workforce Management	Value chain and processes	Logistics 4.0	
Information and Technology	Management 4.0	People	Digital Process Transformation		
Smart factories	Management	Operator 4.0			
Factory 4.0					

From this table it can become more clear that some dimensions are used by most research teams (Technology, Strategy, Workforce, Process, Smart Products and Services). On the other hand, some outliers were identified that do not clearly fit with the maturity model (Industry 4.0 awareness, Method), which can instead be used as sub-dimension. Moreover, the two dimensions *Process* and *Smart Products and Services* seem to have quite an overlap in general and for this reason it might be better to group them. From this analysis, it is also evident that the smart factory concept is sufficiently covered by the existing maturity models in the literature. However, this is not the case for the urban factory, for which no maturity model has been developed. As such, the mapping of the urban factory characteristics that was presented in subsubsection 3.1.2 is key in developing the maturity model for the urban smart factory.

3.1.4 Assessment tools

For the assessment tools there has also been a research interest in the past years. These tools are typically done before a company starts its transformation process, while the maturity model is used in the process of adoption (Rahamaddulla et al., 2021). The assessment is generally done in the form of a questionnaire and is meant to measure the dimension and sub-dimensions of the maturity model, through the items (questions) on the survey. It is important that the questions correlate highly with the measured sub-dimensions in order to get a representative and accurate result. Self-assessment readiness models have gained increased interest as they allow companies to perform the evaluation without needing an outside consultant (Mittal et al., 2018). Examples of such models can be found in the papers about maturity models that were presented in the previous sub-section. Two notable examples are the ones by Akdil et al. (2018) and Cinar et al. (2021). Akdil et. al. (2018) developed a self-assessment readiness tool in the form of a questionnaire, that can be used by any company on its own, thus answering to the need highlighted by Mittal et al. (2018). Questions such as "*Does your company have partnerships for Industry 4.0 projects with following options?*" and "*How often do you conduct a cost/benefit analysis for Industry 4.0 investment?*" were presented in their questionnaire. Çınar et. al. (2021) developed both a maturity model and a readiness framework at the same time, even though it was not meant for self-assessment. The highly detailed maturity model that was proposed has four dimensions (Factory 4.0, Management 4.0, Logistics 4.0, Factory 4.0), five levels (1-5), 60 second-level dimensions, and 246 sub-dimensions. Part of the framework structure is presented on Figure 8. This is in contrast with other models that are much more simple in their classification, such as the one by Sjödin et al. (2018), who only included three core principles (see Figure 6).

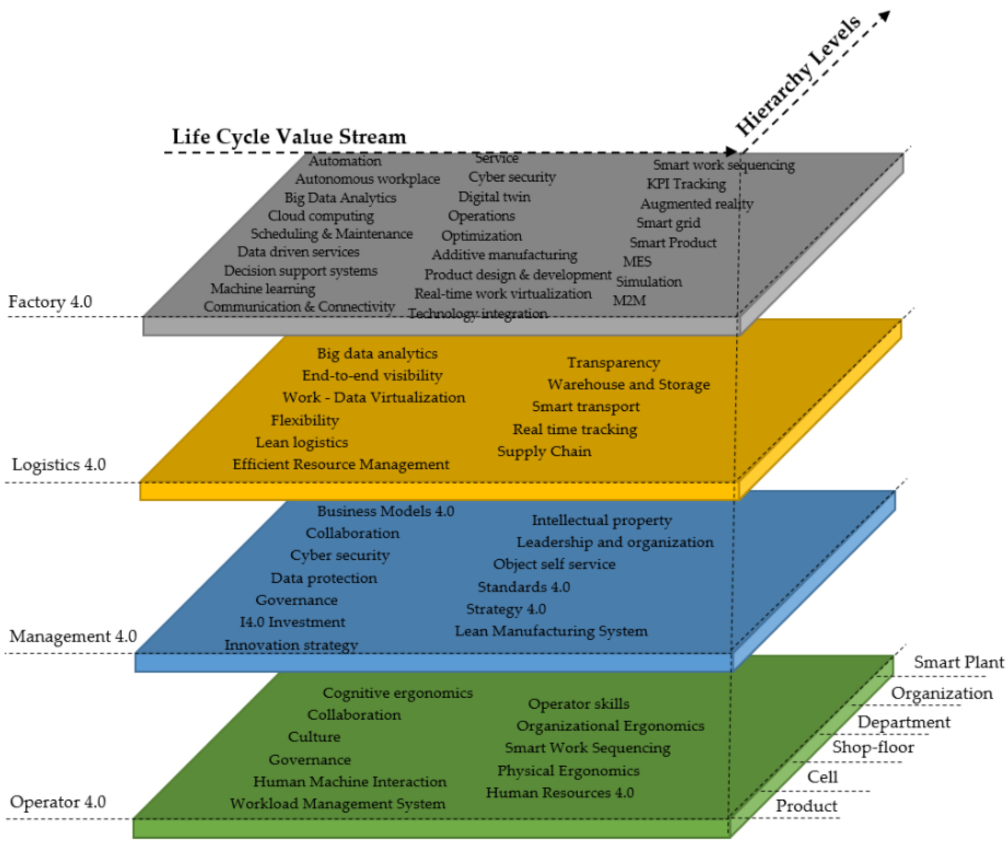

Figure 8: Framework structure as presented by Cinar et. al (2021)

Existing literature also supports the fact that each dimension that is part of the assessment tool might have different weight based on the needs of the company (Schumacher et al., 2016). A part of the assessment therefore should also include the strategic vision and needs of the company in order to have more useful and personalized outcome. For instance, Wagire et. al. (2020) utilized the multi-criteria decision-making technique Fuzzy Analytic Hierarchy Process (FAHP) to calculate the weights of the maturity items. The methodology allows to take the priority input from the experts and then calculate the weights of the items. The result from the questionnaire is therefore a map of all the dimensions and sub-dimensions and their scores along with the final maturity level. An example can be seen on Figure 9.

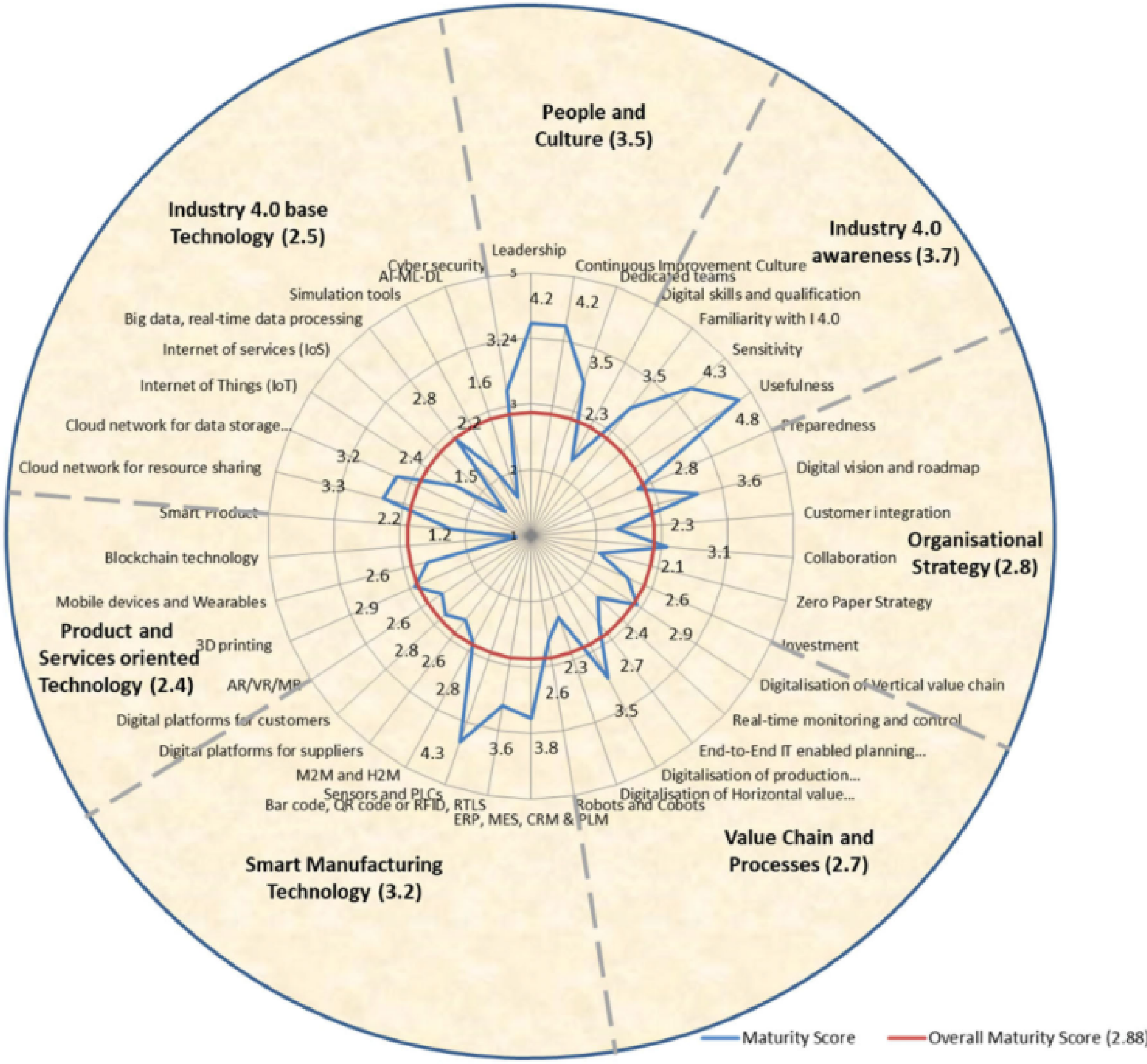

Figure 9: Example of a maturity score map from the model by Wagire et. al. (2020)

Overall, from this type of assessments that were presented a few conclusions can be made. First of all, when developing such assessment the clarity of terms used and the structure of the model are crucial. That is because the assessment should have a clear flow that the companies can follow to complete the questionnaire. By including terminologies that are too complicated or by making the model too convoluted, it is possible that assessment might not yield the desired results. This is especially in the case that the assessment is designed in the form of a self-administered questionnaire. In this case the questionnaire must be created in a way that a representative from the organization can complete it without the need of external assistance. Moreover, there is a clear need of developing the maturity model along with the assessment. That is because when developed together, the visualization of the results of the assessments can also be considered from the ideation. For instance maturity models such as the one that was developed by Cnar et. al (Wagire et al., 2020) (see Figure 9) can visualize the results of the assessment in an easy to understand manner.

3.1.5 Benefits of maturity assessment for Urban Smart Factories

It is important to understand what is the end goal of a company or an organization that is using maturity models or assessment frameworks. In the case of urban smart factories, the focus is generally to improve the integration of smart manufacturing and blend in better with the surrounding urban environment. These, however, are just the first level goals for such factories. The end goals of using such models in this case, as found in the literature are three: becoming more **profitable**, more **sustainable** and **resilient** (Fraser et al., 2002; Correia et al., 2017; Hernantes et al., 2019).

In past decades a vast number of maturity models have been created that can offer organizations an effective possibility to measure the quality of their processes (Wendler, 2012). The processes and the goals of each company can differ significantly from case to case, however one of the most usual goal is profitability. Maturity models allow a company to get better at what they do, by understanding their current capabilities and providing a roadmap to increase their efficiency (Röglinger, Pöppelbuß, & Becker, 2012; Fraser et al., 2002). Since profitability of a company is affected by its efficiency, it is possible to indirectly improve the profitability of the company (Alarussi & Alhaderi, 2018). Aside from that, there have been several maturity models that have focused on improving the sustainability of a company. For instance, Correia et. al (2017) reviewed 11 maturity model for supply chain sustainability that aim to understand the Triple Bottom Line and environmental dimension (eco-design and new product development) of companies. As such, companies that use such models, can drive their processes to improve in a way that they become more sustainable in the people, planet and profit perspective. Finally, maturity models can also focus on making companies more resilient to external and internal adversities. For example, Hernantes et. al (2019) created a maturity model for operationalizing resilience. The framework is focused on giving cities a roadmap towards building resilient ecosystem. Even though this framework is not focused on companies, it showcases that maturity models are also used for this purpose. As such, when talking about urban factories that are part of cities, it is important to also make sure that they are integrating their processes with the nearby environment in a way that they are improving the resilience of the whole system.

3.1.6 Summary of concepts in the literature

In the following table the concepts that were presented in the literature review are summarized.

Table 5: Literature concept summary

	Literature Review Concepts	Analysis in the chapter
1	Urban Factories	• Definition • Components • Opportunities/Challenges
2	Smart Factories	• Definition • Components • Opportunities/Challenges
3	Urban Smart Factories	• Definition • Characteristics
4	Maturity Models	• Definition • Comparison of existing models in the literature
5	Readiness Assessment Models	• Definition • Comparison of existing models in the literature

Key literature findings and input for the expert interviews

Based on the information that was gathered from the literature regarding the maturity models for smart factories and the mapping of the urban smart factory concept it is possible to create a preliminary structure of the concepts that describe the USF concept. Note that at this stage, the input from the experts has not been included yet. After composing this preliminary structure and consulting the experts the concepts were refined and organized in a more clear manner, as it will be explained in subsection 4.1.

Table 6: Preliminary dimensions and sub-dimensions of the maturity model

Technology	**Workforce**	**Strategy and organization**	**Process, products and services**	**Urban integration**
Supporting technologies	Continuous improvement culture	Technology investments	Smart products	Sustainability
Smart manufacturing	Dedicated teams	Digital vision and roadmap	Interoperability	Resilience
Industrial cyber security	Digital skills and qualification	Strategic collaborations	Integrated Business processes	Employee benefits
Information Technology (IT)	Sustainable learning management	Industry 4.0 Awareness	Value chain processes	Customer benefits
Operational Technology (OT)	Leadership innovation openness and change responsivity	Innovation management	Digital platforms	Societal integration

To develop a maturity model it is necessary to fully understand the specific field that it is being applied (de Bruin et al., 2005). In this case, the field of application is the urban smart factory, which has only been cited by one source up until now (Sajadieh et al., 2022). Even though, their work introduces the topic, a more comprehensive analysis is required. As it was showcased in this section, there have been several works on maturity models for Smart factories and none for the urban factory specifically. It is therefore imperative, to enrich the understanding of the urban smart factory as a whole concept, beyond the literature review. For this reason, expert interviews should be conducted with the intention of filling the following conceptual gaps that are presented in the following table.

Table 7: Input for the expert interviews

	Conceptual gaps that should be filled by the expert interviews
1	The Urban Smart Factory concept is not fully understood
2	The benefits and the challenges of integrating a smart factory inside the premises of the city should be explored
3	A comprehensive distinction of the concepts that characterize the Urban Smart Factory should be made
4	The relevant aspects of the Urban Smart Factory that are needed for developing a maturity model should be identified and organized in a consise and clear manner

3.2 Expert interviews

To develop the maturity model for the urban smart factory, it is crucial to obtain a comprehensive understanding of its integration within the urban environment. However, as it was presented in subsubsection 3.1.6 there are several gaps in the literature related to this topic. Therefore, conducting interviews with experts who are actively involved in factories closely aligned with the concept of the urban smart factory can play a pivotal role in bridging this knowledge gap. For this reason, the systematic methodology to select participants and structure the qualitative research was followed, based on the work of (Tong et al., 2007).

Tong, Sainsbury and Graig (2007) studied and analysed seventy-six items from 22 checklists, by using a systematic search method, and compiled them into a comprehensive list. Finally, they grouped those items into three main sections: (i) research team and reflexivity, (ii) study design and (iii) data analysis and reporting. By following this methodology it is possible to ensure transparency and, at the very least, enable readers with the theoretical ability to replicate the study methods. It should be noted that the *codification* that is used to group the information from the interviews, is utilized to structure the maturity model. Specifically, the codes are correlated with the information that is found on the literature review to create the *dimensions* and *sub-dimensions* of the model. As such, the following tables present the method used in this research based on the aforementioned work.

Table 8: Qualitative research checklist *Part (i) Research team and reflexivity*

Personal Characteristics	
Interviewer/facilitator	The author of this work conducted the interviews
Credentials	The author is a Management of Technology Master's student
Occupation	Master's student
Gender	Male
Experience and training	Has conducted semi-structured interviews in the past for academic purposes
Relationship with participants	
Relationship established	The relationship with the participants started after the commencement of the study
Participant knowledge of the interviewer	The participants were informed about the interviewer's position and his research goals
Interviewer characteristics	The characteristics that were reported to the interviewees about the interviewer include his interest and motivation about the research topic

Table 9: Qualitative research checklist *Part (ii) Study design*

Theoretical framework	
Methodological orientation and Theory	Combination of literature review and expert interviews to gather the necessary data for the model development
Participant selection	
Sampling	The participants were selected based on their expertise and position. The participants should have either knowledge regarding smart manufacturing or urban factories, or work in such a factory in either a position related to strategy or technical expertise.
Method of approach	The participants were approached from the internet through e-mail or LinkedIn
Sample size	14 participants. 7 semi-structured interviews and a group interview with 7 (different) participants. The group interview was conducted as it allowed a dynamic interaction and the ability to capture a wide range of perspectives simultaneously
Non-participation	No participant dropped out of the research
Setting	
Setting of data collection	The data was collected through online video calls. The group interview was conducted in person.
Presence of non-participants	No one else was present during the interviews
Description of sample	There was no important characteristic of the sample aside from their technical knowledge or position
Data collection	
Interview guide	A sample of the questions that were asked is included in this report.
Repeat interviews	After the validation of the model with a company, there was an extra interview, with the company representative who filled the questionnaire assessment, to retrieve feedback on the process
Audio/visual recording	The interviews were recorded and transcribed by using the Teams (TU Delft approved) software. The recording and transcription were destroyed after the end of the research for confidentiality reasons
Field notes	Notes were taken during the interviews
Duration	The interviews lasted approximately 30 minutes
Data saturation	Data collection ended approximately one month before the end of the project
Transcripts returned	The transcripts were only used for processing the data and were not shared back to the participants

Table 10: Qualitative research checklist *Part (iii) Data analysis and reporting*

Data Analysis	
Number of data coders	The codes were allocated to the 25 sub-dimensions of the final model
Description of the coding tree	The coding tree is the 5 dimensions and 25 sub-dimensions of the maturity model
Derivation of themes	The themes were derived from the literature review as well as the interviews
Software	The data analysis took place in Excel
Participant checking	One round of feedback session took place after the model was completed
Reporting	
Quotations presented	To prevent identification of the interviewees it was decided that only a summary from the interview would be presented in this work and no quotes
Data and findings consistent	The data was utilized as an input to create the maturity model and to better understand the urban smart factory concept. The findings and conclusions are presented at the final section of this work
Clarity of major themes	The major themes (“dimensions”) are presented in the model development section of this report
Clarity of minor themes	The minor themes (“sub-dimensions”) are presented in the model development section of this report

3.2.1 Selection of interviewees

Specifically, in order to understand the concept of the urban smart factory and how a maturity model can be built for such a factory, experts who either work in an urban smart factories or have knowledge on the topic were approached. The experts were diverse in their expertise as well as their position in the company. The companies that the interviewees work in were as close to the smart factory as possible. To furtherly enrich the understanding of the USF, two interviews with experts that work in a technology consulting company where approached who are experts in smart manufacturing. Lastly, a group interview with 5 technology experts and 2 interns of the *Industry X* department of Accenture took place, to assist in the development of the maturity model. *Industry X* focuses on the latest advancements of industrial technology and digital capabilities, making it an good fit for this research. Below, a list of the selected interviewees is presented.

Table 11: Selection of interviewees

No	Interviewee Job Description	Company	
		Description	Location
1	Sales Leadership & Business Developer	Smart Vertical Farming	Netherlands
2	Data Scientist & Tech Farmer	Smart Vertical Farming	Netherlands
3	Leadership	Vertical Farming	Netherlands
4	Sales Engineer	3D Printer Manufacturer	Netherlands
5	R&D Project Leader	Motor vehicle Manufacturer	Germany
6	Associate Director Digital Manufacturing & Operations	Technology Consulting	Netherlands
7	Consultant Industry X	Technology Consulting	Netherlands
8	Group Session (5 Technology Experts & 2 Industry X Interns)	Technology Consulting	Netherlands

3.2.2 Contribution of individual and group interviews

This sub-section aims to shed light on the significance of conducting both individual and group interviews as part of the research methodology. The utilization of multiple interview methods allowed for a comprehensive exploration of the urban smart factory concept, incorporating diverse perspectives and filling gaps in existing literature. By employing these interview techniques, valuable insights and feedback were obtained, contributing to the refinement of the maturity model and enhancing the understanding of the integration of urban smart factories.

The group interview involving seven participants was a pivotal component of the research methodology. One of the primary reasons for conducting this group interview was to gather feedback and insights from individuals with diverse backgrounds and expertise. By presenting the preliminary model derived from the literature review, the participants were able to provide valuable perspectives, critique the model, and suggest improvements. This dynamic interaction among the participants facilitated rich discussions, allowing for a comprehensive exploration of the urban smart factory concept. Moreover, the group interview format enabled the simultaneous capture of a wide range of perspectives, enhancing the reliability and validity of the findings.

The individual interviews played a crucial role in delving deeper into the knowledge and expertise of the experts involved in factories closely aligned with the urban smart factory concept. As highlighted in Table 7, there were notable gaps in the literature related to the integration of urban smart factories within the urban environment. To bridge this knowledge gap, conducting individual interviews allowed for a comprehensive understanding of the specific challenges, opportunities, and best practices within this context. The in-depth discussions with experts provided valuable insights into various dimensions of the urban smart factory, including technology, workforce, strategy, processes, and urban integration. Through these individual interviews, a more nuanced understanding of the maturity model and its applicability in the real-world context was achieved.

3.2.3 Interview themes and questions

The structure of the semi-structured interviews was based on the grouping of the theoretical concepts that were identified in the literature (Table 5). The questions that were asked to each interviewee was adjusted based on their knowledge and expertise. On Table 12 a list of the questions that were asked to the interviewees is presented.

Table 12: Interview themes and questions

	Literature Review Concepts	Interview Questions
1	Urban Factories	• What are urban factories? • What are the opportunities of urban factories and how are they leveraged? • What are the challenges of urban factories and how are they addressed? • How relevant are the components/characteristics of the urban factories that are found in the literature in practice? (effects of proximity, environmental impact, workforce management, community engagement, technologies and processes, factory design, customer/supplier relations) • Are there any other components/considerations of urban factories that are missing from the literature? • What is the future of urban factories?
2	Smart Factories	• What are smart factories? • What are the components of smart factories? • What are the opportunities of smart factories and how are they leveraged? • What are the challenges of smart factories and how are they addressed? • How relevant are the components/characteristics of the smart factories that are found in the literature in practice? (technologies, products/process optimization, innovation, workforce, collaboration) • Are there any other components/considerations of smart factories that are missing from the literature? • What is the future of smart factories?
3	Urban Smart Factories	• What are the motivations for having such a factory? • What is the future of urban smart factories? (how should they be?)
4	Maturity Models	- (there is sufficient information on the literature)
5	Readiness Assessment Models	- (there is sufficient information on the literature)

3.2.4 Expert interviews summary

The key points from all the interviews are summarized here. The results obtained from the expert interviews served as the basis for constructing the sub-dimensions in the *Model Development* section 4. To ensure a systematic analysis of the interview data, codes were created to capture the main themes and insights derived from the interviews. The complete set of codes and their corresponding discussions can be found in the Appendix (subsection A.3).

Next, these codes were thematically grouped to form the sub-dimensions, which were then correlated with the relevant dimensions. This process involved identifying commonalities and patterns within the interview data, allowing for the emergence of distinct sub-dimensions that represent key aspects of the maturity model. The table that correlates the sub-dimensions with the codes is presented in the Appendix subsection A.4.

The development of these sub-dimensions was not solely based on the interview data, but also took into consideration the findings from the literature review. By integrating insights from both sources, a comprehensive understanding of the USF concept was achieved, and the sub-dimensions were formulated to encompass the essential factors identified through this synthesis. The *Model Development* section of this report (section 4) explains the sub-dimensions that were constructed based on this codification and the literature review.

Table 13: Expert Interviews Summary

No	Key Take-aways
1	• Manual labour is becoming less and less necessary as it can be replaced with smart manufacturing technologies • Workforce is still necessary but requires different skillsets (software, mechanical, robotic engineering) • In-house technology development reduces dependencies on other companies • Sophisticated software is not always needed • Collaboration with retailer and local stakeholder is crucial for the urban factory to succeed • The government must play an active role in supporting local production, which might be more costly than importing • Higher costs of being in the city require special pricing strategy
2	• An urban factory can become a showroom, where collaborators and investors can come and interact. This allows a closer interaction with the community and opens up opportunities for collaboration • Smart manufacturing facilitates scaling up of the factory as well as potential re-location/expansion • Smart manufacturing allows increased modularity as it allows flexibility of the production • A flat organizational structure and a close inter-departmental collaboration allows for a successful flow of information and knowledge within the company • Dedicated teams with people from different departments can furtherly improve this • A robust data infrastructure from the beginning is crucial for avoiding future problems

Table 13: Expert Interviews Summary

No	Key Take-aways
3	• Being in the city has increased costs and sometimes security issues • For industries that take their inputs from the cities or have local customers, it makes sense to have an urban factory • In that case, an urban factory can provide fresh products, have a lower economic footprint and a shorter chain of delivery • It is also a good marketing for its customers as they can advertise that they get their products from local producers • In this case, the pricing strategy can be a bit higher. The business model can shift from wholesale (which can not be competed as it is much cheaper) to tailor made products • Community engagement is facilitated by the location, and can be a very good way to acquire new customers • When scaling up, a new economic approach/pricing strategy must be followed to stay competitive
4	• An urban factory facilitates collaboration between suppliers and companies • In the case where the customers are not local, then it makes sense to be in a semi-urban or rural area due to the lower costs • Urban hot-spots with several companies/factories could be the key to increase the efficiency of the factories, exchange utilities and improve sustainability. • These industrial hubs can also facilitate and promote collaboration between companies • Smart manufacturing allows a new dimension of capabilities as we are shifting towards a digital inventory that is much more flexible • Resistance by conventional manufacturing must be accounted for
5	• Smart factory requires less people which means that location might not be as important • The higher costs of an urban factory might be paid by the customers, which makes it less appealing • The choice of the location of the factory depends on the product, the type of production, and the country • Industrial hotspots with similar technological interests (similar area of expertise) allows increased collaboration which can be mutually beneficial. A key benefit is that much faster response for maintenance can be achieved to fix issues • Additive manufacturing is an especially useful smart manufacturing technology as it can allow decentralized production, which is more robust and resilient • Instead of sending machinery parts, now only digital information needs to be exchanged which saves money and time but also reduces emissions • Some key issues are that the technology is less established and less optimized. Full integration in factories has not been achieved yet due to the reproducibility and consistency issues. Maintenance of such machines is also problematic • We are moving towards a digital design of components and processes

Table 13: Expert Interviews Summary

No	Key Take-aways
6	• The essence of Industry 4.0 is the integration of IT with OT and moving away from a black box in the production area. We can now understand exactly what is happening, analyse the information in real time and make adjustments • This allows to learn from the past data, optimize processes and minimize costs. We are moving towards automated learning • Security is one of the core problems of smart manufacturing. Moreover the shift owards a data driven production means that securing experts that can assess and utilize this information properly is crucial • People are not needed in the shop floor any more. Instead it is important to focus on where are the people needed and how can they help • The gradual shift towards smart manufacturing means that job displacement could be a key issue. This, however, is an opportunity as it can mean better working conditions, less pressure on the workers and less manual labour • Urban factories can allow increased creativity through collaboration with local parties and the community
7	• The essence of Industry 4.0 is using digital solutions to generate data with the end goal of becoming more efficient, sustainable, with less waste, increased profits and people benefits (safer processes). It is also bout using physical technology to get the right information (data) and transforming it to digital information that can be assessed to give specific action for the operations of the plant. • Aside from the IT architecture, company network and physical components, the decision making and response layer is the final step on using the information of the real world, through the utilization of advanced solutions such as machine learning and artificial intelligence. • If the right technology/data infrastructure is not in place then there is a risk of having siloed (inaccessible) data • There must be a clear business case to make the change towards smart manufacturing. Communication of the benefits to the right people withing the organization is key to facilitate the transition • Smart manufacturing can cause an information overload to companies making the transition difficult to implement • The smart manufacturing transition can mean a safer and easier job for the operators. By setting champions of the smart technology so that they can actually utilize it and share it to the other employees can be key. A more bottom up approach might be optimal in this case • Fostering inter-departmental collaboration should start from the top-down and a strategic roadmap should be created. • A transformation team can be setup to drive the change and bridge the gaps between the departments. At later stages of the transition it might be beneficial to adjust the structure of the organization of the company to help break silos and information barriers

Table 13: Expert Interviews Summary

No	Key Take-aways
8	• The benefits of an urban smart factory should be clearly stated and defined • Overall, the dimensions technology and workforce need more polishing regarding their sub-dimensions. The rest are much clearer and easy to understand. • Regarding the maturity model, the measurement items in the questionnaires are crucial. Questions should be clearly defined and representative of the corresponding measurement items • The sub-dimensions supporting technology with IT and smart manufacturing with OT are not completely exclusive. It is suggested to split between supporting IT, supporting/base OT and smart OT. • Dedicated teams is unclear as a sub-dimension to workforce and a suggestion to add employee satisfaction or employee well-being is made

4 Phase 2: Model Development

4.1 Conceptual design of the Urban Smart Factory Maturity Model (USFMM)

Based on the information that was collected on the previous sections, it is now possible to develop the Urban Smart Factory Maturity Model (USFMM). Below, the key dimensions of the model are described.

Table 14: Dimensions of the USFMM

No	Dimension Name	Description
1	Technology	The development, implementation, and integration of advanced technologies and solutions to drive innovation and competitiveness.
2	Workforce	The focus on building a strong and adaptable team that can effectively implement Industry 4.0 technologies and initiatives
3	Strategy and Organization	A forward-thinking approach to leveraging cutting-edge technologies and partnerships to drive innovation, optimize processes, and enhance competitiveness in the rapidly evolving Industry 4.0 landscape.
4	Process, Products and Services	The vision and actions towards operational efficiency, enhancing customer satisfaction, and creating new value streams through the implementation of innovative and integrated solutions, which provide seamless connectivity and collaboration across the entire product development and production lifecycle.
5	Urban Integration	The integration of the factory with the urban environment and the society. It includes characteristics such as sustainability, resilience and a human-centred approach.

Each of these five dimensions can be decomposed into smaller components (sub-dimensions). The following part of this section presents and describes the sub-dimensions of each one of the core dimensions of the USFMM. The explanations are given in the viewpoint of a company that aims to incorporate each sub-dimensions in it operations. In certain sub-dimensions, an explanation of the concept is given to align the readers with the meaning behind the terminology.

1) Technology

Information technologies and connectivity: This concept refers to the use of digital systems, networks, and communication channels to facilitate the exchange, storage, and access of information across various devices and platforms (Frank, Dalenogare, & Ayala, 2019). Based on that, the company should prioritize robust information technologies and connectivity within their urban smart factory. They should establish a strong foundation by implementing a base network architecture and communication protocols to ensure seamless data transmission. By leveraging cloud computing and edge computing, they can optimize resource utilization. To safeguard their data and systems, they should implement security measures such as encryption, access authentication, network segmentation, software patch management, and intrusion detection and prevention systems. Additionally, employing enterprise resource planning software would streamline operations across various functional areas like finance, human resources, manufacturing, supply chain, services, and procurement.

Physical systems: This refers to interconnected and intelligent machinery, equipment, and devices that are integrated with digital technologies to enable automation, data exchange, and smart manufacturing processes (Xu, Xu, & Li, 2018). As such, to enhance efficiency and productivity, the company should implement advanced physical systems in their urban smart factory. Real-time monitoring of processes can be achieved through the use of sensors, while identifiers like QR codes, barcodes, and RFID tags streamline operations and enable seamless tracking. Automation can be facilitated by employing industrial robots and autonomous collaborative robots (Cobots) to handle tasks, and material transportation can be optimized through the use of autonomous guided vehicles. The adoption of additive manufacturing (3D printing) can be beneficial for various processes and manufacturing machine parts. Furthermore, the company should consider implementing automated material handling systems and intelligent sensors that leverage advanced signal processing, data fusion techniques, intelligent algorithms, and artificial intelligence. These systems would optimize operations and enable data-driven decision-making.

Data analytics: This refers to the process of collecting, analyzing, and interpreting large volumes of data generated by interconnected devices and systems to gain valuable insights, optimize operations, and support data-driven decision-making (Zhong, Xu, Klotz, & Newman, 2017). As such, the company should leverage data analytics capabilities in their urban smart factory to drive insights and enhance performance. They should utilize data visualization techniques to present complex data in a user-friendly manner, optimizing processes for improved efficiency and productivity. Real-time monitoring and control can be achieved through Supervisory Control and Data Acquisition (SCADA) systems. Employing artificial intelligence (AI) enables task automation and intelligent decision-making. Machine learning and deep learning techniques should be applied for process optimization and automated learning. Utilizing big data analytics allows for real-time decision-making and operational optimization. Implementing predictive maintenance strategies minimizes downtime and maximizes equipment reliability.

Digital twins and simulation: The company should employ advanced digital twins and simulation technologies in their urban smart factory. By utilizing simulation software and 3D modeling, they can create virtual representations of processes for accurate analysis and optimization. Virtual reality (VR) and augmented reality (AR) applications enhance training, maintenance, and troubleshooting processes. Implementing digital twins allows for real-time virtual replicas of physical assets and processes, enabling continuous monitoring and optimization for improved efficiency and productivity.

Integration and interoperability: This refers to the seamless connectivity and harmonious interaction between various digital technologies, systems, and processes, enabling smooth information flow and collaboration across the entire value chain (Frank et al., 2019). The company should prioritize seamless integration and interoperability in their urban smart factory. Application programming interfaces (APIs) should be employed to facilitate communication and data exchange between different systems and components. Leveraging the Internet of Things (IoT) and Internet of Services (IoS) allows for efficient machine-to-machine and human-to-machine communication. Implementing automated manufacturing processes streamlines production and reduces manual intervention. Adhering to interoperability standards ensures compatibility and smooth interaction between technologies and systems. Middleware or integration platforms facilitate data flow and synchronization, enhancing overall operational efficiency and connectivity.

2) Workforce

Continuous improvement culture: The company should place a strong emphasis on fostering a culture of continuous improvement, constantly seeking ways to enhance processes, products, and services to provide greater value to customers. Ongoing learning and development are prioritized, and the company should invest significantly in employee training. Feedback from customers and employees is collected and analyzed, driving data-driven decision-making and process optimization. Measurement and accountability are key, with regular progress reports and KPIs used to track and evaluate performance.

Teams and collaboration: The company should recognize the importance of teams and collaboration in driving innovation and digitalization. Dedicated teams drive innovation initiatives and promote digitalization efforts across departments. Innovation "champions" promote change and implement quality improvement efforts. Inter-departmental and inter-team collaboration is fostered to achieve organizational goals and drive innovation.

Digital skills and qualification: The company should proactively aligns employees' digital skills and qualifications with the requirements of Industry 4.0. Skill gaps are identified, and training programs are provided to equip employees with necessary digital competencies. Adaptability in learning and development programs ensures responsiveness to industry changes. Nurturing a workforce with up-to-date digital skills enhances readiness for emerging technologies and successful digital transformation.

Workforce management: The company aims to manage employee learning and development with a focus on long-term success. Skills and competencies needed for success are identified, tailored training programs are designed, and continuous improvement processes are established.

Leadership innovation openness and change responsivity: The company should value forward-thinking and agility, adapting quickly to market or industry changes. Leadership empowers employees to drive innovation and take ownership of their work. Change responsivity is prioritized, ensuring adaptability and responsiveness for maintaining a sustainable competitive advantage.

3) Strategy and Organization

Technology investments: The company should place a significant emphasis on investing in new Industry 4.0 technologies. They understand the importance of staying at the forefront of technological advancements and allocate substantial resources to research, development, and implementation of innovative solutions. By prioritizing technology investments, the company aims to enhance capabilities, improve operational efficiency, and gain a competitive edge in the dynamic landscape of Industry 4.0.

Innovation pipeline: The company aims to have a clear digital vision and roadmap for Industry 4.0, outlining strategic direction and objectives in adopting innovative technologies. They have established an innovation pipeline that fosters idea generation, rigorous testing, and market implementation. This systematic approach ensures that promising ideas are identified, developed, and effectively implemented. Relevant metrics are utilized to measure the success of innovation initiatives, evaluating the impact and effectiveness of their innovative efforts.

Strategic collaborations: The company should actively engage in strategic collaborations with external organizations, including Industry 4.0 solution providers, consultants, suppliers, and academia. Recognizing the value of collaboration, they seek partnerships to leverage expertise, access cutting-edge technologies, and gain insights from industry leaders. These collaborations enable the company to embrace Industry 4.0 more effectively, implementing innovative solutions, driving continuous improvement, and staying ahead of industry trends.

Industry 4.0 Awareness: The company should demonstrate a strong understanding of the concept of Industry 4.0 and its potential benefits. They take proactive steps to educate employees and stakeholders about the fundamental principles and transformative nature of Industry 4.0. By fostering awareness, the company ensures that its workforce comprehends the significance of this paradigm shift and the opportunities it brings for improved productivity, efficiency, and competitiveness.

Governance and capabilities: The company should implement a clear governance structure to oversee and manage smart factory initiatives effectively. They foster a collaborative environment that encourages the exchange of ideas and knowledge among employees and partners, driving innovation and leveraging the collective intelligence of the organization.

4) Process, products and services

Smart products: The company should focus on developing and integrating intelligent, connected, and data-driven products into its offerings. This approach allows them to deliver enhanced customer experiences, optimize operations, and gain a competitive edge in the marketplace. The products are designed to be trackable and monitored, enabling effective management throughout their lifecycle.

Interoperability: The company aims to excel in achieving seamless integration and communication between its diverse digital systems, devices, and platforms. Prioritizing interoperability enables different technologies and components to exchange and utilize data efficiently, creating a cohesive digital ecosystem. This interoperability enhances operational efficiency, facilitates real-time data sharing, and enables end-to-end connectivity across the organization, maximizing the benefits of digitalization in the smart factory environment.

Integrated business processes: The company should leverage the data collected from its operations to develop hypothetical scenarios that incorporate various influencing factors. This data-driven approach enables the construction of predictive models that support informed business decision-making. By utilizing these predictive models, the company optimizes its value chain processes, enhances efficiency, and proactively addresses challenges and opportunities, leading to better business outcomes.

Value chain processes: The company should demonstrate a high degree of digitalization throughout its value chain processes, from product development utilizing computer-aided design (CAD) and simulation software, to the production phase where computer vision is utilized to automate quality control and testing processes.

Digital platforms: The company should leverage connected digital platforms to incorporate the requirements and preferences of both customers and suppliers into its product development and production processes. Additionally, the company utilizes open data with selected third-party developers to optimize logistics, improve inventory management processes, and enhance overall efficiency.

5) Urban Integration

Sustainability: The company should be strongly committed to sustainability, implementing energy and resource-efficient manufacturing processes. They embrace a circular economy approach by designing products and services that promote reuse and recycling. The company actively engages in educational and awareness campaigns to foster a culture of sustainability among stakeholders and promote responsible practices throughout the value chain.

Resilience: The company should be built on a foundation of resilience, able to withstand internal and external challenges such as supply chain disruptions, economic downturns, and natural disasters. Their flexible manufacturing processes allow for quick adaptations to changing market conditions, customer demands, and unforeseen events. Dynamic scheduling optimizes production and resource allocation in real-time, ensuring efficient asset utilization and minimizing downtime.

Employee benefits: The company should prioritize employee well-being by offering a range of benefits. This includes assistance in finding housing near the factory, flexible work schedules, transportation allowances, health and wellness programs, and childcare support. The company fosters a safe and inclusive workplace that promotes work-life balance and a sense of community among employees.

Customer benefits: The company should provide customers with a range of benefits to enhance their experience. This includes customizable product options, interactive product displays, and personalized customer service. The factory environment is designed to offer an immersive experience to customers, with interactive showrooms, factory tours, and opportunities to observe the manufacturing process.

Societal integration: The company should collaborate with local community groups and organizations to support social initiatives such as education and workforce development, environmental conservation, and community engagement. They also contribute to the local community by providing employment opportunities and economic benefits, contributing to the growth and development of the surrounding area.

A summary of the dimensions and the sub-dimensions of the Urban Smart Factory Maturity Model (USFMM) is presented on Table 15. The colored cells indicate the changes from the preliminary model that did not include the experts input (Table 6). For instance, as it was mentioned in the group interview, which can be found at the Appendix (subsection A.3), the sub-dimensions of the *Technology* dimension were not completely exhaustive of the concept. Moreover, it was mentioned that *Supporting Technology* with *Information Technology* and *Smart Manufacturing* with *Operational Technology* had significant overlap. Based on this feedback, and the input from the other interviews it became evident that the entire *Technology* dimension, should be restructured. As such, below the final dimensions and sub-dimensions of the Urban Smart Factory Maturity Model (USFMM) can be seen.

Table 15: Dimensions and sub-dimensions of the USFMM.

Technology	**Workforce**	**Strategy and organization**	**Process, products and services**	**Urban integration**
Information technologies and connectivity	Continuous improvement culture	Technology investments	Smart products	Sustainability
Physical systems	Teams and collaboration	Innovation pipeline	Interoperability	Resilience
Data analytics	Digital skills and qualification	Strategic collaborations	Integrated business processes	Employee benefits
Digital twins and simulation	Workforce management	Industry 4.0 Awareness	Value chain processes	Customer benefits
Integration and interoperability	Leadership innovation openness and change responsivity	Governance and capabilities	Digital platforms	Societal integration

Therefore, it is now possible to construct a visual representation of the Urban Smart Factory Maturity Model (USFMM) as it can be seen on Figure 10. In the center, the five core dimensions (Technology, Workfoce, Strategy and Organization, Process Products and Services, Urban Integration) can be seen. Each of those dimensions has 5 sub-dimensions that are adjacent to the outer part of the inner circle of the dimensions and have the same color. The choice behind this wheel schematic was based on the results from the literature review. Specifically, as it was explained, it is important that the visual representation is not only clear and easy to understand, but can also be easily utilized for the visualization of the results for an assessment. An example of using the model is presented in the following subsection 4.2 (see Figure 11).

Figure 10: Urban Smart Factory Maturity Model (USFMM)

Maturity Levels

Based on how well a company scores on the maturity assessment, it is placed on a different maturity level. In the USFMM four maturity levels can be assigned, as shown in Table 16. The analysis of how the maturity levels are calculated is presented in the following sub-section (4.2).

Table 16: List of maturity levels of the USFMM

Level	Maturity Level Name
Level 1	Pilot actions
Level 2	Partial implementation
Level 3	Advanced implementation
Level 4	Exemplary implementation

Strategic Roadmap

Based on the information that was collected regarding the dimensions and the sub-dimensions, as well as the maturity levels that were presented in the previous sub-section, it is now possible to present a generalized strategic roadmap for a company that has performed the assessment. These levels were derived from a combination of factors, including the current state of technology adoption, workforce capabilities, strategic alignment, and integration within the urban context. Each maturity level represents a progressive stage of advancement, indicating the increasing level of sophistication and integration in the respective dimension. It is important to clarify that while this roadmap offers guidance on improving based on the assessed level of maturity in each dimension, it does not provide personalized recommendations tailored to the specific results obtained by each company. For this reason the following table serves only as a generic guideline. *For a more targeted and useful creation of a strategic roadmap, a company should pinpoint the sub-dimensions that it did not perform well and then refer to subsection 4.1, where the concepts are explained in detail.*

As such, the following table presents the generalized strategic roadmap for a company that has undergone the assessment.

	Level 1	Level 2	Level 3	Level 4
Technology	• Basic information technologies and connectivity, including a network architecture and communication protocols • Limitations in terms of data transmission and resource utilization optimization • Security measures are rudimentary, and there is room for improvement in areas such as encryption and access authentication • The company may have implemented some enterprise resource planning software but might not have fully streamlined operations across different functional areas	Previous level implementations and: • Enhanced information technologies and connectivity, leveraging cloud computing and edge computing for optimized resource utilization • Security measures have improved, with encryption, access authentication, network segmentation, and intrusion detection and prevention systems in place • The utilization of sensors, identifiers (QR codes, barcodes, RFID tags), and industrial robots has increased, leading to improved efficiency and productivity • There is initial adoption of additive manufacturing (3D printing) and automated material handling systems	Previous level implementations and: • Robust information technologies and connectivity, ensuring seamless data transmission • Cloud computing and edge computing are fully optimized, leading to efficient resource utilization • Successful implementation of enterprise resource planning software, streamlining operations across various functional areas • Embraced real-time monitoring using sensors, identifiers, industrial robots, and autonomous guided vehicles • Additive manufacturing is well-integrated into processes, and advanced signal processing, data fusion techniques, intelligent algorithms, and artificial intelligence are employed for data-driven decision-making	Previous level implementations and: • They have achieved an exceptional level of information technologies and connectivity, ensuring robust and seamless data transmission • Cloud computing and edge computing are fully optimized, enabling maximum resource utilization • Security measures are comprehensive and regularly updated, including encryption, access authentication, network segmentation, software patch management, and advanced intrusion detection and prevention systems • The company has successfully implemented enterprise resource planning software, streamlining operations across all functional areas • The utilization of digital twins and simulation technologies, including virtual reality and augmented reality applications, is fully integrated, enabling continuous monitoring, analysis, and optimization of operations
Workforce	• Limited focus on fostering a continuous improvement culture • The company may not have established a structured process for collecting and analyzing feedback, and employee training and development efforts may be minimal • Collaboration between teams and departments is limited, hindering the organization's ability to drive innovation collectively • The company may not have a proactive approach to identifying and addressing digital skill gaps	Previous level implementations and: • Progress towards building a strong workforce foundation for innovation and digitalization • Investment in employee training and development • Feedback collection and analysis processes are being established, at a basic level • Collaboration between teams and departments is encouraged • Efforts are made to identify and address digital skill gaps, but they may not be fully comprehensive or adaptive to industry change	Previous level implementations and: • Established robust processes for collecting and analyzing feedback from customers and employees, and the data-driven approach is used to optimize processes and drive innovation • Employee training and development efforts are significant, with a focus on aligning digital skills and qualifications with the requirements of Industry 4.0 • Collaboration between teams and departments is actively promoted, with dedicated innovation teams driving digitalization efforts • The company exhibits strong workforce management practices that align with long-term success and continuous improvement	Previous level implementations and: • At the highest maturity level, the company excels in workforce implementation, demonstrating a strong commitment to innovation, digitalization, and change responsivity • Feedback collection and analysis processes are well-established • Regular use of company key performance indicators (KPIs) to track progress and evaluate performance • The company places a strong emphasis on aligning employees' digital skills and qualifications with the requirements of Industry 4.0, ensuring adaptability and responsiveness to industry changes • Leadership within the company empowers employees to drive innovation, embraces risk-taking, and exhibits agility in responding to market or industry shifts
Strategy and organization	• The level of technology investment is limited • The digital vision and roadmap for Industry 4.0 may not be well-defined, and the company may lack a structured innovation pipeline • Collaborations with external organizations might be infrequent, limiting access to expertise and cutting-edge technologies • Industry 4.0 awareness among employees and stakeholders is limited, and there may not be a robust governance structure to oversee smart factory initiatives	Previous level implementations and: • Clearer digital vision and roadmap, outlining strategic objectives for adopting innovative technologies • Basic innovation pipeline to generate and test new ideas, although it may not be fully systematic or structured yet • Some strategic collaborations with external organizations are initiated, enabling access to expertise and industry insights • The company begins to establish a governance structure to oversee smart factory initiatives but may still be refining the collaborative environment	Previous level implementations and: • High level of technology investment • Eell-defined digital vision and roadmap, outlining strategic objectives and milestones • Industry 4.0 awareness is widespread among employees and stakeholders, and the company fosters a collaborative environment for knowledge exchange • The governance structure is well-established, enabling effective oversight and management of smart factory initiatives	Previous level implementations and: • The company demonstrates a commitment to continuous technology investment, consistently staying at the forefront of technological advancements • The digital vision and roadmap are well-defined, aligning with the organization's strategic direction • The innovation pipeline is highly effective, ensuring the generation, testing, and implementation of innovative ideas • The governance structure is highly efficient, fostering a collaborative and innovative environment for smart factory initiatives

Process, products and services	• Basic understanding of the concept of smart products and the potential benefits they offer • The company may have started to explore the use of tracking and monitoring systems for product lifecycle management • The company has not fully leveraged data-driven approaches or predictive models to optimize its value chain processes	Previous level implementations and: • Progress in developing and incorporating smart products into its offerings • The company has identified the importance of intelligent, connected, and data-driven products to deliver enhanced customer experiences and gain a competitive edge • Implementation of tracking and monitoring systems for product lifecycle management • Efforts are made to improve interoperability between digital systems, devices, and platforms, facilitating better data exchange and utilization • The company is beginning to leverage data-driven approaches and predictive models to optimize some value chain processes, enhancing efficiency	Previous level implementations and: • At this level, the company excels in developing and incorporating smart products into its offerings • Successful integration of intelligent, connected, and data-driven products that deliver enhanced customer experiences and optimize operations • The products can be tracked, monitored, and managed effectively throughout their lifecycle • Real-time data sharing and end-to-end connectivity are established, maximizing the benefits of digitalization • The company leverages data-driven approaches and predictive models extensively, optimizing value chain processes and driving informed business decision-making	Previous level implementations and: • Leader in developing and incorporating smart products into its offerings • They have achieved a high degree of digitalization across their value chain processes. From product development (to production, digital technologies are fully integrated • The company excels in utilizing digital platforms to incorporate the requirements and preferences of customers and suppliers into its product development and production processes • They also leverage open data and collaborate with selected third-party developers to optimize logistics, improve inventory management processes, and enhance overall efficiency
Urban integration	• The company may have some sustainability practices in place, such as energy-efficient manufacturing processes, but they are not fully integrated or comprehensive • Resilience measures may be minimal, with limited flexibility in manufacturing processes and resource allocation • Employee benefits may be standard or limited, with few additional support programs • The company may have basic customer benefits, but personalization and interaction are limited • Societal integration efforts may be minimal, with limited collaboration with local community groups and organizations	Previous level implementations and: • Active development of urban integration initiatives • Implementation of energy and resource-efficient manufacturing processes • The company is starting to embrace a circular economy approach, designing products and services for reuse and recycling • Resilience measures are being strengthened, with more flexible manufacturing processes and dynamic scheduling to adapt to changing conditions • The company is beginning to offer some customer benefits, such as customizable product options, but the level of personalization and interaction is still limited • Societal integration efforts are being explored, with some collaboration with local community groups and initiatives	Previous level implementations and: • Advanced urban integration initiatives and strong commitment to sustainability • Implemented comprehensive energy and resource-efficient manufacturing processes, fully embracing a circular economy approach • The company actively promotes sustainability education and awareness campaigns among stakeholders • Dynamic scheduling optimizes production and resource allocation in real-time, ensuring efficient use of assets • Societal integration efforts are well-developed, with collaborations in education, environmental conservation, and community engagement, contributing to the growth and development of the local community	Previous level implementations and: • Leader in urban integration • The company has established a circular economy model, designing products and services for maximum reuse and recycling • Resilience measures are robust, with flexible manufacturing processes and dynamic resource allocation to ensure worry-free production • Customer benefits are highly personalized, offering interactive experiences, customized product options, and immersive showrooms • Societal integration efforts are extensive, with strong collaborations with local community groups, organizations, and initiatives that drive positive social impact and economic benefits to the surrounding area

4.2 Calculation of the overall maturity score

To calculate the maturity level (M) of a company it is important to first establish the range of the maturity levels. These are presented on Table 17.

Table 17: Maturity levels of the USFMM

Level	Maturity Level Name	Maturity Score (M) Range
Level 1	Pilot actions	$1.00 \leq M \leq 2.00$
Level 2	Partial implementation	$2.00 \leq M \leq 3.00$
Level 3	Advanced implementation	$3.00 \leq M \leq 4.00$
Level 4	Exemplary implementation	$4.00 \leq M \leq 5.00$

For instance, if the resulting maturity level is 2.5 then the level of maturity is Level 2. To calculate the level of maturity, firstly, the sub-dimension scores are measured from the answers on the questionnaire through a 5-point likert scale. Then, an average of the sub-dimensions can be used to calculate the dimensions scores. From the dimensions scores one could directly measure the maturity level through an average. However, as it was explained in the literature review, it is more appropriate to use a weighted averaged, based on the strategic vision of each company. This can give a more tailored result to each company that might have a different focus. It is important to mention, however, that this could actually hide the weaknesses of a company and thus giving a higher-that it should maturity level. For this reason, the weights given by the company should be explained and critically assessed before the calculation takes place to ensure result that can actually be useful for the company.

The equations and the variables to perform these calculations can be seen on the following figures.

$$M = \frac{\sum_i (D_i \cdot W_i)}{\sum i} \tag{1}$$

$$D_i = \frac{\sum_j (SD_j)}{\sum j} for j \in i \tag{2}$$

Table 18: Definitions of symbols

Variable	Explanation
i	set of dimensions
j	set of sub-dimensions
D_i	score of dimension i
W_i	weight of dimension i
SD_j	score of the sub-dimension j as given by the respondents in a 5-point likert scale

Example of USFMM assessment

An example of the use of the USFMM based on this method can be seen on Figure 11. In this example, random values are given for the score of each sub-dimension. These values are represented by the brown line on the figure. Based on these scores and the calculation methodology that was presented earlier it is possible to calculate the total maturity score (4.3). The maturity score is visualized with the red line. As explained, this kind of visualization of the dimensions and the sub-dimensions allows an easy to understand assessment of every aspect of the urban smart factory.

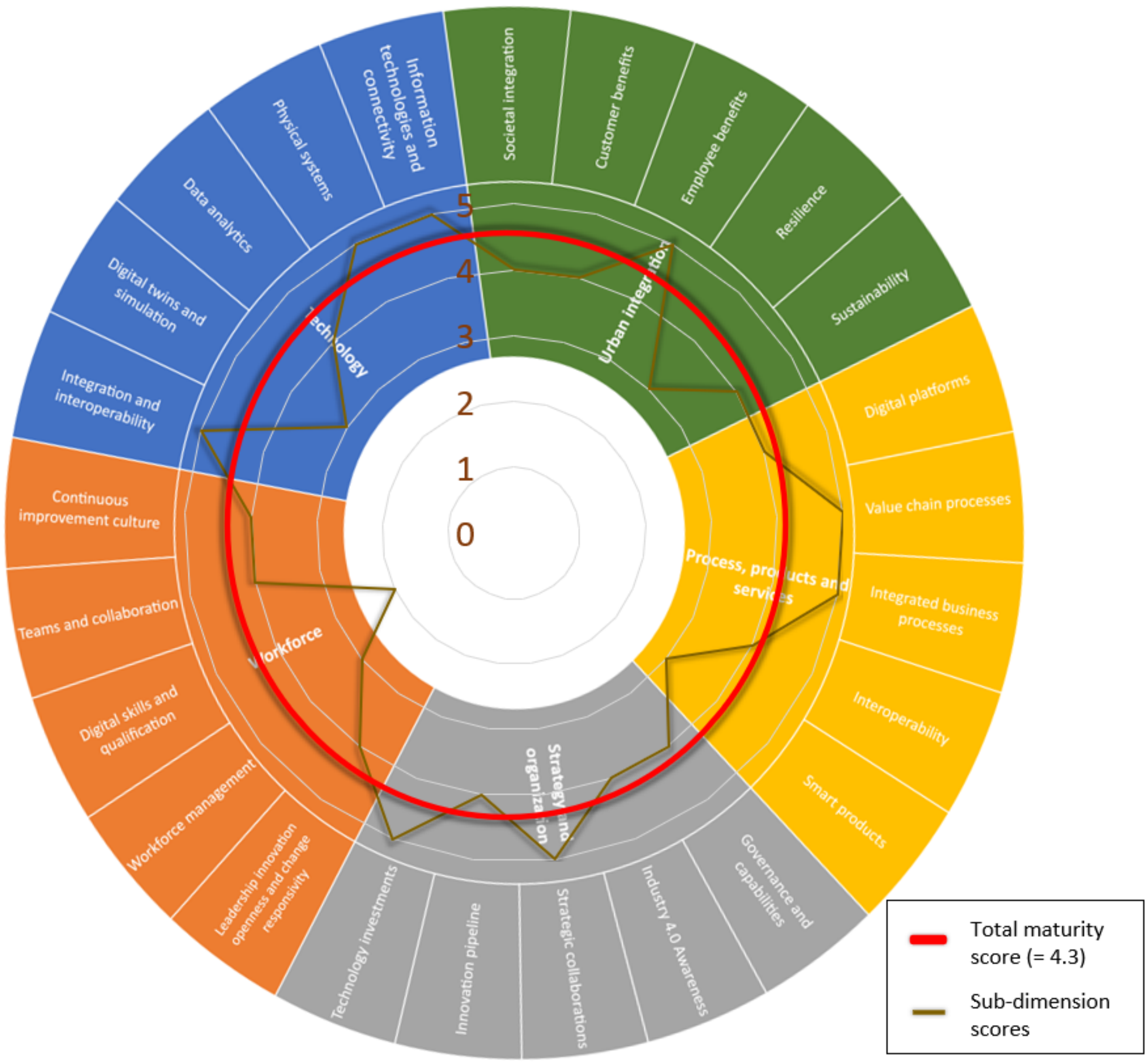

Figure 11: Example of using the USFMM

4.3 Self-assessment design

After designing the maturity model for the urban smart factory, it is necessary to also create a straightforward assessment that companies can use to identify their weaknesses and pinpoint areas for improvement. For this reason an assessment in the form of a **questionnaire** was created.

The questionnaire was organized into four sections (opening statement, concept introduction, dimension priority, assessment) that are explained on the following part of this section. The entire assessment document can be found on the appendix subsection A.5.

Opening Statement

The opening statement's purpose is to provide the relevant information to the the interviewee in a clear and concise manner. Specifically it aims to answer the following questions:

- What is the purpose of the study?
- Who is involved in this study?
- What are the participants asked to do?
- How long will the assessment take?
- What are the measures being taken to minimize the risks of the study for the participants?

Concept Introduction

In this part the concepts that the questionnaire is structured around are briefly explained. Specifically, the questions are organized in the five dimensions (Technology, Workfoce, Strategy and Organization, Process Products and Services, Urban Integration) of the Urban Smart Factory Maturity Model (USFMM) that were presented in subsection 4.1. The purpose for presenting this information is to align the understanding of the participants with the meaning of the concepts. This is especially important as in the next step the participants will have the option to give weights to these dimensions, so they have to understand their precise meaning in the context of this study.

Dimension Priority

As mentioned above, in this part the participants are asked to give a priority, which is translated into weight, on the five dimensions. To achieve that, the following table is presented in the questionnaire:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
The company gives high priority to the "**Technology**" dimension.	○	○	○	○	○
The company gives high priority to the "**Workforce**" dimension.	○	○	○	○	○
The company gives high priority to the "**Strategy and Organization**" dimension.	○	○	○	○	○
The company gives high priority to the "**Process, Products and Services**" dimension.	○	○	○	○	○
The company gives high priority to the "**Urban Integration**" dimension.	○	○	○	○	○

Figure 12: Dimension priority table as presented in the questionnaire

As it was explained in the *Calculating the overall maturity score* (subsection 4.2) part of this report, the weights can on one hand assist in acquiring a personalized assessment on the company, but on the other hand they might hide potential issues of that the company is facing. For this reason it was decided to add a section in the assessment where the participants are asked the reasoning behind giving different weights to the dimensions. By doing that, it is possible to get a personalized assessment that is grounded on reasoning. It is possible that the reasons are good enough to support the usage of weights. As such, the following figure shows how this section is presented in the questionnaire.

In case the answers in the previous five items are **not** the same, in order to help make a personalized maturity assessment, please give a brief explanation in the box below,:

Figure 13: Question asking to explain reason behind dimension priority as presented in the questionnaire

Assessment

The final part of the assessment document is where the questions are asked. The questions are organized into the five dimensions and are categorized by using numbers (1-5), and the corresponding sub-dimensions by using letters (a-e). For instance the questions that relate to the *Teams and collaboration* sub-dimension of the *Workforce* dimension fall under [3b]. Since sub-dimensions vary in their complexity, in some cases the questions that correspond to it can vary from one to three. In the case that there are more than one questions, the maturity scoring of the sub-dimension is calculated through the mean of these questions. The measurement items are assessed in two ways: scoring system, 5-point likert scale. Normally the 5-point likert scale would be sufficient however in the case of the Technology dimension, the questions relate more to whether the company is using a specific technology or not. As such a yes/no type of question is more appropriate. Examples of these two types of questions can be seen on Figure 14 and Figure 15. The entire list of questions can be found at the Appendix (subsection A.5).

1d	The company has adopted the following simulation and digital twin methods:	Simulation software	☐
		3D modelling of processes	☐
		Virtual reality applications	☐
		Augmented reality applications	☐
		Fully implemented digital twin (to monitor the operations and optimize processes in real time)	☐

Figure 14: Example of a checklist type of measurement item in the questionnaire

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
4a	The company develops and incorporates intelligent, connected, and data-driven products for enhanced customer experience.	○	○	○	○	○
	The products can be tracked and monitored, to manage the life cycle of the product.	○	○	○	○	○

Figure 15: Example of a 5-point likert scale measurement item in the questionnaire

5 Phase 3: Model Validation

In order to validate the developed model, an assessment was conducted with a company that serves as an urban smart factory. The production line of the factory is automated using smart manufacturing technologies and it is located within the city, making it an ideal case for validating the maturity model. The validation process followed the steps outlined below:

The comprehensive questionnaire, comprising various sections, was initially forwarded to a representative from the company. The representative took the initiative to complete the questionnaire. Once the representative completed the assessment, they submitted the filled questionnaire back to the researcher. Upon receiving the completed assessment, the researcher processed the collected data and performed a detailed analysis, thus translating the questionnaire results to the assessment of the company's maturity. Following the analysis, the researcher prepared a report that presented the results and provided corresponding analysis. This comprehensive report was then shared with the company. A feedback session was arranged, bringing together the company and the researcher. During this session, the findings and analysis from the report were thoroughly discussed. In the feedback session, the representative shared their perspective on various aspects, including the structure, flow, and usability of the evaluation instrument, as well as their overall experience with the assessment process. By incorporating the valuable feedback received, the model was refined, and suggestions for future work were formulated, ensuring continuous improvement and enhancement of the assessment process.

This validation process allowed for a comprehensive evaluation of the company's maturity level, while also gathering important insights for further development of the model.

5.1 Summary of the assessment

Based on the assessment using the Urban Smart Factory Maturity Model (USFMM), the company obtained an overall maturity score of **3.52** out of 5, indicating a decent level of maturity at *Maturity Level 3: Advanced Implementation*. While strengths were observed in technology adoption, workforce development, strategic vision, product innovation, and urban integration, there are areas for improvement across all dimensions. Table 19 provides a summary of the key points, highlighting both the areas where the company scored well and the areas that require improvement. Specifically, the workforce dimension presents a significant potential for enhancement, emphasizing the importance of investing in employee development and upskilling. Additionally, refining the strategy dimension can align the company's vision more effectively with Industry 4.0 advancements, while continuous assessment and improvement in areas such as process optimization, data utilization, and seamless integration of digital systems are crucial for further progress. With further enhancements and addressing the identified areas of improvement, the company can continue its journey towards becoming a more advanced and mature urban smart factory.

Table 19: Key points that derived from the assessment

Dimension	**Executive Summary**
Technology	The company made significant progress in adopting advanced technologies across various domains, including information technologies, physical systems, data analytics, and integration methods. However, there are areas for improvement, such as implementing network segmentation, intrusions detection and prevention systems, cobots and autonomous guided vehicles, SCADA systems, and VR and augmented reality systems.
Workforce	The company has showed a commitment to employee training and development, aligning digital skills with Industry 4.0, and minimizing labor-intensive processes. However, there was room to enhance employee satisfaction, well-being, and interdepartmental collaboration.
Strategy and Organization	The company exhibited a strong strategic focus, with high investments in Industry 4.0 technologies, a digital vision and roadmap, and collaboration with external partners. The presence of an innovation pipeline and a culture of collaboration contributed to the company's maturity in this dimension.
Process, Products and Services	The company demonstrated maturity in this dimension by developing intelligent, connected, and data-driven products, tracking product life-cycles, and ensuring seamless integration and communication across digital systems. There was an opportunity to further optimize logistics and inventory management through open data utilization.
Urban Integration	The company had made progress in integrating sustainability, resilience, and a human-centered approach into its operations. Commitment to energy and resource efficiency, circular economy principles, and community engagement contributed to its maturity. Areas of improvement include expanding health and wellness programs, childcare support, and economic benefits to the local community.

5.2 Assessment results

The following results were given regarding the scoring of each sub-dimension of the maturity model. Based on the average of each measurement item in each sub-dimension it is possible to calculate the score of each dimension and consequently the total maturity score of the company regarding the urban smart factory:

Dimension	Sub-dimension	Score
Technology	Information technologies and connectivity	3.89
	Physical systems	3.75
	Data analytics	4.29
	Digital twins and simulation	3.00
	Integration and interoperability	3.57
	Dimension Score	**3.70**
Workforce	Continuous improvement culture	1.67
	Teams and collaboration	0.42
	Digital skills and qualification	2.50
	Workforce management	1.25
	Leadership innovation openness and change responsivity	2.50
	Dimension Score	**1.67**
Strategy and organization	Technology investments	5.00
	Innovation pipeline	2.92
	Strategic collaborations	5.00
	Industry 4.0 Awareness	2.50
	Governance and capabilities	5.00
	Dimension Score	**4.08**
Process, products and services	Smart products	3.75
	Interoperability	5.00
	Integrated Business processes	5.00
	Value chain processes	5.00
	Digital platforms	3.75
	Dimension Score	**4.50**
Urban integration	Sustainability	4.58
	Resilience	3.75
	Employee benefits	1.25
	Customer benefits	5.00
	Societal integration	3.75
	Dimension Score	**3.76**
Total Maturity Level		**3.52**

A visual representation of the maturity model along with the assessment results can be seen on the following figure.

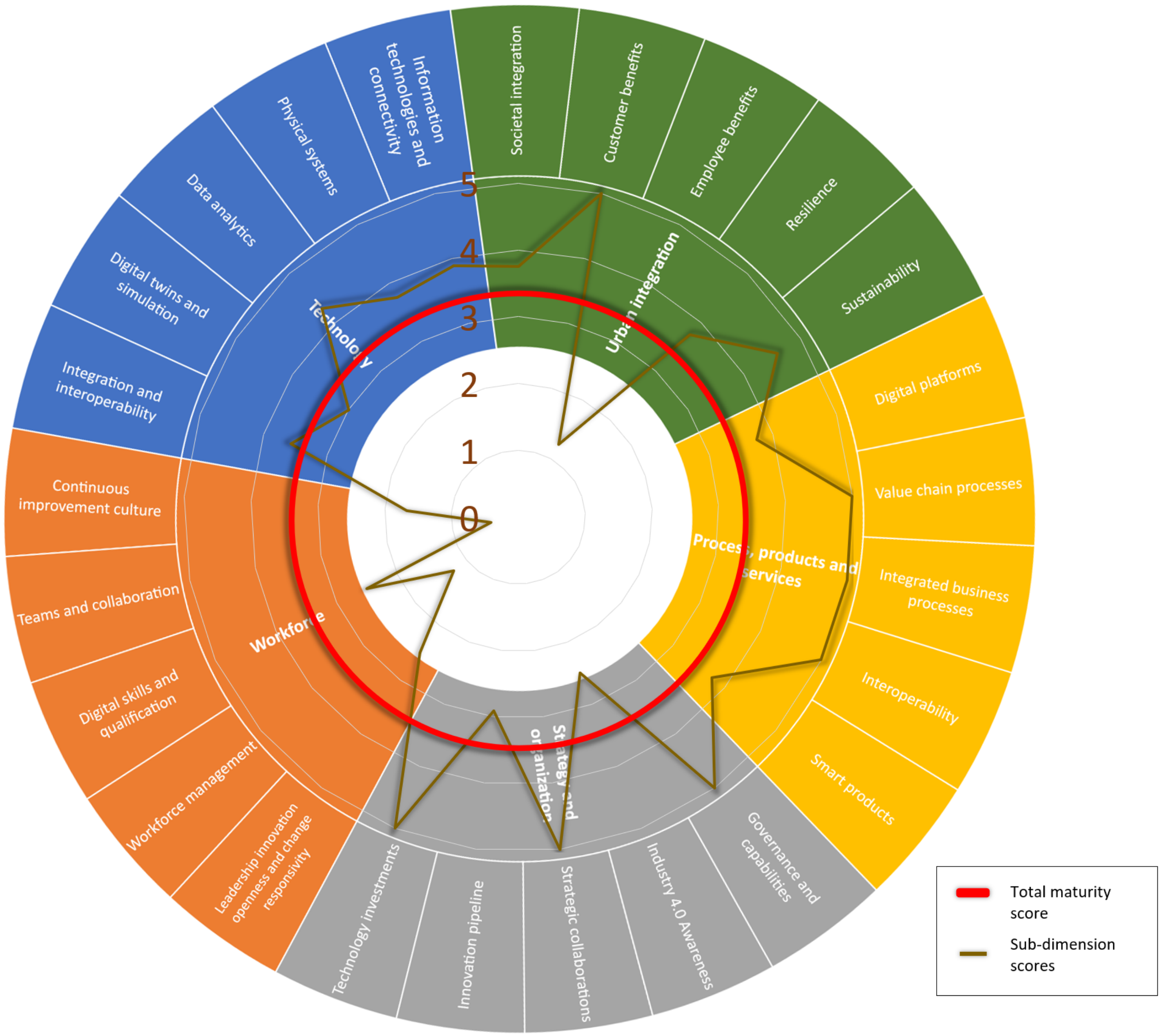

Figure 16: Visual representation of the sub-dimensions score results of the assessment

Since the total maturity score of the company is 3.52, the company is on the "*Advanced implementation*" level, as can be seen on the following table.

Table 20: Maturity level of the company

Level	Maturity Level Name	Maturity Score (M) Range
Level 1	Pilot actions	$1.00 \leq M \leq 2.00$
Level 2	Partial implementation	$2.00 \leq M \leq 3.00$
Level 3	**Advanced implementation**	$\mathbf{3.00 \leq M \leq 4.00}$
Level 4	Exemplary implementation	$4.00 \leq M \leq 5.00$

5.3 Weight of the dimensions

The company gave different priorities to the 5 dimensions of the maturity model based on its strategic vision. This reflects its prioritization and focus areas in the journey towards becoming an urban smart factory. The weights can be seen on the following figure.

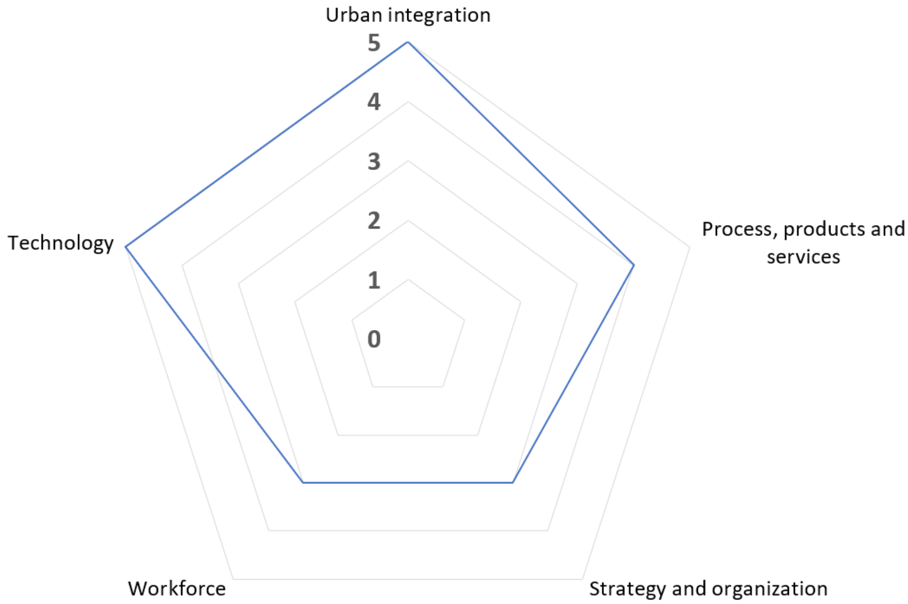

Figure 17: Dimension priorities (weights) as given by the company

Based on the answers that were given, the following can be said regarding the focus of the company. The company placed a strong emphasis on technology, prioritizing the development and integration of advanced technologies like IoT, AI, and data analytics to drive innovation and digital transformation. While also recognizing the importance of a skilled and adaptable workforce, the company invested in employee training and development. It acknowledged the need for effective strategic planning and organizational alignment to successfully implement Industry 4.0 technologies. The company focused on process optimization, product development, and delivering value-added services to enhance operational efficiency and customer satisfaction. Lastly, it demonstrated a strong commitment to urban integration, emphasizing sustainability and contributing to the well-being of the local community.

Important Note

While the company's choice of weights allows for a personalized assessment, it is important to acknowledge the potential limitations. Assigning higher weights to certain dimensions may overshadow existing challenges or weaknesses in those areas. Therefore, it is crucial for the company to remain vigilant and conduct a comprehensive assessment that considers all dimensions and their inter-dependencies.

Overall, the company's strategic vision and the assigned weights indicate its recognition of the multifaceted nature of becoming an urban smart factory. By prioritizing the integration with the urban environment, emphasizing technology and workforce development, and focusing on process optimization and strategic alignment, the company positioned itself for sustainable growth, innovation, and success in the Industry 4.0 landscape. The balanced weight assigned to strategy and organization highlighted the company's recognition that a holistic approach, encompassing all dimensions, is essential for achieving its goals in the realm of Industry 4.0.

Based on that, it is possible to give a more focused assessment of the company. The weighted and non-weighted scores of each dimension can be seen on the following figure:

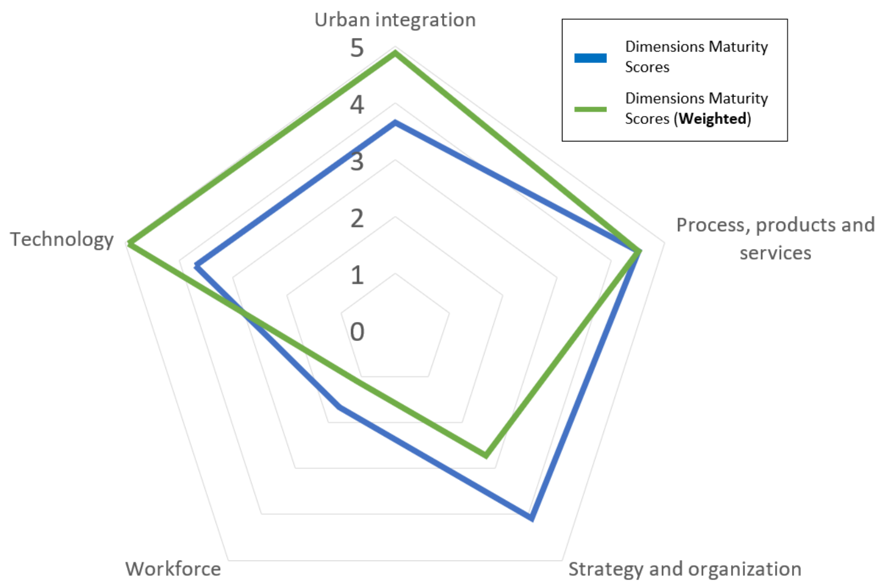

Figure 18: Visual representation of weighed and non-weighted maturity scores of the dimensions

Consequently, the total weighted and non-weighted maturity levels of the company can be seen on the following table:

Table 21: Comparison of weighted and non-weighted maturity level of the company

	Weighted	Non-weighted
Maturity Level	3.63	3.52

5.4 Discussion of the results

Overall, the company excelled in several areas, particularly in technology, urban integration, and process dimensions. These dimensions consistently demonstrated strong scores in both the weighted and unweighted assessments. The company's commitment to technology was evident through its high score and the emphasis placed on advanced technologies and solutions. With a focus on innovation and competitiveness, the company positioned itself as a leader in the urban smart factory space, leveraging cutting-edge tools and integrating them seamlessly within its operations. Furthermore, the company's dedication to urban integration signified its strong alignment with sustainability, resilience, and a human-centered approach. y actively integrating the factory with the urban environment and society, the company showcased its commitment to social and environmental responsibility. This leadership in urban integration further solidified its position as a forward-thinking organization.

However, it is important to note that the higher weighted scores in technology and urban integration should not overshadow the potential for improvement. While these dimensions may be strong, it is crucial for the company to remain vigilant and continuously assess areas where enhancements can be made. Striving for constant improvement, even in areas of strength, will help ensure the company stays ahead of the curve and maximizes its potential for success in the rapidly evolving Industry 4.0 landscape. Overall, the company's strong performance in technology, urban integration, and process dimensions, combined with its strategic vision, positioned it as a leader in the urban smart factory domain. By carefully considering areas for improvement and maintaining a focus on continuous growth and innovation, the company is well-positioned to capitalize on emerging opportunities and remain at the forefront of the Industry 4.0 revolution. On Table 22 a summary of the points that the company excels at can be seen.

Table 22: List of areas that the company showcased strengths

Dimension	**Areas that the company excels**
Technology	• The company effectively utilized various information technologies, such as base network architecture, communication protocols, cloud computing, encryption, and access control. • It implemented physical systems and technologies like sensors, QR/Bar-codes/RFID identifiers, autonomous guided vehicles, additive manufacturing (3D printing), and automated material handling systems. • The company adopted data analytics methods including data visualization, artificial intelligence, machine learning, deep learning, big data analytics, and predictive maintenance. • It utilized simulation software, 3D modeling, and fully implemented digital twin technology for monitoring and optimizing operations in real-time. • The company employed technologies like application programming interfaces (APIs), IoT (Internet of Things), machine-to-machine communication, and human-to-machine communication for seamless integration and interoperability within the smart factory environment.
Workforce	• The company invested in employee training and development. • It had a structured process for collecting and analyzing feedback from employees. • Efforts were made to align employees' digital skills and qualifications with Industry 4.0. • The company minimized the workforce needed for labor-intensive processes. • It prioritized forward-thinking, agility, and risk-taking to stay competitive.
Strategy and Organization	• The company had a high level of investment in new Industry 4.0 technology development or acquisition. • It had a digital vision and roadmap for Industry 4.0. • An innovation pipeline was in place to generate and test new ideas. • Collaboration with external organizations was fostered to embrace Industry 4.0. • The company promoted collaboration between employees and partners, encouraging the exchange of ideas and knowledge.
Process, Products and Services	• The company developed intelligent, connected, and data-driven products for enhanced customer experience. • Products could be tracked and monitored throughout their lifecycle. • There was seamless integration and communication between digital systems, devices, and platforms. • Data collected was utilized to create predictive models for informed decision-making. • The company demonstrated high digitalization from product development to production phases. • Connected digital platforms incorporated customer and supplier requirements and preferences. • Open data was utilized with third-party developers to optimize logistics and inventory management.
Urban Integration	• The company was committed to using energy and resource-efficient manufacturing processes. • It adopted a circular economy approach, designing products and services for reuse and recycling. • The company organized or promotes educational and awareness campaigns. • It had flexible manufacturing processes for quick adaptations to changing market conditions. • Dynamic scheduling was leveraged to optimize production and resource allocation in real-time. • The company offered flexible work schedules and customizable product options. • It collaborated with local community groups and organizations, contributing to social initiatives and offering employment opportunities.

On the other hand, the company had a significant potential for improvement in the workforce dimension, as indicated by its notably lower score compared to the other dimensions. While smart factories increasingly rely on machinery and automation, it is crucial to recognize the importance of the workforce. Investing in the development and upskilling of employees can unlock their potential in interpreting results, driving continuous process improvement, and providing valuable support throughout the factory operations. Strengthening the workforce dimension by implementing comprehensive training programs, fostering a culture of innovation and collaboration, and promoting employee engagement can lead to enhanced performance and productivity.

Additionally, the strategy dimension could benefit from improvement to further align the company's vision with Industry 4.0 advancements. Although the score is relatively lower, it presents an opportunity to refine strategic planning and enhance the organization's overall approach to leveraging cutting-edge technologies and partnerships. Furthermore, it is important to continuously assess and improve other relevant areas such as process optimization, data utilization, and seamless integration of digital systems. By adopting advanced analytics methods, implementing simulation and digital twin technologies, and further enhancing the connectivity and interoperability of systems, the company can optimize its processes, maximize operational efficiency, and deliver even greater value to its customers. Embracing open data initiatives, exploring possibilities for predictive maintenance, and enhancing the utilization of data-driven insights can further drive innovation and competitiveness within the smart factory ecosystem. Table 23 presents a list of areas that the company could improve.

Table 23: List of areas that the company could improve

Dimension	**Areas for improvement**
Technology	• Implement network segmentation to enhance security by dividing the network into segments to prevent unauthorized access. • Install intrusions detection and prevention systems to proactively identify and prevent potential cyber threats. • Introduce cobots (collaborative robots) and autonomous guided vehicles to improve automation and streamline manufacturing processes. • Implement SCADA (Supervisory Control and Data Acquisition) systems for real-time monitoring and control of industrial processes. • Explore the adoption of VR (Virtual Reality) and augmented reality systems to enhance training, visualization, and collaboration in the factory environment.
Workforce	• Increase the emphasis on measurement and accountability by utilizing regular progress reports and Key Performance Indicators (KPIs) to track and evaluate individual and team performance. • Foster inter-departmental and inter-team collaboration by creating platforms and initiatives that encourage knowledge sharing and cross-functional cooperation. • Enhance employee learning and development programs to adapt to industry changes, incorporating training on emerging technologies and digital skills. • Regularly assess and classify employee skills and competencies to identify gaps and align training and development initiatives accordingly. • Design tailored training programs that address specific skill gaps and provide employees with the necessary knowledge and expertise. • Monitor employee satisfaction and well-being more consistently through surveys, feedback mechanisms, and wellness initiatives to create a positive work environment. • Empower employees to take ownership and drive innovation within their roles by encouraging autonomy, providing decision-making authority, and supporting idea generation and implementation.
Strategy and Organization	• Establish comprehensive metrics and Key Performance Indicators (KPIs) to measure the success of innovation initiatives, allowing for data-driven decision-making and continuous improvement.
Process, Products and Services	• Further utilize open data with selected third-party developers to optimize logistics, improve supply chain management, and enhance inventory management processes.
Urban Integration	• Strengthen resilience by implementing measures to withstand internal and external adversities, such as developing contingency plans for supply chain disruptions, economic downturns, and natural disasters. • Provide assistance to employees in finding housing near the factory to enhance work-life balance and reduce commuting challenges. • Offer transportation allowances to support employees' commuting needs and reduce transportation-related burdens. • Enhance health and wellness programs for employees, including initiatives such as fitness classes, mental health support, and healthy lifestyle campaigns. • Provide childcare support to help employees balance their work and personal lives, such as on-site daycare facilities or partnerships with nearby childcare providers. • Foster a safe and inclusive workplace that promotes employee well-being and fosters a sense of community through initiatives like diversity and inclusion programs, employee resource groups, and team-building activities.

5.5 Feedback session

After performing the assessment and providing the results, along with the comprehensive analysis, to the company, a feedback session took place with the purpose of receiving feedback regarding the model and the assessment process.

Firstly, it was noted by the company representative that the maturity model was actually useful and that the results that stemmed from it could be utilized for the improvement of the factory. The entire processes flowed without any issues and the questionnaire items were clear. Moreover, the company representative explained that leadership, which is a core aspect of any firm and can affect every aspect of the operations of a company, is missing from the dimensions of the core model. Even though it is included as part of the *Strategy and Organization* dimension, it is important that the leadership is showcased more within the model. It was also highlighted that non-technological innovation should be included in the model. Innovation can generally either take the conventional form of technology driven innovation or non-technical innovation. This second form is often overlooked even though it can potentially be similarly beneficial. Non-technological innovation can specifically take the form of leadership innovation, allowing organizations to adopt new business models. As Volberda et. al. (2013) explain, as companies come across increased competition and an ever-changing technological landscape, they need to consider other forms of innovation such as the non-technological. This kind of innovation is more difficult to copy by other firms and could lead to a prolonged competitive advantage.

Moreover, it was mentioned that when utilizing assessment models, such as this, honesty is very important. The true value of an assessment can only be realized if the measurements are accurate. And since in this case the measurements are taken in the form of a questionnaire from representatives of a company, it is important that they are as honest as possible, so that they can receive an accurate assessment and therefore a more useful strategic roadmap. Finally, it was mentioned that this work could benefit if more data is available. In other words, if more companies are studied and from different sectors it is possible to acquire a diverse and large sample.

A summary of the key points from the feedback session is presented on the following table:

Table 24: Summary of the discussion points with the company representative during the feedback session of the model validation

No	Feedback Point
1	• Leadership is missing from the dimensions of the core model
2	• Non-technical innovation should be included in the model
3	• Honesty from the participating companies is essential to ensure an accurate and useful assessment
4	• This work could benefit if more data is available • Future work should focus on enriching the sample size of the companies that are being studied both in volume and diversity

6 Discussion

6.1 Model development methodology

The purpose of this work was to identify what maturity model could be utilized by companies that can be considered Urban Smart Factories (USF), to increase their profitability, sustainability and resilience. Initially, an extensive search was conducted to identify relevant approaches for maturity model development. However, it became evident that no single method precisely aligned with the unique requirements of USFs. Recognizing this gap, a decision was made to merge and adapt existing methods to devise a hybrid approach that could effectively capture the essence of USF maturity. As such, the methodology that was followed was based on a combination of the work of two different research teams. The first work was based on structured and clear steps for developing such models, however it included two extra steps (deployment and maintenance), which were out of the scope of this research. On the other hand, the second one highlighted the need to incorporate applicable knowledge from the literature in combination with the business requirements of companies within the development phase. By combining the strengths of different methods, the resulting approach aimed to incorporate the latest applicable knowledge from the literature while accommodating the specific business requirements of USFs. This integration allowed for a more comprehensive and robust maturity model development process.

6.2 Literature review

After designing the methodology approach, it was necessary to first conduct a literature review on the maturity models, which are as close to the USF concept as possible. By identifying them, it was possible to map their key dimensions, sub-dimensions and maturity levels, which are the core of such models. It was revealed that there were numerous maturity models for smart factories, and none for urban factories or urban smart factories. Smart factories (often refereed to as Industry 4.0) have gained a significant attention in the past few years, which explains the rise of such maturity models. On the other hand, the urban factory is not as a popular concept as the smart factory, and thus has not been studied to the same extent. From the smart factory maturity models identified in the literature, the eight most relevant and cited models were selected and studied in great detail. It was revealed that the maturity level are mainly 4-6 with most of them being 5, the dimensions vary from 3-7 with most of them being 4 and the sub-dimensions vary significantly from 25 to 47 with a mean being around 30. Regarding the content of these models, it was revealed that some concepts appear much more than others. For this reason, a grouping of the dimensions from these models was made. The result of this grouping was that 5 dimensions (technology, strategy and organization, workforce, process, smart products and services) appear much more than others, with a similar name or meaning. Moreover, after careful inspection of their sub-dimensions, it was also made evident that the dimensions *process* and *smart products and services* have a significant overlap.

Through the review of these models it was also made evident that several of the reviewed maturity models include the option to give a weighting (priority) to the dimensions, so that the companies that are assessed can get a more personalized analysis of their operations. The usage of such a weighting system can be problematic if not used appropriately. That is because on one hand, the company can get personalized assessment, by indicating their strategic preference on certain dimensions, but on the other hand it is possible that the assessment might hide the areas at which the company really needs to improve on. For this reason, when using such a weighting system it is crucial that the company supports its decision through clear argumentation. If the reason that the company made those choices make sense, then the weights can be incorporated into the assessment. On the other hand, if the reasons are not sufficient, then it could be possible that the areas at which the company gave a lower weight, should conversely be given extra attention.

6.3 Expert interviews: enriching the USF concept

Before developing the maturity model for the urban smart factories, it was crucial that the concept is fully understood. From the literature review, it was also revealed that only one paper has tried to combine those two concepts together (Sajadieh et al., 2022). Even though their work is a great starting point, a more comprehensive understanding and analysis of the concept is still missing. For this reason two steps were taken to fill this gap. Firstly, the USF concept was decomposed into the urban factory and smart factory and their characteristics were mapped from the literature. The smart factory concept was much more analysed in the literature of maturity modelling than the urban factory. As such, a more detailed mapping of the urban factory was created based on five key papers of the literature. The second step was to conduct semi-structured interviews with experts from the field. In total, 14 experts were approached, 7 of whom were interviewed individually, while the rest participated in a group session. The experts were either working on factories that were as close to the urban smart factory concept as possible or working in a technological consulting company and who were experts on smart manufacturing. From the interviews, the key discussion points were identified, coded and then later on incorporated into the maturity model either as sub-dimensions or dimensions.

Through these interviews, it was possible to reveal viewpoints of the urban smart factories that were not listed in the literature, thus enriching the understanding of the concept. For instance, a point that was mentioned by various participants was that the factories that are moving in the cities could increase their benefits if they form industrial clusters. The combination of the close proximity of the factories with the increased capabilities from smart solutions presents the opportunity for enhanced collaboration, efficient exchange of resources and overall optimization of the system. Secondly, novel collaboration models with the supplier and customers is crucial to help these factories succeed. Even though the relationship between those parties can vary significantly depending on the sector, a closer, more honest and cooperative relationship could lead to increased benefits for all. It was also made clear that moving factories within the city is not always an ideal solution, as there must be a clear business case for it. Being closer to the city means that there are increased rent costs which can be translated into an increased product price. In competitive markets this is not always possible however, which means that the business model might also need to change, for instance by focusing on niche markets. Finally, it was made clear by various experts that people are a key component in this equation. Even though, it is becoming less and less beneficial to have workers withing the factory, people are still crucial is setting up the systems, understanding the recommendations from the AI systems, performing maintenance and driving the innovation. Leadership especially, is a key component as it is responsible for finding innovative ways to organize the company, setup transformation teams, assign innovation "champions" and drive a cultural change. These, and many other points were discussed in the interviews, providing a comprehensive understanding of the urban smart factory concept. This enhanced understanding was subsequently integrated into both the maturity model and the assessment process.

6.4 Model development

Moving on, after mapping the information from the literature review and the interviews, it was possible to construct the maturity model. The Urban Smart Factory Maturity Model (USFMM) consists of 4 maturity levels (pilot actions, partial implementation, advanced implementation, exemplary implementation), 5 core dimensions (technology, workforce, strategy and organization, process products and services, urban integration) and 25 sub-dimensions. When structuring the characteristics of the USF concept, from the literature review concept mapping and the interview coding, into the maturity model, it was important that the sub-dimensions were mutually exclusive and collectively exhaustive. In other words, the concepts should not overlap with each other and when put together they should encompass the entire urban smart factory concept. This methodology (MECE) is often used by consulting companies to organize information, and it was also applicable in this case as well. Another consideration, when developing the model was the choice between having more or less dimensions. As mentioned earlier, the sub-dimensions in existing maturity models, varied significantly from 25 to 47. In the cases where the sub-dimensions were more than 30, the concepts became too many, and often it seemed that they could be grouped more efficiently. On the other hand, in some cases, some sub-dimensions that were identified in the models where too simplistic, making them weak for their level. As such, by having this in mind, the structuring of the dimensions and the sub-dimensions was made in a way that a balance between detail and simplicity could be achieved. This is important as the sub-dimensions are translated into the questions in the assessment, where a balance of length of the sub-dimensions is important to have a clear flow.

After having the maturity model ready, the next step, as mentioned, was to create the assessment. This was done by decomposing the sub-dimensions in clear questions that directly measure the concept in a concise manner. The questionnaire items varied in their nature, as some of them were in the form of a 5-point likert scale and others in tick boxes. The reason behind this difference was that in the case of the *technology* sub-dimension the focus was to identify which technologies are being used, and thus it made more sense to have yes/no measurement items, so that the assessment has a clearer structure. It is worth noting here that the intention behind the questionnaire was to create a self-assessment. This was partially achieved, by having a comprehensive questionnaire that can also act as a guide for a company, by identifying key areas for improvement. To add to that a generalized strategic roadmap was also created that can give directions for improvement depending on the maturity level of each dimension. The assessment could become fully self administered by incorporating it into a software solution with all the possible outcomes mapped clearly and the results to return automatically. For the purposes of this research, this final step was out of the scope, as it would be challenging to implement whilst adding little academic value.

The combination of the assessment with the maturity model can allow companies to embark on a transformation journey towards increasing the urban smart factory implementation and thus improving on its strategic goals. It should, however, be highlighted that a company that performs the assessment, which is proposed by this research, is only making its first step towards this transformation journey. In reality, the real benefit for a company would be achieved by a company that actually implements the strategic directives that are revealed through the assessment. After implementing them, the next step would be to perform the assessment again, and consequently assess if there was an improvement. As such, the maturity model presents the first step for a company to begin the process of improvement and it should be used multiple times throughout time to test whether there is an actual impact or not.

6.5 Model validation

The final step, was to validate the model with a company that can be considered an urban smart factory. The purpose behind the validation, was to perform a pilot assessment, to ensure that the process of assessment is straightforward, to investigate if there are any issues with the questionnaire and the assessment items, and to assess if the dimensions of the model are easily understood. For this reason, one company was selected, a representative from the company who knows its operations in depth was selected and the assessment was conducted. The maturity score of the company was 3.52 (or 3.63 weighted) out of five, which means it is on maturity *"Level 3: Advanced Implementation"*. Through this process it was identified that the dimensions *technology*, *urban integration* and *process, products and services* are on an excellent level. On the other hand, the *workforce* dimension is especially lacking, as it scored only 1.67/5.00 and that the *strategy and organization* dimension could also be improved. As such, a key area for improvement was the establishment of a monitoring system for employee satisfaction and well-being thought surveys or other feedback mechanisms. This could help create a positive work environment and ensure that the needs of the employees are regularly received and acted upon. Moreover, regarding the strategic vision of the company, the need for establishing comprehensive metrics and Key Performance Indicators (KPIs) to measure the success of innovation initiatives was revealed. This could enable data-driven decision-making and continuous improvement. Finally, the company could benefit from the utilization of open data with selected third-party developers to optimize logistics, improve supply chain management, and enhance inventory management processes. In summary, through the assessment, it was possible to pinpoint these, and many more, areas for improvement for the company that could not be easily identified without the assessment itself.

An assessment such as this one can only be successful and useful for the company if the information that is provided is accurate. This means, that the people that are completing the questionnaire from the company should have a strong understanding of the operations of the company that are relevant to the urban smart factory concept. For that reason, a combination of a technology expert and someone from the leadership could provide more accurate information. Moreover, it could also be beneficial if various people within the organization took the assessment. This could potentially reveal discrepancies between their answers, which could lead to a more comprehensive understanding of the company. If such differences are identified, a group session could be scheduled to discuss the differences and create a clearer image of the company.

After the assessment took place, one feedback session with the expert from the company was scheduled to discuss the results and to identify areas for improvement for the proposed maturity model. It was revealed that the *Leadership* aspect was not as prominent in the model as it should. Leadership can have a great impact on every aspect of an organization, and thus the model could benefit by incorporating it in a clearer manner. It was also discussed that non-technological innovation could be a part of the model, such as in the form of innovative organizational structures. As a response to this feedback, it is proposed that the sub-dimension "*Leadership innovation openness and change responsivity*" is strengthened by adding more questions focused on innovative leadership. For instance, the following measurement items could be included in the questionnaire: "*The company strives to incorporate non-technical innovation in its organizational structure*" or "*The company is making active efforts improve its leadership methods by using innovative methods*". Finally, as it was mentioned by various other experts, the most important aspect of such assessments is honesty. If the answers given by the company representatives do not reflect the reality, then the assessment results can not be accurate, and thus the strategic roadmap will be lacking.

7 Conclusion

7.1 Main objectives and research question

The main purpose of this research was to develop an integrated maturity and self-assessment model that can help companies that are operating within cities to assess their maturity level in implementing Industry 4.0 technologies. To answer this question a research methodology was followed that included a systematic literature review, interviews with 14 experts from the field (7 individual interviews and one group interview with 7 participants), the development of the model, and a validation with a company that can be described as an urban smart factory.

Through the literature review it was possible to map the dimensions and sub-dimensions of relevant maturity models. It was revealed that the dimensions *technology*, *strategy and organization*, *workforce process* and *smart products and services* appear in most maturity models for smart factories. To the best of the author's knowledge, although there are numerous maturity models available for smart factories, none of them specifically address the unique requirements of either the urban factory or the urban smart factory. To enrich our understanding of the urban factory concept and its integration with smart factories, it was necessary to delve deeper into the characteristics of urban factories and explore their synergies with smart manufacturing paradigms. For this reason, firstly, a mapping of the characteristics of urban factories was created through a review of relevant research papers. From this research five characteristics of the urban factory where singled out: sustainability, resilience, employee benefits, customer benefits and societal integration.

Secondly, semi-structured interviews were conducted with experts from various companies, in order to better understand the characteristics of urban smart factories and to fill the gaps of the literature. The discussion points from the literature were coded and later on integrated into the maturity model in the form of either sub-dimensions or dimensions. Some key takeaways from these interviews were that it is not always optimal for a factory to move within the city, and it depends on the industry, secondly that industrial clusters might prove to solve various issues that the urban factories face, and thirdly that new innovative business models will have to be utilized to reap the full benefits of the urban smart factories.

The information that was collected in the previous steps was used to develop the maturity model. From the maturity model, a self-assessment tool in the form of a questionnaire was designed in order to help companies assess their maturity level. The questionnaire included the option to weight the dimensions based on the strategic vision of the company; however, it should be noted that improper use of this weighting system can result in an overly favorable assessment for the company, potentially compromising the accuracy of the evaluation.

The model was validated through an implementation example, where the maturity of a factory was assessed using the developed maturity model. Following the assessment, a feedback session was conducted to gather insights and improve the model based on the obtained results. The company received the assessment results as well as a strategic roadmap to address the issues that were identified. The company's maturity score was 3.52 out of 5, indicating an 'Advanced Implementation' level. When considering the weighted score, which takes into account the strategic vision of the company, the maturity score was 3.63 out of 5. Excellent performance was observed in the dimensions of technology, urban integration, and process, products, and services. However, the workforce dimension scored low at 1.67 out of 5, highlighting a need for improvement. A key recommendation resulting from this analysis is to establish a monitoring system for employee satisfaction and well-being, and to develop comprehensive metrics and KPIs for measuring innovation success. Additionally, leveraging open data with third-party developers can offer significant benefits such as optimizing logistics and improving supply chain and inventory management. By collaborating with external developers, companies can explore innovative solutions that make use of open data, enabling more efficient and effective operations throughout the supply chain. This can involve developing applications or tools that utilize open data to streamline processes, enhance visibility, and enable real-time decision-making.

As such, with the information that was collected in the steps that were just described the main research question can be answered:

> ***What integrated maturity and self-assessment model can be developed for urban smart factories to increase their profitability, sustainability and resilience?***

Answer: The Urban Smart Factory Maturity Model (USFMM), that was developed in this study, can be used by such factories to increase their profitability, sustainability and resilience. The model consists of 4 maturity levels (pilot actions, partial implementation, advanced implementation, exemplary implementation), 5 core dimensions (technology, workforce, strategy and organization, process products and services, urban integration) and 25 sub-dimensions. All in all, the result of this work is a more comprehensive understanding of the urban smart factory concept and a subsequent creation of a maturity model based on that.

7.2 Research contribution to the field

There are two literature streams that this work builds upon. The first one is the maturity model research and the second one is the urban and smart factory research. Several maturity models have been created in the literature for smart factories however none of the urban or urban smart factories. This work aims to fill this gap. Specifically, the existing maturity models lack the urban aspect, which is described as the *urban integration* dimension in this work. This is a novel dimension in this field, and along with its sub-dimensions could prove a valuable analysis towards this field. Smart factories that are also focusing on the aspect of sustainability could utilize this concept as it incorporates the *people* and *planet* aspect. Moreover, this work is more grounded to practice when compared to the majority of papers that focus on creating maturity models. That is because this model was build and validated with the help of numerous experts who have experience with either the concept of smart or urban factories. This is in contrast with the many papers that were not validated at all. Regarding the literature streams that focus on the USF concept, this is the second work that focuses on this concept. The first one, provided an initial understanding of the concept and characterised the USF as human-centric, sustainable, and resilient. In this work, the concept was enriched with the 5 core dimensions of the maturity model, allowing for a much more detailed analysis of the concept.

7.3 Limitations and future work

The scope of this research allowed for only one validation with a company of the USFMM. Future research that builds upon this model should focus on validating the model with more companies of different sectors. To add to that, for the assessment, only one representative was asked to fill the questionnaire. It would be more beneficial to have a more diverse committee that has a multi-faced knowledge of the company, including both technology and strategy. At this point, it should be noted that, as highlighted by numerous experts, honesty emerges as a crucial limitation in such assessments. If the company representatives' responses fail to reflect the actual reality, the accuracy of the assessment results is compromised, ultimately leading to a skewed strategic roadmap.

Moreover, the next steps after the diagnosis of the transformation journey (assessment) should also be followed. This research only provides the tools for a company to perform a diagnosis and receive a strategic roadmap. However, the true value of this kind of models often emerges after the assessment takes place, particularly during the transformation journey. It is suggested, therefore, that future works with a longer duration to perform multiple assessments on one company and also try to assess how the process of transformation is evolving. Transformation is a constant process and research should also work to reflect on that. This, however, will be possible in works of longer duration (3-4) years with periodic re-assessment in order to ensure that there is an effect of the strategic roadmap on the goals of the company.

Future work could also aim on making a software solution that allows for a more sophisticated true self-assessment. With the power of current AI technologies it is possible to easily get a personalized assessment based on the answers given, thus circumventing the need for an expert to be present in the assessment. It should be noted however, that such a model should be validated with multiple companies to ensure that it is properly working and providing meaningful results.

As it was revealed through the expert interviews, the future of the urban smart factories might be the industrial cluster, where multiple companies are collaborating in a nearby location. As such, a maturity model could also be developed with this concept in mind. In this case, the process of assessment would become more difficult as it would require experts from multiple companies from a cluster. To add to that, companies might also be reluctant to share such information with other companies, and as such confidentiality agreements would need to be established. An open data scheme could in this case prove to beneficial for all the parties involved and it would facilitate the transformation process for the companies.

Finally, this work did not include metrics to measure the goals of the company that were mentioned (sustainability, profitability, resilience), as it was out of the scope. There are several such metrics that exist in the literature and it would be beneficial if they were also examined throughout the transformation process. Of course, each company might focus on different metrics based on its operations, however it would be beneficial to select some core so that the model can be validated across industries and the results that stem from it to be more generalizable.

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A Appendix

A.1 Detailed search process history

1) Factory of The Future

The first search was meant to get broad understanding of the general research theme. Initially, the search term was only "factory of the future", however it soon became evident that the same concept can be described by other terminologies. As such, these were added with an "*OR*" operator. Note that in the search term boxes that will follow, everything with comma is an "OR". If there is an "AND" operator, it will be explicitly stated.

Search Terms
"factory of the future", "industry 4.0", "factory 4.0", "smart factory", "smart manufacturing"

Number of Documents Found: 36.825

Evidently, with 36.825 documents found after 2018, the Factory of the Future and the related terms are of high research interest. However the topic was still too broad and I could not find something that was interesting and relevant yet. As such, I moved on to include the element of sustainable manufacturing to the search terms, as an "AND" condition.

Significant Papers (Smart Factory)
(Hughes et al., 2022; Jamwal et al., 2021; Javaid, Haleem, Singh, Suman, & Gonzalez, 2022; Sartal, Bellas, Mejías, & García-Collado, 2020)

2) Sustainable Smart Factory

Search Terms
"factory of the future", "industry 4.0", "factory 4.0", "smart factory", "smart manufacturing"
AND
"sustainable manufacturing"

Number of Documents Found: 1.603

These results were substantially less, however still too many to research one by one. After a quick check on some papers, it seemed that the problems encountered in these papers still varied significantly. As such, I added one more search term which was interesting for me: "urban manufacturing". With this additional search term the results were reduced to **54**, a much more manageable sample size. However, since I wanted to find a state-of-the-art paper and then understand what problems it encountered, I limited the search to papers published in the final year. The results were then reduced to **11**. After carefully reading through the papers, the one with the most citations was also the most interesting to me. The paper has already been cited by five other papers even though it was published less than a year ago.

This research led to the concept of the Urban Smart Factory (USF). The next step was to research if there was anything similar this concept in the bibliography

Significant Paper (Urban Smart Factory)
(Sajadieh et al., 2022)

3) Urban Smart Factory

In this next search the term ”Urban” is added into the search terms.

Search Terms
”factory of the future”, ”industry 4.0”, ”factory 4.0”, ”smart factory”, ”smart manufacturing”
AND
”Urban”

Number of Documents Found: 492

It was evident that no paper out of this search was conceptually relevant to the proposed paradigm by the author. To confirm that, I searched these terms alone (Urban+Smart+Factory) on both Scopus and Web of Science. The results, even though fewer, were still not conceptually similar. Therefore, the Urban Smart Factory was a new concept that had not been examined before, revealing significant potential for future research.

Based on that the next steps were the following: 1) understand the concept by reading the paper, 2) read the future research proposed by the authors, 3) search the documents that cited this article to see if the future research has already been done by someone else.

For the first step, there were two main threads that resulted in the paper by this authors: the concept of the urban factory and the smart factory. For the smart factory there was enough relevant papers from the previous searches. However the term ”Urban Factory” was still missing from my library of relevant papers. To learn more about it, I went into the key sources by the author and I also did a search on Scopus and selected the most relevant and cited papers on the Urban Factory.

Significant Papers (Urban Factory)
(Bonello et al., 2022; Herrmann et al., 2020; Liu et al., 2022; Juraschek et al., 2018; Kreuz et al., 2020)

The second step revealed that the author had four proposals for future research. Based on my background and my interests, the final two future research opportunities seemed the most interesting to me. The third step, was especially useful as it revealed that none of the five papers that cited this main paper, worked on any of the future research proposals by the author. As such, the research gap still exists: developing a maturity model or/and an assessment model for the Urban Smart Factory. Therefore, the next step was to understand what the maturity model and the assessment models were exactly and how those could be developed.

4) Maturity Models and Assessment Models

Initially, the maturity and assessment models were searched on their own.

Search Terms
“maturity model”, “assessment model”

Number of Documents Found: 2.043

It was evident early on based on the most cited papers, that these models have a usual application on the Industry 4.0 or the Smart Factory. Since this is also part of the scope of this research, the search was adjusted to include that as well.

Search Terms
"factory of the future", "industry 4.0", "factory 4.0", "smart factory", "smart manufacturing"
AND
"maturity model", "assessment model"

Number of Documents Found: 1.472

Based on the top relevant papers, a good understanding of these types of models was able to be acquired.

Significant Papers (Maturity and Assessment Models)
(Elibal & Özceylan, 2021; Neto, Deschamps, Da Silva, & De Lima, 2020; Santos & Martinho, 2020; Sari et al., 2020; Yoo et al., 2018; Rahamaddulla et al., 2021; Çınar et al., 2021; Wagire et al., 2020; Akdil et al., 2018; Sjödin et al., 2018; Gökalp & Martinez, 2021; Mittal et al., 2018)

At this point it was important to check if there were any papers that dealt with these models in the context of the Urban Smart Factory. To search that, the term "Urban" was also added.

5) Maturity and Assessment Models for USF

Search Terms
"factory of the future", "industry 4.0", "factory 4.0", "smart factory", "smart manufacturing"
AND
"maturity model", "assessment model"
AND
"Urban"

Number of Documents Found: 46

Out of these 46 papers, none developed a model related to the Urban Smart Factory. Therefore the research potential for that is still possible. More interestingly, however, another critical paper was identified in the process. The paper titled *"A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs)"* showcased a very important research gap related to the assessment and maturity models, namely that they are disconnected (Mittal et al., 2018). To confirm this finding, the following search was made, that combines the two models in the context of smart manufacturing. Even though the paper is from 2018, by reading the future papers that are related to this kind of models, it is evident that in many cases the authors still develop these models separately.

Search Terms
"factory of the future", "industry 4.0", "factory 4.0", "smart factory", "smart manufacturing"
AND
"maturity model"
AND
"assessment model

Number of Documents Found: 14

Out of these 14 papers and by going through the papers that cited this critical source (442 sources), only a few notable papers develop these models simultaneously. For instance, Cinar et al. (2021) and Rahamaddulla et al. (2021) both develop these models at the same time. Nevertheless, since there is neither a maturity nor an assessment model for the Urban Smart Factory available, a clear research gap exists to develop both these models in an integrated manner.

A.2 Detailed sub-dimension mapping based on the literature review

Table 25: Existing maturity models dimensions and sub-dimensions mapping

Model Name	Maturity Level Names	Dimension	Sub-Dimensions
Smart Manufacturing Readiness-Maturity Model for Small and Medium Enterprise (Rahamaddulla et al., 2021)	Beginner, Newcomer, Learner, Expert Leader	Machine	-
		Management	-
		Man	-
		Method	-
Maturity model for smart factory implementation (Sjödin et al., 2018)	Connected Technologies, Structured data gathering, Real-time process analytics, Smart manufacturing	People	-
		Process	-
		Technology	-
Maturity model for assessing the implementation of Industry 4.0 (Wagire et al., 2020)	Outsider, Digital Novice, Experienced, Expert	People and culture	Leadership Support, Continuous Improvement Culture, Dedicated teams, Digital skills and qualification
		Industry 4.0 awareness	Familiarity with Industry 4.0, Sensitivity towards the impact of digital transformation, Usefulness of Industry 4.0 to company, Preparedness for Industry 4.0 adoption
		Organisational strategy	Digital vision and roadmap, Customer integration, Collaboration, Zero Paper Strategy, Financial Investment, Digitalisation
		Value chain and processes	Digitalisation of Vertical value chain Real-time monitoring and control, End-to-End IT-enabled planning and steering process, Digitalisation of production equipment, Digitalisation of Horizontal value chain
		Smart manufacturing technology	Autonomous and Collaborative robots (Cobots), Software Systems like ERP, MES, CRM and PLM tools, Identifiers like Bar code, QR code or RFID and RTLS, Intelligent sensors, actuators, embedded systems and PLCs, Machine to Machine (M2M) and Human to Machine (H2M) communication, Digital platforms (DP) for supplier integration, Digital platforms (DP) for customer integration, AR, VR and MR
		Product and services oriented technology	Additive Manufacturing (AM), 3D Printing (3DP), Mobile Devices and Wearables, Blockchain Technology (BT), Smart Product
		Industry 4.0 base technology	Cloud Computing (CC) network for resource sharing, Cloud Computing (CC) network for data storing, Internet of Things (IoT), Internet of services (IoS), Big Data (BD), real-time data processing, Simulation tools, Artificial Intelligence (AI), Machine Learning (ML) and Deep Learning (DL), Industrial Cyber Security (CS)
Digital transformation capability maturity model (Gökalp & Martinez, 2021)	Incomplete, Performed, Managed, Established, Predictable, Innovating	Strategic Governance	Strategy development, Portfolio management, Project management, Financial resources and supplier management
		Information and Technology	IT strategy management, Requirement definition, Enterprise architecture development, Infrastructure management, Data governance, Agile software development, Security management, Enterprise architecture integration, Data analytics, Enterprise architecture maintenance
		Digital Process Transformation	Business process digitalization, Business process vertical integration, Business process horizontal integration, Data driven decision management, Quantitative performance management, Self optimized decision management, Business process integration toward life cycle
		Workforce Management	HR skill development, Organizational structure management, Organizational change management, Sustainable learning management

Table 26: Existing maturity models dimensions and sub-dimensions mapping (2)

Model Name	Maturity Level Names	Dimension	Sub-Dimensions
Industry 4.0 maturity model (Santos & Martinho, 2020)	Low implementation, Pilot actions, Partial implementation, Advanced implementation, Reference in applying and implementing Industry 4.0	Organizational strategy, structure and culture	Analysis of impacts of the Industry 4.0 to the company's competitiveness, Strategic management to the Industry 4.0 implementation, Investments in the technologies of Industry 4.0, Innovation management and use of technologies, Resources availability to implement the transformation actions, Focus on benefits to the clients, Collaboration with other companies of the value chain, Existence of a central coordination for the Industry 4.0
		Workforce	Existent and required skills, Skills acquisition, Equips flexibility and autonomy, Creativity and labor enrichment, Innovation openness and change responsivity
		Smart factories	Digital modelling of installations and equipment, Equipment infrastructure with embedded systems, Integrated information, communication and operation systems, Data acquisition through sensors and actuators, Autonomous equipment and artificial intelligence, Reconfigurable layouts, Utilization of mobile devices
		Smart processes	Utilization of cloud computing, Security of assets and data protection, Autonomous processes, Digital modelling and simulation of processes, Agile information share across organization, Visual computing and contextualized tasks interfaces, Data analytical capability and artificial intelligence
Maturity and Readiness Model for Industry 4.0 Strategy (Akdil et al., 2018)	Absence, Existence, Survival and Maturity	Smart products and services	Principles: Real data management, Interoperability, Virtualization, Decentralized, Agility, Service oriented, Integrated Business processes Technologies: Adaptive robotics, Data analytics, Data analytics and artificial intelligence, Simulation, Embedded systems, Communication and networking, Cybersecurity, Cloud, Additive manufacturing, Virtualization technologies, Sensors and actuators, RFID and RTLS technologies, Mobile technologies
		Smart business processes	Smart production and operations (production, logistics R&D), Smart marketing and sales operations (after sales, pricing/promotion, sales and distribution), Supportive operations (HR, information technologies , smart finance)
		Strategy and organization	Business models, Strategic partnerships, Technology investments, Organizational structure and leadership
Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises (Çınar et al., 2021)	Outsider, Beginner, Intermediate, Experienced, Top performer	Factory 4.0	Technology integration, Autonomous workplace, Data-driven services, Robotics and automation, Digital modelling, Big Data, Machine Learning, Smart Products, Product Design and Development, Communication and Connectivity, Operations:
		Logistics 4.0	Transparency, Customers, Inventory control, Supply chain, Real-time tracking, Warehouse and Storage, Automated scheduling
		Operator 4.0	Collaboration, Human resources 4.0, Governance, Operator ergonomics
		Management 4.0	Leadership and organization, Scheduling and maintenance, Investments, Finance, Data security, Intellectual property, Business models 4.0, Standards 4.0, Innovation strategy
Corporate sustainability maturity model for readiness assessment (Sari et al., 2020)	Initial stage, Managed stage, defined stage, quantitatively managed stage, optimized stage	CS driver (external)	Compliance with government and institutional regulations, Place of marketing for products/services produced, Market demand for greener products/services, Demands or pressure from external stakeholders, Support from the realisation of a government programme, Availability of information related to raw materials
		CS driver (internal)	Idea/demand for a change from the management towards the sustainability, The seriousness of an organisation to carry out sustainability, The risk of the goods produced, Supporting the capacity of human resources, Fund availability/allocation, The risk management of products/services, Philosophy/values adopted by the organisation, Appeal/benefits for internal stakeholders, Awareness of being responsible for environmental conservation, Standard of ethics and work cultures, Goals to be achieved by the organisation, Reputation/image to be built by the organisation
		CS strategy	Leader's commitment to realising the vision and mission, Leader's competence to integrate sustainability into the organisation's strategy, To adjust the organisational structure and the applied strategy, The policy made by top management to execute the strategy
		CS action	Corporate Philanthropy, Corporate Social Responsibility, Corporate Sustainable Management, Sustainable Entrepreneurship
		CS performance	Economic benefit, Environmental benefit, Social benefit

A.3 Interview summary

Interview 1: *Sales Leadership & Business Developer* at a Smart Vertical Farm

Discussion Point	Codification
Background • High costs in scaling up business (equipment, building, technology), due to certain events, made the venture not economically feasible • This lead in re-thinking how to structure the business • They developed the farm 100% (including technologies), in order to become competitive and produce against the prices of the market • Combination of technological capabilities and vertical farming, they are able to steer taste and quality of products	• High costs • In-house technology development
Advantages of urban factory • Re-use of waste streams, to be more sustainable and reduce costs • Reduction of the food mile and transportation costs • People nearby the production • Closer to the logistic centre of the retailer • Vertical farming allows less space than conventional farming	• Circular economy • Proximity to supplier/customer • Reduction in OPEX • Faster delivery time • Vertical farming - Space efficiency
Challenges of urban factory • High energy cost. Needs to be reduced • Productivity by labour needs to be improved • Productivity of autonomous manufacturing needs to be improved • Skilled people need to be secured	• High energy costs • Workforce management • Productivity by labour/machine
Dealing with the challenges • Research • Training of people • Building a community that tests everything from lab to shelf	• Collaboration • Research • People training
Effect of proximity to transportation networks, suppliers and customers on the design of the factory • Being the hub of the retailer, the value chain becomes much smaller • The retailer can become the co-owner of the farm • This allows the optimization of product assortment and optimised pricing based on the consumer demand • Little to no transportation time	• Open business model (retailer) • Short transportation time
Minimization of environmental impact • 100% renewable energy sources (solar, wind) • Cooling from the available hot and cold wells • Bio-digestor on site • Waste stream from retailers	• Renewable energy • Utilization of energy streams from the city • Utilization of waste stream
Workforce management • Within the factory people are not necessary. Minimization of the workforce in the operations is crucial. • The goal is to have an autonomous vertical farm with no people in the chambers. • The only reason to have people is when issues arise. • Mechanical engineers, software engineers and robotics engineers are necessary • The farm is steered from the city and almost everything can be done remotely	• Minimization of unneeded labour • Autonomous manufacturing • Remote control
Community engagement initiatives • Close collaboration with the local municipality and also minimalities from other countries • Collaboration with various universities from around the globe • Government is crucial to assist in the processes of the factory. For example building a digestor, which is needed for the operations, in the city is hard due to regulations	• Collaboration with local community/universities/ Municipalities • Government assistance
Technologies and processes to improve productivity • Philosophy of automatization: • Bringing the crop to the robot and not vice versa • Tailor made production • In-house development of all the technologies and devices, including updates • Dependencies on other companies might be problematic • Especially when you have different technologies that need to become integrated • Sophisticated software is not always needed • A more affordable approach. Simple can be better.	• Automation • In-house development • Less dependency on other companies • Simple software can be good enough
Future of urban smart factories • Collaboration with retailers and municipalities is key • Retailers must become more open, to have real collaboration and not just an agreement • Government needs to provide assistance to incentivize companies to come to the cities • If a nation wants to become more independent in needs to incentivize local products	• Collaboration • Open communication and stakeholder engagement • Governmental support
Pricing strategy • Capex is very important • The costs to be within the city are generally quite high • Bringing the capex down is key	• Pricing strategy is key

<u>Interview 2: Data Scientist & Tech Farmer at a Smart Vertical Farm</u>

Discussion Point	Codification
<u>Background</u> • Working on data platforms, computer vision and computer robotics • Company wants to imitate natural conditions to produce plants • Needs to provide the necessary nutrition and biological conditions • At the same time be more efficient and use less water • The farm is more of a prototype and is scaling up now	• Efficiency improvement • Prototype scaling up
<u>Advantages of urban factory</u> • Easy to access the city • Employees are closer to the factory • Customers can be reached easier • The factory can become a showroom. Collaborators and investors can come to the factory.	• Employee benefits • Customer benefits • Interactive showroom
<u>Disadvantages of urban factory</u> • Cost of rent	• Rent costs
<u>Benefits of smart manufacturing</u> • Scale up is facilitated by technology • Modularity is crucial as it allows flexibility • Smart solutions make the burden on humans less • By having the data base you can get the know-how to improve the processes. • With this knowledge potential issues can also be avoided	• Scale up using smart manufacturing • Employee benefits • Issue avoidance
<u>Examples of technologies being used</u> • Robots with camera systems and sensors • Elevators, climate and lighting control • Software cloud systems • Inhouse development of the technologies (software and hardware) • In its core it is also an engineering company • Artificial intelligence and machine learning: data management and automation can be achieved	• Robotics • Elevators • Sensors • Control • Cloud systems • Inhouse development • AI, ML
<u>Effect of smart manufacturing on quality of products</u> • Easily identifying problems in the process • Eliminating issues • Predicting demand and producing based on customer needs • Adapting marketing strategy smartly	• Issue avoidance • Predictive approach • Adaptation
<u>Innovative initiatives</u> • Factory itself is an innovation • Minimization of the environmental burden • Location does not matter as long as the inputs are available • This new production paradigm allows easy creation of new factories based on the information and techniques that have been developed • The business model revolves around collaboration with other parties but keeping the crucial information under control	• Sustainability • Resilience • Adaptability • Collaboration
<u>Workforce management</u> • Every department has their own know-how and tools • Regular meetings between the departments allows the exchange of knowledge • Training or the personnel highly depends on the department however in the beginning of onboarding happens with rotation between the departments	• Regular meetings • Tailored employee training • Inter-departmental collaboration
<u>Collaboration between departments</u> • Flat organizational structure • Involving people in multiple roles so that information can flow within the company • Teams are created to work within different departments	• Flat organizational structure • Information flow • Teams
<u>Advice for new urban smart factories</u> • Data focused solution from the start • Building a core data infrastructure and expand from that can solve many future problems • The more data that is acquired the better • By using this data with AI algorithms it is possible to improve processes • Preparing the architecture and structure of the platforms and data as well as their interconnections is crucial • This can allow much easier changing and integration of also the physical components	• Data management • Core infrastructure early • AI key • Integration and ease of scaleup
<u>Future of urban smart factories</u> • Less people	• Minimization of labour

<u>Interview 3: Leadership at a Vertical Farm</u>

Discussion Point	Codification
<u>Background</u> • Vertical farm within the city • Stopped operations some years ago due to high OPEX and CAPEX • The customers were restaurants and local facilities which closed due to the pandemic • Government could not provide the necessary assistance	• High urban costs • Local customers • Government assistance
<u>Advantages of urban factory</u> • Short chain of delivery. Lower transportation costs • Local production • Fresh products • Low economic footprint • Good marketing for the customers (restaurants) as they can pinpoint exactly where the products come from. They can also advertise that the products are sustainably produced	• Short supply chain • Low operating costs • Local production • Sustainability • Good marketing
<u>Challenges of urban factory</u> • High energy costs • Pre-built infrastructure (older building) can affect the lighting programme of the factory. The reason of using such a factory was also the unique selling proposition of utilizing existing infrastructure • Water management more difficult and expensive • Waste management difficult • Higher cost on security (personnel, cameras), due to the potential theft of equipment and produce.	• High energy costs • Challenges with pre-built infrastructure • Resource (waste/water) management issue • Security costs
<u>Design of the urban factory</u> • Older building meant small elevator which was problematic for designing the factory and transporting the equipment • Smaller farm meant higher flexibility to produce what is needed for each customer – selling point	• Flexibility • Customer benefits
<u>Effect of proximity to transportation networks, suppliers and customers on the design of the factory</u> • Depends on the business model (tailor made products vs wholesale) • Tailor made was chose for this case • Marketing advantages and product quality meant that a higher price could be placed on the produce • Being in the city was more problematic as the trucks could not be parked everywhere	• Marketing advantages • Transportation trucks issues
<u>Community engagement</u> • Organized tours • The location of the factory was within an innovative area • Through these tours new customers were acquired as they saw the benefits of the farm (special growing method, quality)	• Local community engagement • Showroom
<u>Technologies and processes</u> • Low tech farm • In-house development of the ERP system to collect some data	•
<u>Customer benefits</u> • Flexibility to produce various products based on customer needs • Fast delivery • Responding and solving issues fast (wrong produce, packaging) • Customers advertise the fact that their supplier is an urban farm that does not use pesticides • Fresh and long lasting products	• Flexibility • Short supply chain • Faster response to issues • Customer benefits for advertisement • Fresh products
<u>Collaborations</u> • Collaborated with touristic branches • Shared dinners for big companies. Acquired more customers that way • University collaborations to optimize processes	• Local collaborations • University collaborations
<u>Future of urban production</u> • There is a future • Energy prices need to be accounted for • Shift towards semi-urban environments • Slow process	• Governmental support • Urban not always optimal
<u>Other</u> • Honesty is important • It is a new manufacturing paradigm that requires new economic approach, especially when scaling up • Relationship with customers and producers is key • The location (urban) is beneficial as you can have better access to a bigger customer base near you	• Communication • Pricing strategy • Collaboration with stakeholders • Customer access

<u>Interview 4: Sales Engineer at a 3D printer manufacturer</u>

Discussion Point	Codification
<u>Background</u> • Interface between sales and engineering teams • Company is a manufacturer of 3D printers	• Background
<u>Advantages of urban factory</u> • Collaboration with suppliers and companies is much easier. This allows to surpass the higher barriers of entry in this industry • Transportation and logistics	• Collaboration with suppliers • Transportation benefits
<u>Disadvantages of urban factory</u> • Employees might face traffic	• Employee challenges (traffic)
<u>Effect of proximity transportation networks, suppliers, and customers on the design of factory</u> • Highly affects the suppliers • Assembly is happening on the factory • Mainly international customers mean that locally the benefits are not so much	• Location affects suppliers • Optimal location depends on customer location
<u>Minimization of environmental footprint</u> • There are several high tech companies on the location of the factory making it an industrial hotspot. This allows for minimization of the footprint as the plants can also share utilizes and exchange material flows.	• Technology hubs improve sustainability
<u>Customer benefits</u> • Specific industrial hub makes good marketing association for the customers • Meetings with companies and customers that are nearby are facilitated	• Industrial hub provides marketing benefits • Collaboration is made easier due to proximity
<u>Collaboration benefits</u> • Supplier with knowledge on manufacturing can be utilized instead of competed with. Sharing of information and experience can be mutually beneficial	• Coopetition for mutual benefits
<u>Community engagement</u> • Several events with companies that are nearby to promote technology and share expertise • Location is crucial and allows this kind of engagement	• Events are made easier due to location
<u>Advantages of smart manufacturing</u> • Digital inventory allows the production of any part that is needed very easily (on-demand production) • New dimension of capabilities	• Digital inventory improves flexibility and resilience
<u>Disadvantages of smart manufacturing</u> • New technology presents several issues • Resistance by conventional machine manufacturers • Trust by the customers that the product is good enough • Clients need to become aware of the capabilities	• Resistance by conventional manufacturers • Customer awareness
<u>Future of urban smart factories</u> • Hotspots of companies is the way to go to provided mutual benefits	• Industrial hotspots present benefits for the future

Interview 5: R&D Project Leader at a motor vehicle manufacturer

Discussion Point	Codification
Background • Additive manufacturing expert/ New technology scouting • Factory with a fully automated production line • Several companies involved in the projects/ Factory is in the outskirts of the city	• Background
Advantages of an urban factory • People work close to the factory • Higher quality of life • Smart factory that requires less people means that location might not be as important! • Connected to city means it can reap the benefits of transportation and networks • Better connected to suppliers and customers. • Better supply chain	• Employee benefits • Connection to suppliers and customers • Flexible supply chain
Disadvantages of an urban factory • Higher cost of location • Consumers might pay the price • In the case of this factory, space was a problem and they had to move out from inside to outside the city	• Increased urban
Customer benefits • Highly depends on the product • For cars there are no benefits • For local, proximity can be key	• Urban factory benefits depend on customer location and product
Collaboration • Many similar, additive manufacturing, companies are nearby • This allows collaboration between those companies which is usually mutually beneficial • It is also much easier and faster to fix problems if they occur • Faster response for maintenance • Collaboration projects can be organized is an easier manner	• Industrial hotspots • Collaboration between companies • Customer benefits
Minimization of environmental footprint • Low impact type of process • 100% green energy is used (taken from the grid, not produced from the factory) • The focus however is to make the processes more efficient. This can reduce the total amount of energy needed, which allows more green energy to be available on the grid • Focus in understanding the CO2 footprints • Collaboration with external partners such as universities to help achieve that • They deal with waste by re-using it! The processes allow this type of circular economy	• Process efficiency is crucial • Collaboration with universities and external partners • Circular economy processes
Community engagement • Several initiatives by the main plant that is situated within the city	• Community engagement events
Advantages of smart manufacturing • Decentralized production • Heavy and expensive machinery is not needed everywhere due to the possibilities that are enabled by additive manufacturing. These were produced centrally and distributed. Which is a big problem, especially in the case where the supply chain faces issues • With additive manufacturing one printer is enough to produce any component that is needed. Only the digital information needs to be transmitted • By just sending the data file, new or spare parts can be manufactured easily • This saves money, time and CO2 • Overall, this allows a supply chain independency and a more resilient production • This can avoid global crisis. • Not everything can be produced and not everything is perfect, however it is good enough to solve issues that come for the short term	• Decentralized production • Increased resilience and efficiency • Digital information exchange instead of physical
Disadvantages of smart manufacturing • This type of manufacturing is less established and much newer • This means that expertise is still being developed. • There are many surprises in the production. It has not been fully integrated in the industrial production • Lots of trial and error is happening to produce what is needed. Reproducibility is a core issue currently along with stability. A consistent quality is required which is not currently at the required level • Maintenance of such equipment can also be problematic	• Smart manufacturing not fully established yet • Optimization needed
Future of urban smart factories • Space issue within the cities is critical • Depends on the product, country, city and circumstances • Renewable energy needs to go into transportation • Smart factories are definitely the future • The design aspect is currently changing • We are moving towards a digital design of components and processes • Manufacturing especially with the opportunities of additive manufacturing will change the approach to production. This will allow less waste and improvement of processes. • Design freedom is key.	• Spatial issues within the urban environment • Future depends on type of product and country • Design freedom • Digital design

Interview 6: Associate Director of Digital Manufacturing & Operations at a technology consulting company

Discussion Point	Codification
Background • Experienced in product management, digitization of products, manufacturing and operations • Large scale implementation • Overseeing large projects • Industry X manufacturing expert	• Background
Essence of Industry 4.0 • Integration of the shop floor with IT • Integration of IT and OT • The utilization of information allows us to know exactly what is happening in the production area • We no longer have a black box	• Integration of IT and OT • Process monitoring and transparency
Key components of a smart factory • Learning what you are doing • Automation is one thing but now we can interpret what is happening and adjust. This allows process optimization with minimization of costs. • Automated learning • Capturing insights from the production area and translating them into actions	• Automated learning from data • Process optimization • Insights from processes that are translated into actions
Key technologies of smart manufacturing • Intelligent sensors • Edge computing • Machine learning and analytics	• Intelligent sensors • Edge computing • ML and analytics
Challenges of smart manufacturing • Security is No 1 issue, when integrating various systems • Older factories often mean that investment is needed • People adaptation is crucial • Data requires expertise to be able to assess and utilize information correctly	• Security issues • System integration • Investment problems • Employee adaptation • Digital expertise
Workforce management • People are not needed in the shop floor any more • Instead it is important to focus on where are the people needed and how can they help • More than simple analysis is need. What can we do with the data to improve the processes? • Hands-off approach to manufacturing • Job displacement issue. It is about how you frame it. Less pressure and less labour. A gradual shift.	• Minimization of manual labour • Hands-off approach • Job displacement issue
Product and process customization • Smart solutions allow a shift in the design of products, production and usability. An example is creating a custom made product much easier. This would not be possible with conventional production techniques. • Adapting the production based on supply and demand, through real time monitoring and response. • Automated quality inspections and adjustments • Less issues in the production line in general	• Product customization • Real-time monitoring and response • Automated inspection • Process optimization
Advantages of an urban (smart) factory • Closer to the workforce • Increased creativity potential through collaboration with local parties and the community	• Employee benefits • Increased creativity potential
Disadvantages of an urban (smart) factory • Logistics can be challenging but it depends on who is the customer • Environmental burden • Expanding the production can be problematic	• Logistics challenges • Environmental issues • Expansion limitation
Maturity assessment • Questions must be representative of the measurement items • Level of integration should be included	• System integration

Interview 7: Consultant of Industry X at a technology consulting company	
Discussion Point	**Codification**
Background • Experience on smart factory topics and connected plants • Helped introduce various smart technologies into factories such as virtual reality, augmented reality and Internet of Things • Assisted in joining the data that come from different platforms and systems. Main goal was to gain value out of the data and break the silos (wall between data platforms)	• Background
Industry 4.0 essence • Using digital solution to generate data with the end goal of becoming more efficient, sustainable, with less waste, increased profits and people benefits (safer processes) • Using physical technology to get the right information (data) and transforming it to digital information that can be assessed to give specific action for the operations of the plant.	• Digital solutions to improve efficiency, sustainability and safety • Connection between physical technology and digital to make informed actions
Key components of a smart factory • IT architecture is the core foundation • Internet network of the company to send, store and access the right information • Physical components of the factory (IOT sensors, PLCs, etc.) • Digital application that can structure the data and give actionable insight to provide better solutions. High-tech solutions can be based on this digital platforms to provide value • Decision making and response layer is the final step on using the information of the real world, through the utilization of advanced solutions such as ML and AI	• IT architecture • Internet network • Physical components • Digital application • Decision making and response layer • ML and AI
Benefits of smart manufacturing • Three core benefits based on sustainability • People • Planet • Economic • All of those mean higher quality of products, with less waste, more efficient processes, less downtime and more importantly safer for people	• Sustainability • Process optimization • Safety
Challenges of smart manufacturing • Technology perspective: not the right foundation can create inaccessible data (siloed) • People perspective: on the operational level the transition to smart manufacturing might be hard as the right skillset might not be present. The change to smart manufacturing means that less people are necessary, which is problematic for the current employees especially if the company wants to undergo such a transition • Strategic perspective: there must be a clear business case to make such a change. If the benefits are not clear and are not clearly communicated to the right people within the organization, then the change cannot happen easily • Information overload: the smart manufacturing can be a very tough processes even for large companies. For example the full transition of a factory to a digital twin can be extremely difficult to actually implement	• Siloed data • People digital skillset • Strategic difficulties • Clear communication • Information overload
Workforce management and Job displacement • There must be a clear value case for this to happen. • The operators must actually be encouraged to embrace the change • It is not about the money for the operator, but how this can be translated to their actual benefit • And this can mean an improvement to their everyday life such as a safer and easier job • It is also crucial to set champions of the smart technology so that they can actually utilize it and share it to the other employees • A more bottom up approach might be optimal in this case • The training must become different to adapt to the new circumstances • The approach should be to encourage the employees to embrace the change as it can also be beneficial for them	• Clear value case • Clear communication of benefits to facilitate transition • Employee benefits (safety, easier job) • Technology champions • Bottom up approach • Training
Fostering inter-departmental collaboration • The approach should start by being top-down. Questions like: what do we want? or What value is this change going to bring? Are crucial in the initial stages • Then a roadmap of specific goals in the following years must be created. The roadmap must include goals for different departments along with how these should be implemented. An alignment with the departments to achieve those goals begins at this point • The next step is the setting up of the transformation team. This includes a specific set of people who will be in charge of the change and drive it. This change management team can actually become the bridge between the groups to help foster collaboration and communication. • Communication strategy is also key at this point as to not discourage operators in the change. Setting up a theme around the change might be beneficial. • As the maturity is increasing within the company, there will be a need to change the structure of the company such as the teams and the departments. This restructuring is necessary to help break the silos and the information barriers within the company.	• Top doen approach • Strategic roadmap • Department alignment • Transformation team • Inter-departmental collaboration • Communication strategy • Restructuring of company • Championing • Fully integrated digital twin

• Championing the projects is also a key bottom-up approach that could be implemented. Since the people in the floor know most about the problems and the issues in the factory they can help come up with ideas and solutions for change • The end goal could be a fully integrated digital twin that has complete connection with the factory.	
Advantages of urban factory • Employee benefits regarding transportation from and to work • Important in changing the view that factories are dirty and unsustainable • Examples such as vertical farms could be beneficial in that sense. Heavier industries such as steel manufacturing might not be the best • The perception of citizens about production could thus be improved in that sense	• Employee benefits (transportation) • Negative citizen perception of factories
Disadvantages of urban factory • Space is the major issue. Factories are being pushed out to the edges of the city as there is no actual space for them • Reactions of the people might negatively affect this transition and should be engaged in an appropriate manner so that they don't become barriers • Electricity network might not be able to support the entrance of a high consumption factory	• Urban spatial limitation • People perceptions • Limitation of electricity network
Future of urban smart factories • The way to go is towards smart and sustainable factories. • Probably building vertically can solve the space issue. • In many cases there is no business case for a factory to be placed within the city. On the other hand if the suppliers and the customers are local then it might make sense. • The factories could potentially add value to the city and become a strong pillar that supports it	• Vertical building • Urban vs rural depends • Factories as pillars of the city

Interview 8: Group Session (with 5 Technology Experts & 2 Industry X Interns) at technology consulting company

Discussion Point	Codification
• Clearly define the goals in the research question (competitiveness and sustainability).	• Main research question clarity
• Measurement items in the questionnaires are crucial. Questions should be clearly defined and representative of the corresponding measurement items.	• Questionnaire questions clarity
• Supporting technology with IT and smart manufacturing with OT are not completely exclusive. Suggestion to split between supporting IT, supporting/base OT and smart OT. • IT and OT seem unclear	• Technology dimension improvement
• Is inter-team collaboration captured under "Dedicated teams"? • Add employee Satisfaction sub-dimension • Add employee well-being sub-dimension • Skills and learning overlap. If the difference is between current skills and vision for the future, maybe rename sustainable learning management something with vision/strategy. • Sustainable confusing • Dedicated teams, Digital skills and qualification, Sustainable learning management a bit unclear	• Workforce dimension improvement
• Add Innovation Pipeline sub-dimension • Add Continuous improvement sub-dimension • Add organisation, like governance and capabilities, dimension	• Strategy and Organization dimension improvement
• No comments	• Process, products and services dimension improvement
• Restate employee benefits • Put resilience in process dimension • Specify sustainability with environmental sustainability	• Urban Integration dimension improvement

A.4 Codification for designing the sub-dimensions

Table 27: Usage of codes for designing the sub-dimensions

Dimension name	Sub-dimension name	Codes from interviews
Technology	Information technologies and connectivity	• Remote control • Core infrastructure early key • Process monitoring and transparency • IT infrastructure is core / internet network • Avoid siloed data
	Physical systems	• Autonomous manufacturing • Scale up using smart manufacturing • Robotics, Elevators, Sensors, Control • Cloud systems, Inhouse development • Intelligent sensors • Edge computing • Physical components core
	Data analytics	• AI, ML • Predictive approach • Adaptation • Data management • Automated learning from data • Process optimization • Insights from processes that are translated into actions • Digital application to connect • Decision making and response layer • Prevent information overload
	Digital twins and simulation	• Focus on automation • Digital solutions to improve efficiency, sustainability and safety • End goal - Fully integrated digital twin
	Integration and interoperability	• Efficiency improvement • Key aspects • Smart manufacturing not fully established yet • Optimization needed • Integration of IT and OT • Security issues • System integration • Connection between physical technology and digital to make informed actions
Workforce	Continuous improvement culture	• People training • Employee adaptation • People digital skillset needs to be improved • Bottom-up approach
	Teams and collaboration	• Regular meetings • Inter-departmental collaboration • Teams • Department alignment • Transformation team
	Digital skills and qualification	• Minimization of unneeded labour • Tailored employee training • Digital expertise is a new requirement
	Workforce management	• Challenges • Productivity by labour/machine • Minimization of labour • Hands-off approach • Championing innovations
	Leadership innovation openness and change responsivity	• Job displacement issue • Communication of benefits of SM (safety, easier job)

Table 28: Usage of codes for designing the sub-dimensions (2)

Dimension name	Sub-dimension name	Codes from interviews
Strategy and organization	Technology investments	• Simple software can be good enough • Investment issues for upgrading infrastructure • Clear value case
	Innovation pipeline	• Research • In-house development benefits • Less dependency on other companies
	Strategic collaborations	• Collaboration (local) • Open business model • Collaboration with local community/universities/ Municipalities • Government assistance • Industrial hub • Coopetition • Strategic difficulties in implementation
	Industry 4.0 Awareness	• Awareness
	Governance and capabilities	• Flat organizational structure • Resistance by conventional manufacturers • Clear communication is key • Top-down approach • Strategic roadmap • Restructuring of company • Innovative leadership
Process, products and services	Smart products	• Digital inventory • Digital information exchange instead of physical • USF future depends on type of product and country • Design innovation and freedom • Product customization • Automated inspection
	Interoperability	• Asset integration is crucial • Real-time monitoring and response
	Integrated Business processes	• Reduction in OPEX • Smart marketing • Challenges with pre-built infrastructure • Industrial hotspots present benefits for the future
	Value chain processes	• Proximity to supplier/customer • Faster delivery time • Short transportation time • Pricing strategy is key • Decentralized production • Logistic challenges
	Digital platforms	• Process efficiency is crucial • Increased creativity potential

Table 29: Usage of codes for designing the sub-dimensions (3)

Dimension name	Sub-dimension name	Code from interviews
Urban integration	Sustainability	• Circular economy • Space efficiency • Utilization of energy streams from the city • Rent costs • Environmental issues for an UF
	Resilience	• Renewable energy • Utilization of waste stream • Resource utilization(waste/water) • Security issues • Increased resilience and efficiency • Expansion limitations for UF / Spatial limitations • Limitation of electricity network
	Employee benefits	• Easier access • Flexibility • Transportation benefits / traffic issues
	Customer benefits	• Closer • Local • Faster issue response • Advertisement benefits • Depending on location might make urban not optimal • Awareness
	Societal integration	• Open communication and stakeholder engagement • Interactive showroom • Local community engagement • Industrial hub for sustainability and collaboration benefits • Event scheduling • Negative citizen perception of factories • Factories as pillars of the city

A.5 Self-assessment: Questionnaire

Opening Statement

You are being invited to participate in a Master's thesis research study titled "Integrated Self-Assessment and Maturity Model for the Urban Smart Factory". This study is being conducted by the student Konstantinos Dimitriou, supervised by prof. Paola Ibarra Gonzalez and prof. Anneke Zuiderwijk van Eijk from the TU Delft.

The purpose of this research study is to develop a maturity model for factories that can be described as "Urban Smart Factory". A maturity model is a framework for measuring an organization's maturity, with maturity being defined as a measurement of the ability of an organization for continuous improvement in a particular discipline. As part of the validation of the model we are asking you to perform the maturity assessment by using the provided questionnaire. The assessment will take you approximately 15 minutes to complete. We will be asking you to provide information regarding the operations of the company. This information will be used to assess the maturity level of your company in relation to its goals. The data will be used for the master's thesis and will be published at the TU Delft Educational repository.

To the best of our ability, your answers in this study will remain confidential. The following measures will be followed to minimize risks:

- The survey is anonymous.
- Personal research data (name and e-mail addresses) will be used for administrative purposes only, will not be shared and will be destroyed after the end of the research project.
- The name of the company will be kept anonymous, and information that could lead to its identification will be kept vague. Specifically, only the general area of expertise of the company will be mentioned.
- Anonymised data (the answers of the questionnaire) will be shared with others, as part of the thesis in the TU Delft Educational repository.
- All the data collected will be safely stored and backed-up only in TU Delft approved databases.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. Your data provided can also be withdrawn within one month after completing this questionnaire.

By answering this questionnaire, you agree to this Opening Statement.

Concept Introduction

The questionnaire is structured around five key dimensions. Below you can find a brief explanation of the concepts:

No	Dimension Name	Description
1	Technology	The development, implementation, and integration of advanced technologies and solutions to drive innovation and competitiveness.
2	Workforce	The focus on building a strong and adaptable team that can effectively implement Industry 4.0 technologies and initiatives
3	Strategy and Organization	A forward-thinking approach to leveraging cutting-edge technologies and partnerships to drive innovation, optimize processes, and enhance competitiveness in the rapidly evolving Industry 4.0 landscape.
4	Process, Products and Services	The vision and actions towards operational efficiency, enhancing customer satisfaction, and creating new value streams through the implementation of innovative and integrated solutions, which provide seamless connectivity and collaboration across the entire product development and production lifecycle.
5	Urban Integration	The integration of the factory with the urban environment and the society. It includes characteristics such as sustainability, resilience and a human-centred approach.

Dimension Priority

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The company gives high priority to the "**Technology**" dimension.	○	○	○	○	○
The company gives high priority to the "**Workforce**" dimension.	○	○	○	○	○
The company gives high priority to the "**Strategy and Organization**" dimension.	○	○	○	○	○
The company gives high priority to the "**Process, Products and Services**" dimension.	○	○	○	○	○
The company gives high priority to the "**Urban Integration**" dimension.	○	○	○	○	○

In case the answers in the previous five items are **not** the same, in order to help make a personalized maturity assessment, please give a brief explanation in the box below,:

Assessment

1. Technology

1a	The company is using the following information technologies:	Base network architecture	☐
		Communication protocols/data transmission systems	☐
		Cloud computing/Edge computing	☐
		Encryption/Data security measures/Malware protection	☐
		Access authentication measures/access control	☐
		Network segmentation (to improve performance and security)	☐
		Regular software patch management	☐
		Intrusion detection and prevention systems (IDS/IPS)	☐
		Enterprise resource planning software (for finance, human resources, manufacturing, supply chain, services, procurement etc.)	☐
1b	The company is using the following physical systems and technologies:	Sensors (for monitoring)	☐
		Identifier QR/Bar-codes/RFID (to facilitate operations)	☐
		Industrial robots	☐
		Autonomous collaborative robots (Cobots)	☐
		Autonomous guided vehicles	☐
		Additive manufacturing (3D printing) for processes/machine parts	☐
		Automated material handling systems	☐
		Intelligent sensors (that use advanced signal processing techniques, data fusion techniques, intelligent algorithms, and artificial intelligence)	☐
1c	The company has adopted the following data analytics methods:	Data visualization	☐
		Process optimization based on collected data	☐
		Supervisory Control and Data Acquisition (SCADA) systems	☐
		Artificial Intelligence	☐
		Machine Learning/Deep Learning (for process optimization and automated learning)	☐
		Big data analytics (to collect and analyse data enabling it to make real-time decisions and optimize their operations for efficiency and productivity)	☐
		Predictive maintenance (to minimize downtime)	☐
1d	The company has adopted the following simulation and digital twin methods:	Simulation software	☐
		3D modelling of processes	☐
		Virtual reality applications	☐
		Augmented reality applications	☐
		Fully implemented digital twin (to monitor the operations and optimize processes in real time)	☐
1e	The company is using the following technologies to integrate and interoperate seamlessly within the smart factory environment:	Application programming interfaces (APIs)	☐
		Internet of things (IoT)/ Internet of Services (IoS)	☐
		Machine to machine communication	☐
		Human to machine communication	☐
		Automated manufacturing	☐
		Interoperability standards	☐
		Middleware or integration platforms	☐

2. Workforce

		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
2a	The company invests in employee training and development.	○	○	○	○	○
	The company has a structured process for collecting and analysing feedback from its employees.	○	○	○	○	○
	There is a strong emphasis on measurement and accountability, with regular progress reports and KPIs used to track and evaluate performance.	○	○	○	○	○
2b	There are dedicated teams in the company to drive innovation and digitalisation across the organisation.	○	○	○	○	○
	The company utilizes innovation "champions" who dedicate themselves to promoting a change, such as implementing a new intervention or quality improvement effort.	○	○	○	○	○
	The company is making significant efforts to promote inter-departmental and inter-team collaboration.	○	○	○	○	○
2c	The company is making efforts to align employees' digital skills and qualifications to adopt Industry 4.0.	○	○	○	○	○
	The company manages employee learning and development in a way that is adaptable to changes in the industry.	○	○	○	○	○
2d	The company regularly identifies and classifies the skills and competencies of its employees.	○	○	○	○	○
	The company designs tailored training programs for its employees.	○	○	○	○	○
	The company regularly monitors employee satisfaction and well-being.	○	○	○	○	○
	The company minimizes the workforce needed for labour intensive processes.	○	○	○	○	○
2e	The company prioritizes forward-thinking and agility in its business practices making it quick to adapt to changes in the market or industry.	○	○	○	○	○
	The company is open to taking risks to be competitive.	○	○	○	○	○
	Leadership within the company focuses on empowering employees to take ownership of their work and drive innovation within their roles.	○	○	○	○	○

3. Strategy and Organization

		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
3a	The company's has a high level of investment in new Industry 4.0 technology development or acquisition.	○	○	○	○	○
3b	The company has a digital vision and roadmap for Industry 4.0.	○	○	○	○	○
	The company has an innovation pipeline in place to generate new ideas, test them and bring them into the market.	○	○	○	○	○
	The company has established metrics to measure the success of innovation initiatives.	○	○	○	○	○
3c	The company is collaborating with external organisations (e.g. with Industry 4.0 solution providers, consultants, suppliers and academia) to embrace Industry 4.0 and reap its benefits.	○	○	○	○	○
3d	The concept Industry 4.0 is understood within the company and its benefits are known.	○	○	○	○	○
3e	The company has a clear governance structure in place to oversee and manage smart factory initiatives.	○	○	○	○	○
	The company fosters collaboration between employees and partners, encouraging the exchange of ideas and knowledge.	○	○	○	○	○

4. Process, Products and Services

		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
4a	The company develops and incorporates intelligent, connected, and data-driven products for enhanced customer experience.	○	○	○	○	○
	The products can be tracked and monitored, to manage the life cycle of the product.	○	○	○	○	○
4b	The company demonstrates seamless integration and communication between its various digital systems, devices, and platforms.	○	○	○	○	○
4c	The data that is collected from the company is utilized to create hypothetical scenarios, taking into account various influencing factors, to build predictive models that aid in making informed business decisions.	○	○	○	○	○
4d	The company demonstrates a high degree of digitalisation from the product development phase (computer-aided design (CAD) and simulation software) to the production phase (computer vision to automate quality control and testing processes).	○	○	○	○	○
4e	The company uses connected digital platforms to incorporate the requirements and preferences of both its customers and suppliers into its product development and production processes.	○	○	○	○	○
	Open data are utilized with selected third-party developers, so that logistics are optimized and inventory management processes are improved and efficiency is improved.	○	○	○	○	○

5. Urban Integration

		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
5a	The company is committed to using energy and resource-efficient manufacturing processes.	○	○	○	○	○
	The company has adopted a circular economy approach by designing products and services for reuse and recycling.	○	○	○	○	○
	The company organizes or promotes educational and awareness campaigns among its stakeholders.	○	○	○	○	○
5b	The company is built on a foundation of resilience, with the ability to withstand internal and external adversities such as supply chain disruptions, economic downturns, and natural disasters.	○	○	○	○	○
	The company has a flexible manufacturing processes that allow for quick adaptations to changing market conditions, customer demands, and unforeseen events.	○	○	○	○	○
	The company leverages dynamic scheduling to optimize production and resource allocation in real-time, ensuring the efficient use of its assets and minimizing downtime.	○	○	○	○	○
5c	The company offers to its employees assistance in finding housing near the factory.	○	○	○	○	○
	The company offers to its employees flexible work schedules.	○	○	○	○	○
	The company offers to its employees transportation allowances.	○	○	○	○	○
	The company offers to its employees' health and wellness programs.	○	○	○	○	○
	The company offers to its employees childcare support to help employees balance their work and personal lives.	○	○	○	○	○
	The company provides a safe and inclusive workplace that promotes employee well-being and fosters a sense of community among its workforce.	○	○	○	○	○
5d	The company offers its customers a range of customizable product options.	○	○	○	○	○
	The company offers its customers personalized customer service.	○	○	○	○	○
	The company's factory environment is designed to provide customers with an immersive experience, with features such as interactive showrooms, factory tours, and opportunities to observe the manufacturing process.	○	○	○	○	○
5e	The company collaborates with local community groups and organizations to support social initiatives such as education and workforce development, environmental conservation, and community engagement.	○	○	○	○	○
	The company offers employment opportunities and economic benefits to the local community, contributing to the growth and development of the surrounding area.	○	○	○	○	○