Designing a Maturity Model for Industry 4.0 in conjunction with Enterprise Architecture

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Thesis Report

Designing a Maturity Model for Industry 4.0 in conjunction with Enterprise Architecture

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Abstract

This thesis has developed the EAI4.0 Maturity Model, a maturity model with the aim to guide organizations in maturing in Industry 4.0 and Enterprise Architecture. The model can be used to assess maturity, while also providing guidance through a dedicated roadmap. The maturity model is designed as a focus area-oriented maturity model, where each focus area has its own maturity development path balanced against the other areas. The method of design science research was utilized to design the maturity model. A systematic literature review was conducted to extract focus areas relevant to the combination of Industry 4.0 and Enterprise Architecture from the literature. Subsequently, multiple validation rounds were performed to verify the model's definitions and dependencies between focus areas. To evaluate the model on, among others, fidelity with practice and ease of use, assessments of twelve organizations were taken and discussed during a final round of interviews. In general, the evaluation of the EAI4.0 Maturity Model and corresponding assessment was found to be positive. Furthermore, a significant positive relationship was found between maturity in the EAI4.0 model and general digital transformation maturity. This research contributes to practice by providing a holistic assessment and concrete roadmap for organizations that aim to mature in Industry 4.0 and Enterprise Architecture. The EAI4.0 model contributes to the literature by filling the research gap on artifacts able to combine and provide guidance in improving Industry 4.0 and Enterprise Architecture

Keywords: Industry 4.0, Enterprise Architecture, Maturity Model, Assessment Model

Executive Summary

Introduction

Organizations are currently in the middle of their digital transformation toward Industry 4.0, which revolves around cyber-physical systems and the Internet of Things (IoT) (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014). Examples of these technologies are, among others, cloud computing, the use of Big-Data analytics, the Internet of Things, virtual & augmented reality, and cybersecurity (Bierhold, 2018). These innovations require efforts in the technical domain, as well as in corresponding business processes, and are therefore heavily affecting the way enterprises operate (Xu, Xu, & Li, 2018). When businesses implement Industry 4.0 technologies as part of their digital transformation, the facilitating IT landscape and consequently the enterprise's business and information architecture are influenced (Lu, 2017; Gampfer, Jürgens, Müller, & Buchkremer, 2018). Enterprise architecture is indicated in the literature as a means to guide organizations in such digital transformation efforts (Gampfer et al., 2018). Therefore, research suggests that the realization of Industry 4.0 transformation and integration throughout the business can benefit greatly from Enterprise Architecture (Xu et al., 2018). However, through literature, a research gap has been identified which claims that research on growth and guidance is missing within the combinatory domain of Industry 4.0 and Enterprise Architecture (Nowakowski, Häusler, & Breu, 2018). To fill the distinguished gap in the literature, the goal of this thesis is to develop a maturity model which can guide companies in their transformation towards Industry 4.0, by combining Industry 4.0 with the use of Enterprise Architecture. More specifically, a focus area-oriented maturity model is created, which is different from other types of maturity models in that each focus area has its own maturity development path that is balanced against the maturity development paths of the other focus areas, which is deemed especially useful for the guiding properties of the model (van Steenbergen, Bos, Brinkkemper, van de Weerd, & Bekkers, 2010). The research objective of this thesis is as follows: *"The development of a maturity model which can guide companies in their transformation towards Industry 4.0, by combining Industry 4.0 with the use of Enterprise Architecture."*

Research design

The method of design science research was utilized to design the maturity model. First, a systematic literature review was conducted to extract focus areas relevant to the combination of Industry 4.0 and Enterprise Architecture from the literature. Next, a first round of interviews validated the correctness and completeness of these focus areas, which prompted the number of focus areas to change from twenty to fourteen. The maturity levels for each focus area were derived as a combination of literature and results from the first round of interviews, and were altered to fit better with Industry 4.0 and the four established general maturity levels definition. Next, a validation round with content experts verified the definitions, after which two focus group sessions derived the dependencies between the focus area maturity levels. Lastly, assessments of twelve organizations were taken and discussed during the last round of interviews, with the goal of evaluating the usability and effectiveness of the model.

EAI4.0 Maturity Model

The goal of the EAI4.0 maturity model is to guide companies in the digital transformation through Industry 4.0 through the use of Enterprise Architecture. Industry 4.0 projects and applications require the integration of technological implementations into the existing infrastructure of the company, which can be achieved by Enterprise Architecture.

The EAI4.0 maturity model is structured as a focus-area oriented maturity model, consisting of fourteen focus areas relevant to the implementation and growth of Industry 4.0 and Enterprise Architecture. Each focus area contains four subsequent levels of maturity, ranging from the first stage of 'performed', to the final stage of 'optimized'. This leads to 56 focus area maturity levels that a company can achieve. Every level contains a handful of requirements to reach this level, including a couple of best practices to do so. Fourteen focus areas have been identified in this research, and make up the structure of the model. All focus areas can be found in the first column of Figure 1. Table 1 highlights the information present in the model for the 'Performed' maturity level of the 'Alignment' focus area, for which the remaining 55 focus area maturity levels can be found in section 4.5.

Focus area definition	Best practices	Requirements	Questions
An understanding of Industry 4.0 and Enterprise Architecture within the company is present, based on business goals. The current situation is known, and a future plan has been drafted regarding the "why" and "what" of Industry 4.0 and Enterprise Architecture.	- A fully integrated strategy and vision are not required here, but make sure a basic view is present for where your organization wants to go. - Business should be the driving force, not the technology.	- Understanding of I4.0 & EA in business - Known current situation - Future plan for I4.0 and EA	1.Does your company have an understanding of how Industry 4.0 and Enterprise Architecture should look in your company, based on business goals? 2.Is the current status regarding Industry 4.0 and Enterprise Architecture within the company known? 3. Has a plan been drafted regarding the 'why' and 'what' of Industry 4.0 and Enterprise Architecture?

Table 1: Maturity Model content for the Performed level of the Alignment focus area

An organization's maturity in the EAI4.0 Maturity Model is assessed through a questionnaire containing 115 questions, one for each requirement. An exemplary assessment can be found below in Figure 1, showing fully completed maturity levels per focus area in dark green, partly completed in light green, and nothing completed in white. The X's in the model highlight the identified dependencies between the maturity levels, which can guide the company in what levels to achieve first as they are deemed prerequisites to others.

As a direct result of the assessment a roadmap can be derived which highlights what requirements need to be achieved in what order, based on the dependencies. These requirements are highlighted in red in Figure 1 and aim to fulfill the element of guidance of the model.

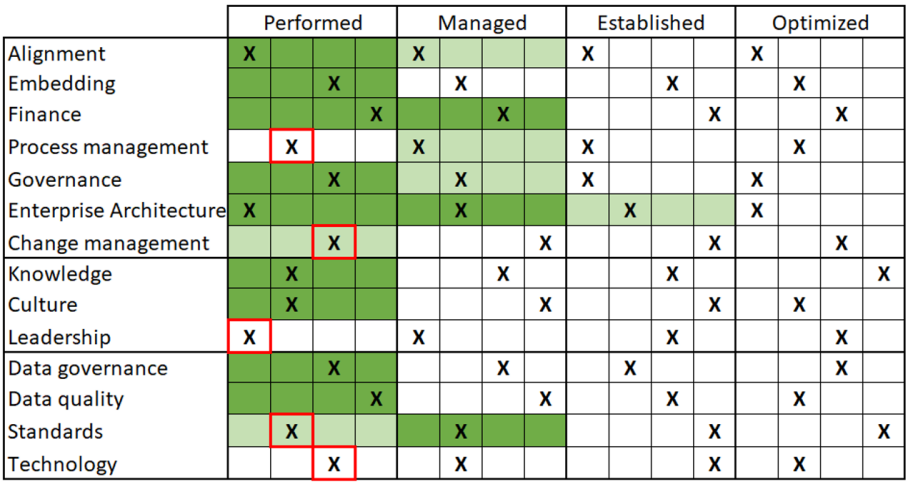

Figure 1: Example maturity assessment

Evaluation of the model

In general, the EAI4.0 Maturity Model, the assessment, and the corresponding roadmap were evaluated positively by participants in the final round of interviews, both on a content level as well as on a thought-provoking level. Across all participants, the maturity assessment per focus area was evaluated to be perfectly in line with the real situation 72% of the time, with only one participant indicating one focus area to be 'not at all' in line. Therefore, we conclude that the 'fidelity with practice' of the model is evaluated positively. The 'perceived usefulness', 'perceived ease of use', and 'intention to use' of the model were evaluated through a Technology Acceptance Model questionnaire on a Likert scale ranging from 1 to 5. These criteria were evaluated across all participants with average values of 3.97, 3.69, and 4.33 respectively, and are therefore concluded to be positively evaluated. Some participants indicated that specifically the concrete actions combined with the storyline presented to them during the roadmap section of the interview insured their intention to actually utilize the model to improve their maturity. Lastly, participants were asked to grade their organization's general digital transformation maturity, as opposed to the maturity in our model. The correlation results and significant effect found between these two variables suggest that organizations that are more mature in the digital transformation, in general, tend to be more mature in the Industry 4.0 and Enterprise Architecture domain. However, due to the low number of participants, we cannot conclusively positively evaluate the generality of the EAI4.0 Maturity Model such that our model comprising an element of the digital transformation is generalizable to the digital transformation as a whole.

Conclusion

Overall, we conclude that the main research objective of this thesis has been successfully achieved, both through the achievement of the solution objectives and through the overall positive evaluation of the artifact mainly during the last round of interviews. This research contributes to the academic literature on Industry 4.0 maturity, the connection between Industry 4.0 and Enter-

prise Architecture, and maturity models in general by holistically combining the two domains and responding to the demand for a model able to guide organizations through the assessment and roadmap. This research contributes to practice by identifying all relevant focus areas surrounding Industry 4.0 and Enterprise Architecture, combined with concrete requirements and best practices to mature in these areas. To verify the long-term effect of the model on an organization's maturity, future research might track an organization utilizing the model over a longer time period. Moreover, the evaluation results suggest notable differences between different industries, which further validation of the model should examine. Additionally, future research might explore a different way of gathering the assessment data, possibly through a workshop setting, to improve the quality of the assessment. Lastly, the addition of a temporal element to the maturity model is seen by the researchers as the end goal of the model, where through intensive data collection a fully detailed planning outline could be made possible to increase the level of guidance.

Preface

Firstly I would like to thank my supervisor Banu Aysolmaz for her guidance and knowledge these past months, which greatly helped me in not only maturing the model itself but also my own academic skills. Moreover, Banu always provided me with detailed feedback in a very short time span which gave me the opportunity to refine every step of the process. Also, I would like to thank Sybren de Kinderen and Baris Ozkan for their feedback and knowledge.

Secondly, I would like to thank my supervisor from Atos, Hans van Drunen, for his expertise and guidance. Hans inspired me to embrace the subject of Enterprise Architecture while contributing greatly with his knowledge to reach our end goal of a guiding maturity model. Also, I would like to thank Atos for always providing the required resources when requested.

Lastly, I would like to thank all participants that contributed to my thesis through either the interviews or the focus group sessions, without whose knowledge the end result would not have been possible.

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List of Acronyms

I4.0	Industry 4.0
EA	Enterprise Architecture
ADM	Architecture Development Method
AI	Artificial Intelligence
CMM	Capability Maturity Model
CPS	Cyber-Physical System
DYAMM	DYnamic Architecture Maturity Matrix
ERP	Enterprise resource planning
IOT	Internet Of Things
IT	Information Technology
KPI	Key Performance Indicator
OT	Operational Technology
PLC	Product Lifecycle Management
PLS-SEM	Partial Least Squares Structural Equation Modelling
RAMI4.0	Reference Architecture Matrix Industry 4.0
SME	Small and Medium-sized Enterprise
TAM	Technology Acceptance Model
TOGAF	The Open Group Architecture Framework

1 Introduction

Industries were revolutionized firstly by mechanization, then by mass production, and finally, by computer automation. We are now in the middle of the fourth iteration of the industrial revolution: Industry 4.0, which revolves around cyber-physical systems and Internet of Things (IoT) (Lasi et al., 2014). Around the world, companies are going through digital transformations to evolve and remain competitive as an enterprise, with varying success (Holzhauser & Schalla, 2016). Especially in the traditional manufacturing industries, businesses are racing to implement the newest technologies and solutions that are fundamental to Industry 4.0 (Chehri, Zimmermann, Schmidt, & Masuda, 2021). Examples of these technologies are, among others, cloud computing, the use of Big-Data analytics, Internet of Things, virtual & augmented reality, and cybersecurity (Bierhold, 2018). These innovations require efforts in the technical domain, as well as in corresponding business processes, and are therefore heavily affecting the way enterprises operate (Xu et al., 2018).

Developments regarding Industry 4.0 bring numerous challenges in various areas (Cohen, Faccio, Pilati, & Yao, 2019). New technologies lead to integration issues within the current Information Technology (IT) architecture like, for example, differences in master data between legacy and new systems (Xu et al., 2018), but also bring problems regarding domain knowledge of employees or struggles with budget and security (Benešová, Hirman, Steiner, & Tupa, 2019; Marzano & Siguencia, 2021). Challenges are encountered both by large enterprises and by SMEs but differ in content and in the means to deal with them (Matt & Rauch, 2020; Dallasega, Woschank, Zsifkovits, Tippayawong, & Brown, 2020). Therefore, the digital transformation towards efficiently using Industry 4.0 is seen as a substantial challenge in the decades to come (Bauer, Hämmerle, Schlund, & Vocke, 2015).

When businesses implement Industry 4.0 technologies as part of their digital transformation, by introducing new technologies with the aim of modifying and improving their business to meet changing business and market requirements (Ebert & Duarte, 2018), the facilitating Information Technology (IT) landscape and consequently the enterprise's business and information architecture are influenced (Lu, 2017; Gampfer et al., 2018). Enterprise architecture is indicated in the literature as a means to guide organizations in such digital transformation efforts (Gampfer et al., 2018). Enterprise Architecture is defined by Wagter, van den Berg, Luijpers, and van Steenbergen (2005) as a consistent set of rules and models that guide the design and implementation of processes, organizational structure, information flows, and the technical infrastructure within an organization. The introduction of new technologies should be seen as a holistic project, affecting all levels of the organization (Levina, Borremans, Lepekhin, Kalyazina, & Schroder, 2020). Therefore, to assure the implementation of these technologies throughout the entire organization, an Enterprise Architecture approach would be beneficial to adopt (Levina et al., 2020). Thus, the Industry 4.0 transformation will lead to fundamental changes in the enterprises' operations and value creation, the sufficient realization and integration of which throughout the business requires Enterprise Architecture (Xu et al., 2018; Aliee, Kashfi, & Farahani, 2019). Likewise, Aliee et al.

(2019) claim that using Enterprise Architecture is crucial in Industry 4.0 transformations, but also that current Enterprise Architecture models lack guidelines for the initial stages of incorporating Industry 4.0 in Enterprise Architecture. Before the fourth industrial revolution, manufacturing systems were often separate entities, unable to communicate. However, Industry 4.0 creates the ability to connect the entirety of a company's operational technology systems not only with each other but with the complete array of complementary IT systems (Gilchrist, 2016). Enterprise Architecture is mainly concerned with the alignment between business and the IT systems and processes of an enterprise (Wagter et al., 2005). However, research claims that with the change towards Industry 4.0, a more clear link with operational technology (OT), monitoring, and control of equipment is required (Martynov, Shavaleeva, & Salimova, 2018; Aldea, Iacob, Wombacher, Hiralal, & Franck, 2018).

Previous research has explored the benefits of using Enterprise Architecture to structure the company-wide integration of Industry 4.0 (Nowakowski et al., 2019). However, research on clear guidelines or growth models on how to progress from the initial stages remains scarce. Research on using Enterprise Architecture to guide Industry 4.0 often assumes already existing capabilities within these domains, instead of highlighting the relevant initial steps to take to reach this point. This lack of research is stated by Nowakowski, Häusler, and Breu (2018), who claim that an appropriate guideline for an EA application in the Industry 4.0 domain in the form of a dedicated planning process is needed. To fill this gap in research, we aim to create a maturity model with the goal to assess enterprises in the combination between Industry 4.0 and the use of Enterprise Architecture, and guide organizations in increasing their maturity through the addition of a prescriptive roadmap. Maturity Models are used as a means to measure the maturity of functional domains, by distinguishing different maturity levels that an organization successively progresses through (Van Steenbergen, 2011). Subsequently, every maturity level highlights relevant capabilities corresponding to a certain area (Van Steenbergen, 2011). Maturity Models are able to give enterprises insight into which areas are more developed than others, and subsequently which areas require attention (Becker, Knackstedt, & Pöppelbuß, 2009). Moreover, when businesses are at the beginning of this transformation, such a model can help in directing attention to where to start (Ochoa-Urrego & Peña-Reyes, 2021).

To fill the distinguished gap in the literature, the goal of this thesis is to develop a maturity model which can guide companies in their transformation towards Industry 4.0, by combining Industry 4.0 with the use of Enterprise Architecture. The model aims to capture all domains that are relevant for organizations attempting to manage their Industry 4.0 projects in an integrated manner with the company's Enterprise Architecture. Subsequently, the model highlights capabilities for different levels of maturity in this combination. More specifically, a focus area-oriented maturity model is created, which is different from other types of maturity models in that each focus area has its own maturity development path that is balanced against the maturity development paths of the other focus areas (van Steenbergen et al., 2010). The model created in this study,

the so-called *EAI4.0 Maturity Matrix*, solves the guidance aspect of the gap in the literature, by showing what areas need to be addressed in what order (van Steenbergen et al., 2010). In this model, focus areas consider specific subjects that are relevant to the combination between Industry 4.0 and Enterprise Architecture.

This leads to the main research objective of this thesis:

The development of a maturity model which can guide companies in their transformation towards Industry 4.0, by combining Industry 4.0 with the use of Enterprise Architecture.

This study utilizes the method of design science research to develop the maturity model. First, an initial model containing main domains and relevant focus areas is developed by performing a systematic literature review. This review is focused on finding focus areas for which literature clearly supports that using an EA approach helps in transforming towards I4.0. The initial model is subsequently validated by performing interviews with the two different types of content experts that might be using this model; first, people working in an industry for which such a model can be used to assess the maturity of their enterprise, and second, people working in advisory domains might use the model to assess the maturity of a client. The dependencies between focus areas are derived from focus group sessions with experts that are highly knowledgeable in the fields of Industry 4.0 and Enterprise Architecture. A last round of interviews took place to validate the model, consisting of organizations filling in the maturity model as a means to gauge where their enterprise stands regarding using Enterprise Architecture in their Industry 4.0 journey, as well as evaluating design science evaluation criteria like the ease-of-use and utility of the model. The results from this round of interviews are used as final validation and are used to improve the model accordingly.

1.1 Industrial context

This research is performed in collaboration with Atos, more specifically the Atos Department of Digital Transformation Consulting in the Netherlands. This department consists of, among others, experts in the fields of both Industry 4.0 and Enterprise Architecture. These experts have guided the research content-wise in developing and validating the design artifact. Moreover, the network of Atos has been utilized to identify and reach both advisory-focused content experts, as well as staff working in relevant domains in industry, for the interview purposes of this research. Clients of Atos cover a wide range of industries and company sizes, including enterprises in the manufacturing area, that differ in their digital maturity.

1.2 Thesis structure

This thesis will first present background literature on the topics of Industry 4.0, Enterprise Architecture, maturity models, and the link between these domains. Next, the research design and execution section elaborates on the research process used to create the EAI4.0 Maturity Model by

highlighting the different research steps taken. The full and final version of the model is presented in section 4, after which the 'Evaluation of EAI4.0' section covers the last evaluation step of the research process. Lastly, the thesis is concluded through its contribution to theory and practice, and limitations and possibilities for future research are discussed.

2 Background and related work

This section dives deeper into the concepts of Industry 4.0 and Enterprise Architecture, and subsequently the relationship between the two. Next, already existing maturity models for both concepts are discussed.

2.1 Industry 4.0

Initially introduced in Germany, Industry 4.0 captures the current trend of automation technologies in industry, mainly in the domain of manufacturing. Industry 4.0 technologies are mostly enablers of improvements on already existing processes and aim to connect the physical world with a virtual environment (Xu et al., 2018). More specifically, Industry 4.0 technologies focus more on integrated solutions, and less on stand-alone applications (Möller & Möller, 2016). These new technologies open up a wide range of possibilities to advance current processes and systems, giving rise to smart factories, smart cities, healthcare 4.0 and more (Bogner, Voelklein, Schroedel, & Franke, 2016; Masuda, Zimmermann, Shepard, Schmidt, & Shirasaka, 2021; Tortorella, Fogliatto, Kurnia, Thürer, & Capurro, 2022). For Industry 4.0, connectivity and integration are keywords, as the ability for machines to automatically work together not only improves production speed and efficiency but also gives the possibility for more flexibility, leanness, and customization (Xu et al., 2018; Mofolasayo, Young, Martinez, & Ahmad, 2022).

Cyber-Physical Systems (CPS) are defined by the National Science Foundation as: "engineered systems that are built from and depend upon the synergy of computational and physical components", and are seen as highly relevant within Industry 4.0 in their purpose to connect the physical and digital world (Dumitrache, Caramihai, Sacala, Moisescu, & Popescu, 2020; Xu et al., 2018). CPS focuses on interoperability and connectivity between individual components, which is crucial in integrating data solutions and Industry 4.0 technologies. Sensors and other means of perceiving the environment are critical for this integration, as they both feed and rely on the Cyber-Physical system to interact and operate (Dumitrache et al., 2020). The systems that monitor and control these physical components are part of a company's Operational Technology (OT), which aims to manage automated manufacturing (Patera, Garbugli, Bujari, Scotece, & Corradi, 2022). An example of typical OT hardware is a Programmable Logic Controller (PLC), a standardized industrial computer crucial to manufacturing machines (Morgan, Halton, Qiao, & Breslin, 2021), and thereby in extension an important element in Industry 4.0 implementation (Chehri et al., 2021). A key element in Industry 4.0 is the integration between these manufacturing processes and technology (OT) and associated IT systems, which enables smart factories to control the end-to-end management of the entire manufacturing process (Gilchrist, 2016). This merger of OT with IT should lead to a scenario where engineering, production, marketing, and sales are closely linked, where administrators are able to control and streamline processes which will enable collaboration between and among producers, suppliers, and other stakeholders along the value chain (Gilchrist, 2016).

A large range of technologies and systems are considered part of the Industry 4.0 domain (Xu et al., 2018). One of the main technologies that plays a central part in Industry 4.0 is Artificial Intelligence (AI), which illustrates the need for integration and connectivity between systems. Artificial intelligence functions as a key element in creating integrated solutions by automating decision-making for which human interference is otherwise required (Sigov, Ratkin, Ivanov, Li, & Xu, 2022). Additionally, recent advancements in AI mainly in the manufacturing sector have the ability to greatly improve speed and efficiency in manufacturing processes (Sigov et al., 2022). New AI techniques are found to be crucial for monitoring, optimization, and control of technological processes in the growing digital footprints of enterprises (Dudukalov, Munister, Zolkin, Losev, & Knishov, 2021), and can be a basis for the usage of more intricate implementations like high-quality AI-driven predictive maintenance (Gogineni, Lindow, Nickel, & Stark, 2020). Thereby, AI is, similar to cloud technology, also a prerequisite for other more advanced technology in Industry 4.0.

Technologies that are central in Industry 4.0 both use and create large data streams, which increases the demand for data that is accessible anytime and anywhere (Schumacher, Erol, & Sihn, 2016; Xu et al., 2018). Cloud storage and cloud computing solve these requirements and are therefore seen as key drivers of Industry 4.0 (Zorrilla & Yebenes, 2022). Cloud computing and manufacturing specifically contribute to the realization of Industry 4.0 as a prerequisite to efficiently deal with the technological needs of Industry 4.0. These cloud systems utilize a network of resources in a highly distributed way, which is found to be crucial in the highly technical transformation towards Industry 4.0 (Sigov et al., 2022). Finally, a range of other relevant technologies that are a part of and influence Industry 4.0 include the Internet of Things, 5G/6G, the Blockchain, and many more (Sigov et al., 2022).

Industry 4.0 technologies can bring various operational excellence advantages (Murat Çınar et al., 2021). Additionally, by utilizing Industry 4.0 technologies to connect and automate processes, an increase in flexibility of the production process can be acquired (Murat Çınar et al., 2021). The demands for flexibility in the form of mass-customized products are increasing, and cannot be reliably met without the use of technological advancements brought by Industry 4.0 like IoT and Cloud (Erasmus, Vanderfeesten, Traganos, Keulen, & Grefen, 2020). However, this flexibility is not fully exploited due to the lack of dynamism in current operations management techniques (Erasmus et al., 2020).

Organizations going through a digital transformation towards Industry 4.0 face challenges not only in the technical domain but also on a more structural and social level (Xu et al., 2018). One of the main issues in the technical domain is the lack of readiness of existing IT infrastructures for the digital demands brought by Industry 4.0 (Cohen et al., 2019; Grooss, Presser, & Tambo, 2022). An example of this is the large-scale deployment and semantic integration of the large amounts of data utilized by Industry 4.0 technologies (Bi, Xu, & Wang, 2014). New technologies

need to be integrated within the already existing digital architecture, which requires a redesign of the current infrastructure (Xu et al., 2018). The integration of Industry 4.0 technologies within the existing infrastructure causes a demand for changes in the current business models that guide enterprises in decision-making, both at an intra-organizational and inter-organizational level (Xu et al., 2018). Additionally, structural changes in how a company operates due to Industry 4.0 technologies also require corresponding human knowledge and skills, which are found to be often lacking (Cohen et al., 2019). The social element of the human & automation collaboration in digital transformations remains a challenge for management, as the required skills to deal with these developments are often complicated (Marzano & Siguencia, 2021). Moreover, digital transformations often bring a cultural paradigm shift where the roles of employees might drastically change compared to what they used to be, often handing over responsibilities from humans to machines or technologies (Marzano & Siguencia, 2021). Research shows that many employees, especially employees of older generations, might struggle with technological adoptions like these, making it an important element to consider within digital transformations (Hülür & Macdonald, 2020).

2.2 Enterprise Architecture

Enterprise Architecture is defined as "the consistent set of rules and models that guide the design and implementation of processes, organizational structure, information flows, and the technical infrastructure within an organization" (Wagter et al., 2005). Accordingly, Enterprise Architecture is a discipline that focuses on holistic management of the enterprise, based on aspects of its architecture such as business processes, applications, information, and hardware, as well as the relationships between them (Buckl, Matthes, Schneider, & Schweda, 2013). Similarly, Lankhorst (2009) defines Enterprise Architecture as: "a coherent whole of principles, methods, and models that are used in the design and realization of an enterprise's organizational structure, business processes, information systems, and infrastructure". These definitions both highlight the structural nature of Enterprise Architecture, which is used to align not only business and IT but the entire organization's way of working. An effective Enterprise Architecture can help organizations in, among others, determining how they can achieve goals, guide (re-)engineering of business processes, and improve the quality of information flows (de Freitas, de Freitas Rocha Loures, Deschamps, & Cestari, 2020; Stelzer, 2009). Through this approach, organizations are able to align their IT with corresponding business goals in a standardized fashion (Aier, Kurpjuweit, Saat, & Winter, 2009), while simultaneously providing usage potentials for the business side in the form of corporate planning, compliance management, business continuity management, and risk management (Winter & Schelp, 2008).

However, a more recent empirical study by Kotusev (2019) found that in none of the organizations evaluated in their study, Enterprise Architecture resembles a holistic overarching description of the whole organization. Rather, Enterprise Architecture consists of different artifacts as part of the architectural practice, guiding their definition of Enterprise Architecture as: "EA is a collection of special documents (EA artifacts) describing various aspects of an organization from an

integrated business and IT perspective intended to bridge the communication gap between business and IT stakeholders, facilitate information systems planning and thereby improve business and IT alignment" (Kotusev, 2019). Common Enterprise Architecture artifacts identified in the study consist of solution designs, roadmaps, technology reference models, principles, and business capability models (Kotusev, 2019). This research underlines the main Enterprise Architecture definition used in this study of Wagter et al. (2005), as a set of rules and models to guide processes and infrastructure in the organization. Nevertheless, it also highlights that in practice Enterprise Architecture is hardly used as a blueprint of the entire organization, and is instead concerned with more concrete practices.

The Open Group Architecture Framework (TOGAF) is the most notable method for developing and maintaining a company's Enterprise Architecture (Kornyshova & Barrios, 2020). TOGAF is an open standard for Enterprise Architecture which at its core has techniques and processes to achieve this goal (Aldea et al., 2018). Central in TOGAF is the Architecture Development Method (ADM), which describes an iterative process for developing Enterprise Architecture in different phases (de Freitas et al., 2020). TOGAF offers viewpoints, techniques, and reference models to design an Enterprise Architecture, but does not include a modeling language (Aldea et al., 2018). Therefore, the ArchiMate specification was developed which can assist organizations to model and describe their Enterprise Architecture (Josey, 2017; Aldea et al., 2018). Research over the years has enhanced and added upon the original TOGAF framework, as well as on the ArchiMate language (Baptista & Barata, 2021; Franck, Iacob, van Sinderen, & Wombacher, 2018). However, literature remains critical, as research on both flexibility and the link with operational technology is scarce (Goerzig & Bauernhansl, 2018; Franck et al., 2018).

2.3 Link between Industry 4.0 and Enterprise Architecture

The implementation of Industry 4.0 technologies affects the entire enterprise, including its IT, information architecture, business processes, and employees (Benešová et al., 2019), but also physical manufacturing components and corresponding OT (Grefen, Vanderfeesten, Traganos, Domagala-Schmidt, & van der Vleuten, 2022; Morgan et al., 2021; Gilchrist, 2016). Subsequently, integration is one of the main challenges of Industry 4.0, not only with existing technical systems but with the entire enterprise (Holzhauser & Schalla, 2016). Research on Enterprise Architecture in combination with Industry 4.0 has suggested that the core problem of Industry 4.0 related to alignment could be addressed by Enterprise Architecture (Aldea et al., 2018). More specifically, research notes that Enterprise Architecture has already proved its value in providing solutions for the business-IT alignment, but can also be an effective method for addressing the IT-OT alignment issues which are common in Industry 4.0 (Aldea et al., 2018; Grefen et al., 2022). The alignment of strategy and vision through new technologies and the corresponding IT infrastructure is an important capability in Industry 4.0 and can be supported by the use of a standardized Enterprise Architecture (E. Gökalp & Martinez, 2021). Additionally, the development, integration, and maintenance of new technologies should be a standardized process that logically covers relevant software, hard-

ware, business process layers, management of infrastructure, and data collection & distribution, which can be achieved through Enterprise Architecture (M. O. Gökalp, Gökalp, Kayabay, Koçyiğit, & Eren, 2021). Specifically, the integration of new technologies and concepts with existing business elements and processes is important for digital transformation projects, which by definition falls in the realm of Enterprise Architecture (de Freitas et al., 2020). Although the introduction of Industry 4.0 increases a company's IT complexity, Enterprise Architecture can aid to achieve the intended Industry 4.0 goals by systematically managing this process (Nowakowski, Farwick, et al., 2018). For example, communication issues between IT and OT departments that have to work closely together due to technical implementations can be solved by Enterprise Architecture as it enforces both departments to create a single source of standards that they both can utilize (Nowakowski, Farwick, et al., 2018). In an ideal world, all Industry 4.0 processes and outcomes are integrated into a company's Enterprise Architecture (Aldea et al., 2018). As an example, a company's business vision and strategy should be reflected in the way Industry 4.0 technologies operate, which can be maintained by the integration in its Enterprise Architecture (Bousdekis et al., 2019).

Research generally agrees on the advantages Enterprise Architecture can bring in the implementation of Industry 4.0. However, there is also criticism of the current status of Enterprise Architecture models, as well as some challenges that require attention (Aldea et al., 2018; Goerzig & Bauernhansl, 2018). Currently, agile and lean methods are changing the way software is planned and developed while existing Enterprise Architecture models contrastingly offer an extensive but inflexible way of planning (Goerzig & Bauernhansl, 2018). Industry 4.0 technologies generate large sums of data which can lead to subsequent insights about, for example, process effectiveness (Sigov et al., 2022). These insights should in an ideal world be utilized to further develop a company's architecture. However, current models are often unsuitable to evolve (Aldea et al., 2018). Flexibility is one of the cornerstones of Industry 4.0 (Xu et al., 2018), and should therefore receive more attention in Enterprise Architecture models (Goerzig & Bauernhansl, 2018). Nonetheless, Enterprise Architecture should be able to facilitate flexibility by means of standardized organizational components, which will enable easy re-orchestration of components while implementing changes (Van der Raadt, Bonnet, Schouten, & Van Vliet, 2010). Lastly, the shift towards Industry 4.0 often requires organizations to develop new capabilities through the skills and knowledge of employees, which are currently often overlooked in Enterprise Architectural models (Aldea et al., 2018).

Extensions to Enterprise Architecture models have been proposed that cover the relevant, but currently often lacking, aspects of Industry 4.0 (Franck et al., 2018; Bi et al., 2014). However, this area of literature consequently assumes an already existing presence of Enterprise Architecture models and other related peripheral matters like budget and the required knowledge and skills. Anecdotal evidence from practice, derived from discussions with Atos consultants, on Enterprise Architecture and Industry 4.0 reveals that this is often not the case and that research frequently

assumes a too-perfect situation. Especially guidance on evolving from an initial situation, without already existing Enterprise Architecture frameworks, towards successful practices and standardization is desired, as a result of the rising pressure on IT systems that follow the digital transformation (Auth, 2021).

An important element in the digital transformation especially in the manufacturing industry is ERP systems and their integration with both IT and OT (Basl & Novakova, 2019) Applications that fall within the domain of Industry 4.0 are partly reliant on existing, often production, data (Nardello, Han, Møller, & Gøtze, 2020), which is often found in an ERP, MES or PLM system (Xu et al., 2018) Therefore when integrating Industry 4.0 technologies within the organization through the use of Enterprise Architecture ERP systems of the company cannot be ignored (Basl & Novakova, 2019). Nevertheless, this specific integration is heavily IT-influenced, and will therefore only be briefly explored on an abstract level in this thesis.

2.4 Maturity models

Maturity models are multistage and conceptual models that describe the development of domains in organizational capabilities (Pöppelbuß, Niehaves, Simons, & Becker, 2011). Continual improvement of a company's (IT) capabilities requires an examination of the current status of these capabilities, which involves a comparison with the company's goals, external requirements, or benchmarks (Becker et al., 2009; Becker, Niehaves, Pöppelbuß, & Simons, 2010). For each different area or capability, it needs to be clear what has to be measured, how this should be measured, and in comparison to what. Maturity models realize this, by assessing the as-is situation of a company and assigning it a specific degree of maturity (Becker et al., 2009), and subsequently presenting benchmarking information for the next level of maturity (Khoshgoftar & Osman, 2009). For decision-makers, maturity models are valuable tools to assist in distinguishing relevant focus areas (Pöppelbuß et al., 2011).

A high number of maturity models in literature are concerned with IT or Information systems (Becker et al., 2009; Van Steenbergen, Van Den Berg, & Brinkkemper, 2008), and are being developed by international consortia, governments, software companies, and consultancy firms (Becker et al., 2010). One of the most prominent and widely used maturity models is the Capability Maturity Model (CMM), which contains two main distinguishable variants (CMMITeam, 2001). The first variant is the continuous 5-level capability model, which is the most used format for maturity models in information systems (Becker et al., 2009). This model distinguishes five general maturity levels and a number of focus domains, where every single focus domain has attributes for every level of maturity. Opposed to this continuous CMM, the alternative is the staged 5-level capability model. This model distinguishes the same five levels of maturity but instead attributes a number of focus domains per maturity level (CMMIProductTeam, 2002; Van Steenbergen et al., 2008). A visual representation of these models is provided in figure 2. In the staged model, a number of domains are associated with each maturity level, indicated by X. On the other hand, in the

continuous model, every domain has the same 5 maturity levels, represented by X.

	1	2	3	4	5
Domain 1	X	X	X	X	X
Domain 2	X	X	X	X	X
Domain 3	X	X	X	X	X
Domain 4	X	X	X	X	X
…					

A Continuous 5-level model

	1	2	3	4	5
Domain 1	X				
Domain 2		X			
Domain 3		X			
Domain 4			X		
…					

A Staged 5-level model

Figure 2: Types of maturity models

The main goal of the continuous model is to show levels of maturity within domains, while the main goal of the staged model is to show levels of maturity based on different stages and thus between domains (CMMITeam, 2001). A type of model that covers both within and between dependencies also exists, and additionally departs from the idea of five generic maturity levels (van Steenbergen et al., 2010). The focus area-oriented maturity model gives each focus area its own number of specific maturity levels, that are additionally staged in comparison to the other areas' maturity levels (van Steenbergen et al., 2010). Subsequently, the maturity of the organization is measured as a combination of the levels of maturity of these focus areas (Van Steenbergen et al., 2008). A visual representation of this type of model is provided in figure 3.

	1	2	3	4	5	6	7
Domain 1		X			X		X
Domain 2	X				X		
Domain 3	X			X			X
Domain 4			X			X	
…							

A Focus Area Oriented model

Figure 3: Type of maturity model

The focus area-oriented maturity model is not used often in practice but is found to be useful in research on Enterprise Architecture due to the ability to give more detailed guidance to priorities as a result of smaller steps between stages (Van Steenbergen et al., 2008). Moreover, due to following a non-continuous approach the model is able to define dependencies between focus areas. These dependencies are relevant in research on Industry 4.0 where new technologies often rely on existing processes to be properly executed, for example, transformations of business processes relying on big-data analytics (Aldea et al., 2018).

2.5 Existing Frameworks and Models for EA and I4.0

Other models to manage Enterprise Architecture are available next to the TOGAF framework like MIT's Enterprise Architecture guide or Gartner's Enterprise Architecture framework (MIT, 2014; De Vires, 2010). These models are comparable in their high-level planning and inclusion of the link between business and technical layers, but often lack an explicit developmental component (Bui, 2017). Although these three frameworks are seen as relevant means to manage Enterprise Architecture, they are also found to be rather broad (Aldea et al., 2018). Research on Enterprise Architecture has subsequently tried to create models on specifically how to develop and improve the architectural practice (Van Steenbergen et al., 2008). A detailed maturity model for this purpose is the Dynamic Architecture Maturity Matrix (DYAMM) (Wagter et al., 2005), which is a focus area-oriented model that has been assessed and updated in numerous case studies over the years (Van Steenbergen, Schipper, Bos, & Brinkkemper, 2010). The DYAMM operates based on the notion that there are many factors that determine the success of Enterprise Architecture, but that at different points in time, different aspects require attention (Van Steenbergen et al., 2008). The DYAMM considers eighteen different focus areas that make up the entire vision on how to develop, improve and maintain an Enterprise Architecture. Each of these eighteen areas has its own maturity growth path, which takes relative priorities to the other areas into account (Van Steenbergen et al., 2008). The DYAMM is utilized extensively by Atos experts in Enterprise Architecture and is firmly accepted as a means to assess and improve Enterprise Architecture maturity due to its high level of detail as well as its ability to highlight relative growth paths. Figure 4 shows the architecture maturity matrix where each key area is associated with corresponding individual maturity levels ranging from A to D (Van Steenbergen et al., 2008). Every level of each area consists of one to four checkpoints, which have to be positively scored to achieve a certain level. The scale highlights when these levels have priority relative to the other maturity levels. A company's overall maturity is assessed as a combination of the progress in all eighteen focus areas.

Scale / Area	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Development of architecture		A			B			C						
Use of architecture			A			B				C				
Alignment with business		A				B				C				
Alignment with the development process			A				B		C					
Alignment with operations					A			B			C			
Relation to the as-is state					A				B					
Roles and responsibilities				A		B					C			
Coordination of developments							A			B				
Monitoring				A		B		C		D				
Quality management								A		B			C	
Maintenance of the architectural process							A		B		C			
Maintenance architectural deliverables					A			B					C	
Commitment and motivation		A					B		C					
Architecture roles and training				A		B			C			D		
Use of an architectural method				A						B				C
Consultation			A		B				C					
Architectural tools							A				B			C
Budgeting and planning				A							B		C	

Figure 4: The Dynamic Architecture Maturity Matrix

Whereas research on maturity models in Enterprise Architecture is not abundant, the contrary is true for Industry 4.0. Numerous maturity models in Industry 4.0 have been created over the past decade, from high-level overviews to models for specific technologies of Industry 4.0 (E. Gökalp, Şener, & Eren, 2017; De Carolis, Macchi, Negri, & Terzi, 2017; Schumacher et al., 2016; Bierhold, 2018; Rafael, Jaione, Cristina, & Ibon, 2020; Leyh, Schäffer, Bley, & Forstenhäusler, 2017; Murat Çınar et al., 2021; Pessl, Sorko, & Mayer, 2020; Caiado et al., 2021; Burggräf, Lorber, Pyka, Wagner, & Weißer, 2020). A meta-analysis by Basl (2018) summarizes eighteen Industry 4.0 maturity models and discusses the main findings. Firstly, most Industry 4.0 maturity models deal with enterprise-wide topics like strategy, leadership, corporate culture, and human resources. These aspects are important to ensure new technologies are aligned with the overall goals of the company (Xu et al., 2018). Moreover, dimensions covering IT supporting processes and control are often mentioned as elements that require attention to correctly integrate such technologies. Finally, almost all of the models contain some form of a technology dimension that covers the technological aspects related to Industry 4.0 (Basl, 2018). Many of the models are built on CMM principles and differ greatly in their degree of specialization and guidance. A large part of these maturity models are continuous X-level models and are subsequently mainly used to assess the company's maturity in the relevant areas (Basl, 2018).

To facilitate the ongoing digital transformation in industry, the Reference Architectural Model Industrie 4.0 (RAMI 4.0) was created (Adolphs et al., 2015), which aims to combine Industry 4.0 with the architectural domain. The goal of RAMI4.0 is to support companies that are adopting projects under the scope of Industry 4.0 and need support in the technological and organizational migration process (Paiva, Vasconcelos, & Fragoso, 2020). RAMI4.0 is a three-dimensional model which shows enterprises how to tackle the deployment of Industry 4.0, with the purpose of enabling standards and improving understanding between participants (Bousdekis et al., 2019).

Even though RAMI4.0 is a step in the right direction in giving companies guidance in digital transformations, the combination of RAMI4.0 with Enterprise Architecture as a whole is scarcely discussed in literature. Moreover, the RAMI4.0 is sometimes found to be fairly abstract and subsequently unable to provide a guiding element to organizations (Kornyshova & Barrios, 2019; Nardello, Møller, & Gøtze, 2017). A study by Paiva et al. (2020) proposes a reference architecture for Industry 4.0, by combining RAMI4.0 and ArchiMate. However, this study is mainly performed on a technical and functional level. Paiva et al. (2020) conclude that future work in this combination is required to also incorporate the business layer and subsequently build a more holistic model for the organization, from strategy to implementation. Similarly, the HORSE framework was developed with the aim to assist in integrating new Industry 4.0 technologies and thereby support efficient and flexible manufacturing (Erasmus et al., 2020). The resulting framework is a reference architecture for a manufacturing operations system based on the application and extension of business process management (Erasmus et al., 2020). Even though the HORSE system has been deployed and evaluated positively in practical cases, it focuses mostly on the specific manufacturing process level instead of also incorporating the link with the business level.

2.6 Summary of research and problem identification

The transition towards Industry 4.0 is seen as one of the biggest challenges for companies in the coming decades (Holzhauser & Schalla, 2016). Organizations often face issues while implementing Industry 4.0 and its corresponding technologies, not only in the specific technical and operational domain (OT) but also in the employee domain, business process domain, and information systems domain (Benešová et al., 2019). Due to the connected nature of Industry 4.0 technologies, it reaches further than just innovations in operational technology but influences the entire enterprise (Xu et al., 2018). Enterprise Architecture provides a view of how the enterprise should be structured and thereby encompasses all aspects of the organization. Therefore, the transformation towards Industry 4.0 can benefit strongly from the use of Enterprise Architecture (Xu et al., 2018). Connecting Industry 4.0 practices with the company's Enterprise Architecture can assist in integration throughout the organization by giving structure to processes, information flows, and (technical) infrastructure, thereby aligning business with both IT and OT (Martynov et al., 2018; Morgan et al., 2021).

The research gap for this study is based on exploratory meetings with industry professionals from Atos, as well as research on background literature. Where the combination between Industry 4.0 and Enterprise Architecture has been discussed (Xu et al., 2018), research on guidelines or growth models that can guide enterprises on how to mature in this combination is scarce. Nowakowski, Häusler, and Breu (2018) states that an appropriate guideline for an EA application in the Industry 4.0 domain in the form of a dedicated planning process is needed, which reinforces the notion that a lack of maturity guidance is a gap in the current literature. Organizations in the process of a digital transformation can benefit from an overview of relevant focus areas in the link between Industry 4.0 and Enterprise Architecture, as well as information on how these areas relate to one

another.

To fill the distinguished gap in the literature, a maturity model has been created as the main artifact of this study. Maturity models are a means to measure and improve the maturity of functional domains, by distinguishing different maturity levels that an organization successively progresses through (Van Steenbergen, 2011). The main purpose of most maturity models is to highlight how each focus area individually matures, by showing what steps are initially relevant within this area and what steps should subsequently be taken to increase maturity (CMMIProductTeam, 2002). However, dependencies between different focus areas can also convey relevant information, by indicating how the maturity of each focus area relates to the maturity of the other focus areas (Koomen & Pol, 1999). These dependencies are significant when initial actions for a certain focus area depend on the progress of other focus areas (Van Steenbergen et al., 2008). As an example, a company's maturity in using data analytics as a result of Industry 4.0 technologies is dependent on sufficiently valid data acquisition and data quality. To fill the need for a model able to guide organizations, a focus area-oriented maturity model has been created. This type of model is different from other maturity models in that each focus area has its own maturity development path that is balanced against the maturity development paths of the other focus areas (Van Steenbergen et al., 2008). Due to the detailed nature and found success in practice of the DYAMM (Van Steenbergen, 2011), a similarly structured maturity model has been created in this study. Maturity models often have two types of users, namely industrial practitioners using the model to assess their organization's maturity and employees in advisory roles that utilize the model to assess different organizations (Becker et al., 2010). To ensure the model's purpose of guidance and to improve its validity both these groups of users fall within the scope of this research.

To conclude, the digital transformation towards and efficient use of Industry 4.0 has its challenges, but research suggests that these challenges might partly be overcome by incorporating efforts of Enterprise Architecture. The distinguished research gap is concerned with the lack of growth or maturity models in research, which can assist in reaching the ideal end goal of a fully integrated Industry 4.0 and Enterprise Architecture. Maturity models for both Industry 4.0 and Enterprise Architecture are plentiful in research, but a combined effort is found to be scarce. Therefore, this study developed the *EAI4.0 Maturity Matrix*, covering aspects of both domains and structured specifically as a focus area-oriented maturity model, to assist companies in both between and within focus area dependencies.

3 Research design & Execution

This section details the research design and corresponding tasks that were performed to complete the stated research objective. The aim of this study is to create a model able to guide companies in the digital transformation towards Industry 4.0 by combining it with the usage of Enterprise Architecture. More specifically, this is achieved by developing a maturity model which covers both these domains, through fusing relevant theory, called the *EAI4.0 Maturity Matrix*.

To develop this model the method of design science research is used, which consists of three main phases (Hevner, March, Park, & Ram, 2004). The research process of this study is shown in figure 5. Firstly the problem has been investigated, which was done by performing a literature review on relevant literature to identify the research gap. Concurrently, a problem-identification and motivation were defined, guided by background literature consisting of further research on the concepts of Industry 4.0, Enterprise Architecture, and Maturity Models. Solution objectives were subsequently defined, which guided the second and third stages of the design science research. Next, an initial model artifact was created as the first step of the design and development phase, containing definitions of the relevant domains and focus areas, for which a systematic literature review was used as defined by Kitchenham and Charters (2007).

In the demonstration and evaluation phase, each iteration of the model is validated and where applicable improved upon. Firstly, interviews were performed with content experts working in relevant fields with the aim of validating the defined focus areas. Next, we created maturity levels for each focus area based on both literature and results from the first round of interviews, which were verified in a validation round with a new group of experts, mainly active in the advisory domain. The participants of the validation round subsequently participated in a focus group session with the goal of defining dependencies between individual focus area maturity levels. A final interview took place with organizations currently engaged in the transformation towards Industry 4.0, where these companies filled in the maturity model for their own organization, with the aim of providing them with a helpful roadmap to increase maturity. At the same time, this interview was used to assess a number of design science research evaluation criteria, while also collecting data on some general digital transformation KPIs. Feedback from this interview has led to the final model artifact. The setup and results of this final interview are presented separately in section 5.

Due to the detailed and rather abstract content of the information required from experts, semi-structured interviews are chosen as an extraction method over questionnaires, to assure rich data (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Moreover, background research on Maturity Model validation shows a large portion of studies using interviews for this purpose (Van Steenbergen, 2011).

Different types of maturity models exist, the most straightforward being a continuous x-level model. These models distinguish a number of focus areas, together with x levels of maturity per

domain (CMMIProductTeam, 2002). In this study, however, a focus area-oriented model has been created, which instead has specific maturity levels per domain (Van Steenbergen et al., 2008). The advantage of this type of maturity model is that it enables the researchers to present dependencies between areas, instead of only within areas (Van Steenbergen et al., 2008).

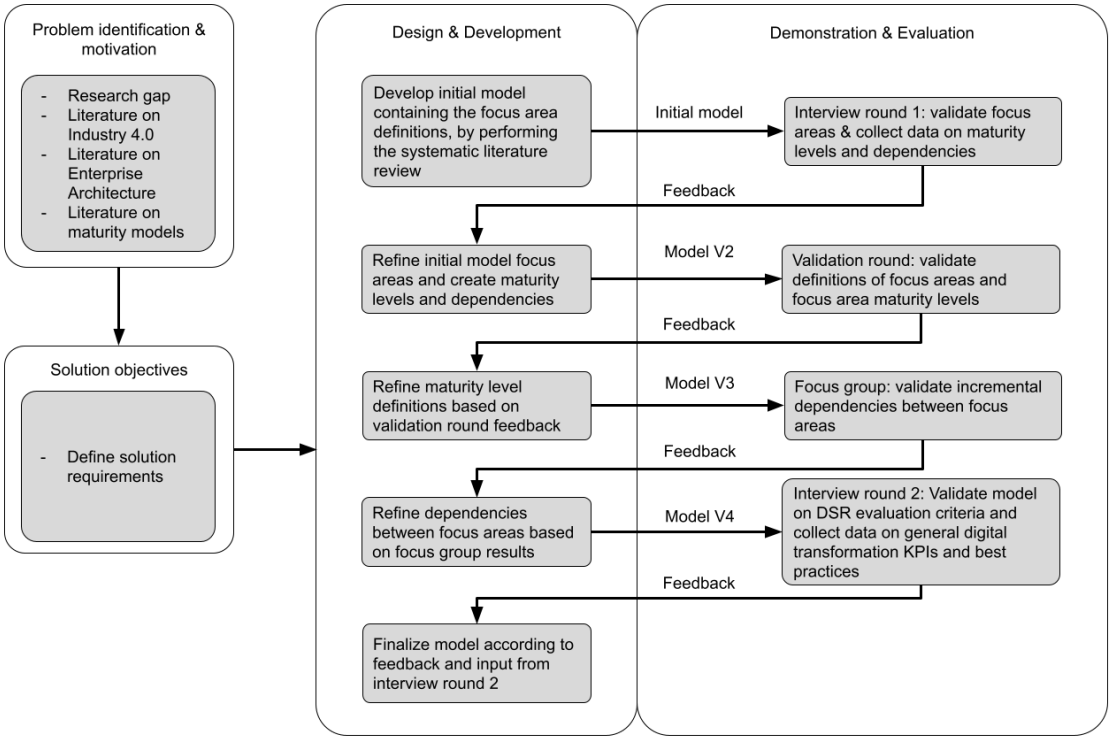

Figure 5: Research process

Figure 6 below illustrates specifically the progress, from left to right, between the development of the model versions and the different demonstration and evaluation rounds.

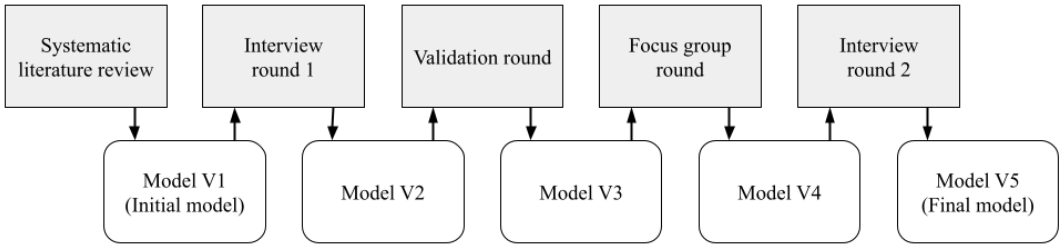

Figure 6: Maturity model version progress

3.1 Solution objectives

Solution objectives were defined to specify how to develop the final artifact and what conditions the maturity model must meet. The solution requirements are based on background literature on Industry 4.0, Enterprise Architecture, and Maturity Models (Pöppelbuß & Röglinger, 2011). Pöppelbuß and Röglinger (2011) propose a set of general design principles for maturity models, which guided the rationale behind the solution objectives.

To tackle the lack of guidance in current models regarding Enterprise Architecture and Industry 4.0, a focus area-oriented maturity model is created consisting of overarching domains and subsequent more detailed focus areas (Van Steenbergen et al., 2008). By not using fixed levels of maturity, the focus area-oriented model is more flexible in defining its focus areas and the dependencies between the areas (Van Steenbergen et al., 2010). Therefore, this type of model allows us to pinpoint to organizations specifically what area requires attention at what stage of their maturity. One of the basic maturity model design principles according to Pöppelbuß and Röglinger (2011) is that maturity levels are the central constituents of the individual maturation paths for the different dimensions, and should thus be included in the artifact. In the DYA Maturity Matrix, the researchers highlight that some focus areas require more levels of maturity than others, to assist in balancing the relative development paths (Wagter et al., 2005). In comparison, a meta-analysis on Maturity Models for Industry 4.0 by Basl (2018) shows that these models use a minimum of three, but often more levels of maturity. Thus, the artifact is designed as a focus area-oriented maturity model including corresponding maturity levels. However, due to the divergence in research, the number of different maturity levels was not immediately specified but instead later derived as a result of further research and the first evaluation results. This results in the following requirement:

- *R1: The artifact should be designed as a focus area oriented maturity model, including focus areas, their definitions, and corresponding maturity levels.*

According to Pöppelbuß and Röglinger (2011), maturity models need to be documented in a target group-oriented manner, as well as have a clear purpose of use. The target group of users of this study comprises enterprises aiming to combine Industry 4.0 and Enterprise Architecture, or people in advisory industries aiming to use this model in assessing maturity. The purpose of use of the artifact is guidance in the digital transformation to Industry 4.0 in combination with Enterprise Architecture. Implementing elements of a digital transformation into a company's enterprise architecture is however often complex, and covers many different areas (Van Steenbergen et al., 2010). Therefore, it is important that the artifact covers all areas that might be affected by this implementation so that practitioners will not be faced with surprises down the road. To ensure the artifact fills its purpose of guidance for the defined target group, the maturity model should be exhaustive of all relevant focus areas for the implementation of Industry 4.0, Enterprise Architecture, and its combination.

- *R2: The artifact should contain all focus areas that are deemed as relevant, by both literature and industry, for implementing Industry 4.0, Enterprise Architecture, and its combined use.*

Focus area-oriented maturity models are sequenced, to highlight what needs to ideally be achieved in what order. To visualize this in the maturity model, a scale containing different stages should be added to the artifact, which highlights the relative order between the different levels of maturity for each individual focus area (van Steenbergen et al., 2010). Each stage on this scale contains maturity levels for focus areas that should be achieved at a similar degree of maturity. Subsequently, maturity levels in a certain stage are seen as prerequisites for the next stage on the scale. A visual representation of this can be found in figure 4, highlighting the DYA Maturity Matrix, which uses a similar approach. Consequently achieving maturity levels according to the sequencing the scale highlights, ensures enterprises have the necessary capabilities to progress in their overall maturity. In other words, organizations will not start too soon with developing a maturity level in a certain focus area, while prerequisites for this maturity level are not yet fulfilled. This results in the following requirement:

- *R3: The artifact should contain relative dependencies between focus areas and their maturity levels, depicted on a scale that highlights ordering between areas.*

According to De Bruin, Rosemann, Freeze, and Kaulkarni (2005), maturity models can be structured hierarchically into multiple layers referring to different levels of granularity of maturation. The advantage of this method is that these different levels pose means to compare maturity on a high level, while also giving context to lower-level complex domains (Pöppelbuß & Röglinger, 2011). Therefore, all focus areas acquired from the literature are categorized under one of several general domains. This indication can help organizations better understand focus area definitions, as well as guide which department or subdivision might be responsible for its improvement.

- *R4: The artifact should categorize every focus area under an over-arching general domain.*

To ensure the communicative and guiding aspect of the artifact, basic information, central constructs, and their interrelations need to be documented in a target group-oriented manner (Pöppelbuß & Röglinger, 2011). Moreover, maturity models should include clear definitions of central constructs in the application domain, to conform to understandability (Pöppelbuß & Röglinger, 2011). As such, the usefulness and 'ease of use' of the artifact are important elements to consider, which might be evaluated by the use of a Technology Acceptance Model questionnaire (Davis, 1989). This leads to the next requirement:

- *R5: The artifact should be deemed both useful and easy to use by practitioners.*

Finally, an assessment methodology needs to be provided with the artifact, which features a procedure to guide users in how to assess an enterprise's maturity. This procedure needs to show the assessment steps and their interplay and advise on how to elicit the criteria's values (Pöppelbuß & Röglinger, 2011).

- *R6: The artifact should contain an assessment procedure able to guide users in the company's maturity assessment.*

3.2 Design & Development

In the design and development phase(s), the artifact distinguished in the research gap was created and updated, with the identified solution requirements in mind. The main steps for the design of the model were derived from the development methods for focus area maturity models as described by van Steenbergen et al. (2010). After each development stage followed the last step of Design Science Research: the demonstration and evaluation stage. This section is critical to reflect on the designed artifact after every new design step. As can be seen in table 5, the design and evaluation phases form a cycle, with the eventual goal of improving the model through feedback, while also increasing problem understanding and product quality (Hevner et al., 2004). According to Hevner et al. (2004), this process not only has the goal to evolve the design artifact but also when necessary the design process itself. To design the initial maturity model, Model V1, and its domains and focus areas, we performed a systematic literature review based on the relevant literature. After the first round of interviews, the model has been revised to Model V2 based on the received feedback and information from the content experts. The individual maturity levels for each focus area were created by combining literature on maturity models for Industry 4.0 and/or Enterprise Architecture, combined with results from the first round of interviews, and were subsequently verified in the validation round. The focus group had the goal to establish the dependencies between focus areas, by having an open discussion on the order of the areas and the corresponding maturity levels, which, together with feedback on the model definitions, led to Model V4. Finally, the feedback and information from the last round of interviews finalized the Maturity Model in Model V5 by letting experts evaluate its utility, while also giving interviewees insights into their situation regarding the combination between Enterprise Architecture and Industry 4.0. The remaining subsections of section 3 cover one by one all steps in the design and development and demonstration and evaluation stages.

Before starting the design of the model, the focus of the model was identified. For this study, the focus is twofold, as the proposed artifact should serve as useful guidance for both organizations working with these topics in the industry, as well as experts in advisory domains who aim to use this model to assist companies. Therefore, the evaluation of the model in the second round of interviews from two different angles ensures the utility of the model in a broad industrial context.

Triangulation and sampling

To help confirm the results of our research and to get higher-quality data different types of triangulation were utilized (Wilson, 2014). Triangulation refers to the use of multiple theories, data sources, methods, or investigators within the same study (Heale & Forbes, 2013), as a strategy to validate results (Flick, 2004). In this study, we used two different types of triangulation: data and methodological triangulation. Data triangulation refers to the use of different sources of data, through data collection from different places, different participants, or different time-frames (Flick, 2004). Methodological triangulation, the most common type of triangulation, refers to the use of different methodologies to collect data like the use of both qualitative and quantitative data (Heale & Forbes, 2013). Through the use of different methods of data collection, limitations from each

method can be dealt with by comparing the findings of the different perspectives (Heale & Forbes, 2013).

Firstly, we used three different methodologies to validate the content of the maturity model: an interview setting, an offline validation round, and a focus group setting. These different means of gathering feedback on the model make it possible to capture different aspects of the research topic (Flick, 2004). Moreover, these three settings differ in their way of interacting with the researcher and other participants, which reduces the effect of possible cognitive biases like groupthink (Park, 1990) or social desirability bias (Grimm, 2010). Within the interview and focus group rounds, both qualitative and quantitative data were acquired with the aim of limiting the disadvantages of both methods. During the interviews, participants were able to quantitatively grade, for example, the completeness of the model, while at the same time being prompted to qualitatively comment on their decisions. Similarly, the focus group sessions resulted in quantitative results regarding the dependencies between focus areas. However, during these sessions, participants were also prompted to give remarks on their reasoning behind the dependencies.

Data triangulation took place by purposely sampling different groups of people across the interviews and focus-group sessions to increase the validity of the results. To reach this goal, We interviewed academics with large amounts of expertise on the topics of Industry 4.0 and Enterprise Architecture, consultants experienced with using suchlike models in practice, and practitioners working in industry currently undergoing their organization's digital transformation. Moreover, we purposely sampled different types of industries to validate our findings across separate industrial domains. Nevertheless, due to the high level of knowledge required to partake in the interviews some convenience sampling (Baltes & Ralph, 2022) took place. Therefore, we are unable to make grounded conclusions on generalizability regarding our sampling (Baltes & Ralph, 2022).

3.3 Development of the initial version of the model

To design an initial maturity model a systematic literature review has been conducted. This review had the purpose of exhaustively and rigorously going through the relevant literature, and subsequently gaining consistent insights (Kitchenham & Charters, 2007). Whereas the scope of this thesis is focused on enterprises in the manufacturing industry, the systematic literature review did not necessarily dis-include material if that is not the case. Nevertheless, the focus did lie more heavily on the literature surrounding the manufacturing industry. The systematic literature review's main purpose is to find domains and focus areas that are relevant to Industry 4.0, Enterprise Architecture, and most importantly their combination. Plenty of maturity models on both domains separately exist, of which focus areas that are mainly relevant to only one of the two domains will also be included for completeness' sake. However, identifying focus areas that are applicable in both domains is the main purpose of this systematic literature review.

This section details the process of conducting the systematic literature review in this thesis, by

showing how results have been acquired and subsequently used to develop the initial maturity model focus areas. First, the different steps of performing a systematic literature review are described, after which the execution of these individual steps is further highlighted. Finally, the first version of the maturity model focus areas is shown.

This systematic literature review was conducted in two parts. Initially, literature has been searched that is relevant to the combination of Industry 4.0 and Enterprise Architecture. From there, areas were derived that these papers argue are relevant when combining the two domains. Subsequently, we checked if these areas are also seen as separate capabilities in both Industry 4.0 Maturity Models, as well as Enterprise Architecture Maturity Models. When these are seen as relevant capabilities in both domains, we claim that this focus area should be included as a combinatory focus area, which in turn is reflected in its definition. For completeness purposes, this list of combinatory focus areas was added upon with focus areas that are relevant in either Industry 4.0 maturity papers, or in Enterprise Architecture maturity papers. When a domain is seen as relevant for either one of the two, this is reflected in its definition. Hereby we highlight the applicability of the focus areas for the relevant domain.

The systematic literature review has followed the guidelines as proposed by Kitchenham and Charters, to systematically search and select relevant studies. The performed steps, as adapted for this study, are featured in the table below.

1	Define the research objective.
2	Conduct several example searches; review the scopes.
3	Define the search string; identify inclusion and exclusion criteria.
4	Conduct an initial search.
5	Review the title, abstract, and keywords of the initially retrieved studies.
6	Revise inclusion and exclusion criteria; select potentially relevant studies.
7	Remove duplicate studies.
8	Review potentially relevant studies selected; discuss any issues.
9	Review the entire content of initially selected studies; identify relevant ones.
10	Review relevant studies selected; discuss any issues.
11	Identify the final set of relevant studies.

Table 2: Overview of followed Systematic Literature Review steps

The research objective of this SLR was to determine a set of focus areas relevant to maturing the combination of Industry 4.0 and Enterprise Architecture. Because the goal of the model is to help companies in linking the efforts of Industry 4.0 and Enterprise Architecture, we were specifically looking for papers that mention which areas are important in this combination. However, to ensure the completeness of the initial model, we also considered the literature on maturity models for just Enterprise Architecture or Industry 4.0 separately. The final objective of the Systematic Literature Review was to identify a set of domains and focus areas which exhaustively cover the relevant spectrum for Industry 4.0 and Enterprise Architecture, both separately and combined.

Example searches on the combination between Enterprise Architecture and Industry 4.0 together with Maturity Models yielded few search results. Example searches on the combination between Enterprise Architecture and Industry 4.0, without mentioning Maturity Models, led to a large set of relevant literature. Also, searches in the field of Maturity Models for both domains separately showed high quantities of papers, especially those concerned with Industry 4.0 or its corresponding aspects, such as IoT and Cloud.

Due to the results from the initial searches, the research string for the combination between domains was changed from:

"Industry 4.0" AND "enterprise architecture" AND ("maturity model" OR "MM")

To:

"Industry 4.0" AND "enterprise architecture"

Moreover, for completeness purposes maturity models and similar terms were explored for both domains separately, with the following search strings:

- "Industry 4.0" AND ("Maturity Model" OR "MM" OR "Maturity" OR "Capability model" OR "Process improvement model")
- "Enterprise Architecture" AND ("Maturity Model" OR "MM" OR "Maturity" OR "Capability model" OR "Process improvement model")

An initial search was performed in four different scientific databases: Scopus, SpringerLink, Web of Science, and ScienceDirect. These databases were chosen for their size and content, as well as their accessibility. The established search strings led to a total of around 900 studies for the combination of both domains. Initial searches in the field of maturity and Industry 4.0 granted over 10000 hits, and searches in the field of maturity and Enterprise Architecture around 3000 papers. The initial inclusion criterion was that a focus must lie on either Enterprise Architecture or Industry 4.0. The initial exclusion criterion was that articles not written in English will not be used.

Figure 7 highlights the different steps taken to go from the initial searches to the final set of studies from which data is extracted, including the number of studies remaining at each step.

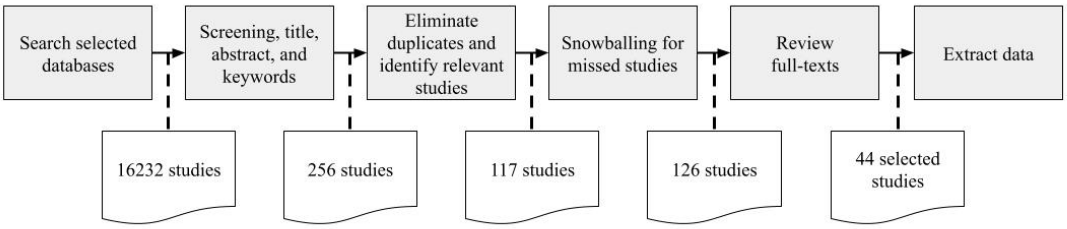

Figure 7: Systematic literature review progress

All studies were reviewed on their title, abstract, and keywords, except studies not written in English. 256 studies remain after the initial screening. By reviewing the studies, the inclusion and exclusion criteria were further worked out as some studies were deemed as not useful for this research. The resulting inclusion and exclusion criteria are shown below in table 3.

Criterion type	Description
Inclusion 1	Articles' main focus must either be on Enterprise Architecture or on Industry 4.0
Inclusion 2	Articles that focus on either just Enterprise Architecture or just Industry 4.0, must fall within the manufacturing industry.
Inclusion 3	Articles must be either white or 1st tier grey literature, as defined by Adams, Smart, and Huff
Exclusion 1	Articles not written in English
Exclusion 2	Articles that only focus on specific architecture elements like PLM or MES
Exclusion 3	Articles that only focus on specific technical Industry 4.0 solutions, like Cloud or AI solutions
Exclusion 4	Articles that do not contain specific capabilities or relevant focus areas for Industry 4.0 and/or Enterprise Architecture
Exclusion 5	Articles that define general Industry 4.0 or Enterprise Architecture areas solely on a high level.

Table 3: Inclusion and exclusion criteria

To ensure relevance for this literature review, articles must focus mainly on either Enterprise Architecture or Industry 4.0. For example, papers about maturity models for innovation might mention Industry 4.0 but are therefore not sufficiently focused on the topic of Industry 4.0 itself.

The scope of this research falls mainly within the manufacturing domain, due to the clear link with Industry 4.0. Therefore, and also to keep the set of studies manageable, papers that highlight either Industry 4.0 or Enterprise Architecture not in the manufacturing domain will be deemed as not relevant. An example of this is studies about health4.0 or smart cities.

Studies that are relevant to the combination between Industry 4.0 and Enterprise Architecture were all initially taken into account. The first reason for this is that the main goal of this study is to combine elements that are relevant in both Industry 4.0 and Enterprise Architecture. Therefore, we wanted to explore all papers clearly highlighting this combination. The second reason for this is the relative scarcity of papers that directly aim to combine the two domains, instead of focusing on one of the two, and shortly mentioning the other.

The contribution of information from books is also deemed as relevant in this study, as a lot of literature on especially Enterprise Architecture is written via this medium. Therefore, the first tier of grey literature as defined by Adams et al. (2017) was also explored in this systematic literature review.

Articles not written in English were excluded due to linguistic constraints. Notably, Industry 4.0 originated in Germany, and therefore a substantial amount of studies about Industry 4.0 are written in German. In performing the systematic literature review, however, English equivalents could often be found.

Some papers focus on specific elements concerned with a company's architecture or overall business processes. Since the purpose of this study is to find focus areas relevant to the entire Enterprise Architecture, these papers were excluded. Examples of this are studies about PLM, MES, CRM, or ERP.

The purpose of this literature review is to find focus areas relevant to Industry 4.0 integration in Enterprise Architecture, and areas relevant to the general implementation of Industry 4.0 in the organization. Therefore, papers that only focus specifically on technical Industry 4.0 solutions were excluded. Examples of this are studies specifically concerned with technological solutions for Cloud, IoT, AI, VR, AR, or Digital twins. The goal of this systematic literature review is to find focus areas that are capabilities for implementing Industry 4.0 throughout the organization, instead of areas focused specifically on technical applications.

A part of the literature is concerned with Industry 4.0 and Enterprise Architecture in general but does not explicitly mention the capabilities or areas of expertise required to manage and integrate these. The aim of this systematic literature review is to specifically find focus areas or capabilities that are relevant in the area of Industry 4.0 and/or Enterprise Architecture so that the model can guide companies in what to do and what to focus on during such a transformation. Therefore, papers were excluded that do not mention specific capabilities or focus areas relevant to Industry 4.0 and/or Enterprise Architecture.

Finally, papers were excluded that highlight relevant areas for Industry 4.0 and/or Enterprise Architecture solely on a high level, instead of in a detailed manner. To guide companies on a

practical level, detailed focus areas and maturity levels are required. Therefore, papers that only briefly mention overall domains are excluded.

Table 4 depicts the initially selected studies stemming from the corresponding search terms and databases.

Search term	Database	Initially retrieved	Initially selected
"Industry 4.0" AND "enterprise architecture"	Scopus	68	19
"Industry 4.0" AND "enterprise architecture"	SpringerLink	631	30
"Industry 4.0" AND "enterprise architecture"	Web of Science	48	15
"Industry 4.0" AND "enterprise architecture"	ScienceDirect	140	21
"Industry 4.0" AND ("Maturity Model" OR "MM" OR "Maturity" OR "Capability model" OR "Process improvement model")	Scopus	639	24
"Industry 4.0" AND ("Maturity Model" OR "MM" OR "Maturity" OR "Capability model" OR "Process improvement model")	SpringerLink	6201	37
"Industry 4.0" AND ("Maturity Model" OR "MM" OR "Maturity" OR "Capability model" OR "Process improvement model")	Web of Science	810	14
"Industry 4.0" AND ("Maturity Model" OR "MM" OR "Maturity" OR "Capability model" OR "Process improvement model")	ScienceDirect	4314	49
"Enterprise Architecture" AND ("Maturity Model" OR "MM" OR "Maturity" OR "Capability model" OR "Process improvement model")	Scopus	233	6
"Enterprise Architecture" AND ("Maturity Model" OR "MM" OR "Maturity" OR "Capability model" OR "Process improvement model")	SpringerLink	2254	11
"Enterprise Architecture" AND ("Maturity Model" OR "MM" OR "Maturity" OR "Capability model" OR "Process improvement model")	Web of Science	206	12
"Enterprise Architecture" AND ("Maturity Model" OR "MM" OR "Maturity" OR "Capability model" OR "Process improvement model")	ScienceDirect	688	18

Table 4: Overview of search terms and search results

From the initially retrieved studies, a selection was made based on the set criteria, which was subsequently checked on duplicates and potential issues. Among the potentially relevant studies, not all studies immediately clearly highlight their relevance in the abstract, thus further reading was required. To verify the potentially relevant studies selected, a scan was performed with the aim to remove studies that do not hold to the inclusion and exclusion criteria. Subsequently, papers were removed where a lack of relevance is clear through scanning which brings down the remaining set of studies to 117.
We used the procedure of snowballing to find studies that we potentially missed, by checking the reference sections of the found relevant studies (Wohlin, 2014). Via this method, 9 additional

studies were added to a total of 126 relevant studies.

Next, the remaining relevant studies were reviewed. Potential issues included that some papers might not clearly show relevant focus areas in tables with corresponding definitions, which requires a thorough reading of every article. For the remaining 126 studies, a full-text review was performed. Studies that do not hold to the set of inclusion and exclusion criteria were removed. Subsequently, 44 studies remain in the final set of papers. This set includes literature on the combination between Industry 4.0 and Enterprise Architecture, as well as papers separately mentioning either one of the two, in combination with maturity.

To extract data from the relevant set of studies, first, all relevant studies for the combination of Industry 4.0 and Enterprise Architecture were reviewed. Each time a topic was mentioned as relevant or required for maturing this combination, it is kept track of. Subsequently, this list of topics was added upon with relevant focus areas or capabilities from papers on maturity for either Industry 4.0 or Enterprise Architecture. We validated the topics stemming from the studies about the combination of the domains by verifying if that topic is seen as a capability or maturity area in separate maturity papers. So, when a study hints at the importance of, for example, strategy in the combination of Industry 4.0 and Enterprise Architecture, we verified if strategy as a capability is mentioned in both Industry 4.0 maturity papers as well as Enterprise Architecture maturity papers. These results can be found in Table 5, where focus areas are presented, together with their quantity of mention in the set of relevant studies, as well as their relevance in either Industry 4.0 or Enterprise Architecture. When a focus area was deemed as relevant in a combinatory paper, while also being found to be a capability in both domains separately, this was reflected in the definition. Similarly, focus areas relevant to either just Industry 4.0 or Enterprise Architecture were covered in the initial list of areas, and their definition reflects this relevance.

Different definitions for focus areas are used throughout different papers while covering the same topic. Therefore, synonyms for focus areas as found in the literature were used to guide which focus areas cover the same aspect, and which focus areas are distinctly different.

For readability purposes, table 5 highlights one source per area to illustrate the reasoning behind the decision-making. All further literature results can be found in Appendix B. The specific sources chosen below were identified for having a clear motivation on the importance of the respective areas. All sources used in Appendix B can be found in the reference section of this report. Not all sources in the relevant set of studies yielded direct relevant results for the systematic literature review. Nevertheless, a large part of these studies contained valuable information and was subsequently used in this report.

Areas distinguished in literature	**Quantity of mentions**	**Distinguished as relevant area for the combination by:**	**Distinguished as capability for domain Industry 4.0**	**Distinguished as capability for domain Enterprise Architecture**
Strategy, vision	11	(Aliee et al., 2019)	Industry 4.0 Readiness Evaluation for Manufacturing Enterprises (Schumacher et al., 2016)	DYAMM (van Steenbergen et al., 2010)
Alignment with business, alignment IT and business	7	(Xu et al., 2018)	Industry 4.0-MM (E. Gökalp et al., 2017)	DYAMM (van Steenbergen et al., 2010)
Skills, talent, human skills, domain knowledge, technological knowledge	12	(Dallasega et al., 2020)	APM Maturity model (Dennis, Ramaswamy, Ameen, & Jayaram, 2017)	DYAMM (van Steenbergen et al., 2010)
Security, privacy	4	(Ilin, Levina, Borremans, & Kalyazina, 2021)	Industry 4.0: Building the digital enterprise (Reinhard, Jesper, & Stefan, 2016)	MIT Enterprise Architecture guide (MIT, 2014)
Capital, costs, budget	8	(Xu et al., 2018)	Industry 4.0: Building the digital enterprise (Reinhard et al., 2016)	DYAMM (van Steenbergen et al., 2010)
Data infrastructure, data warehousing, data management, computing power, data quality	10	(Aldea et al., 2018)	APM Maturity model (Dennis et al., 2017)	MIT Enterprise Architecture guide (MIT, 2014)
Data acquisition, sensors, real time data	6	-	Industry 4.0-MM (E. Gökalp et al., 2017)	
Process change management	5	(Xu et al., 2018)	Industry 4.0-MM (E. Gökalp et al., 2017)	TOGAF ADM based MM (Proença & Borbinha, 2017)
Supporting tools, supporting technologies	9	(Aldea et al., 2018)	APM Maturity model (Dennis et al., 2017)	DYAMM (van Steenbergen et al., 2010)

Areas distinguished in literature	**Quantity of mentions**	**Distinguished as relevant area for the combination by:**	**Distinguished as capability for domain Industry 4.0**	**Distinguished as capability for domain Enterprise Architecture**
Culture, mindset	12	(Dallasega et al., 2020)	Industry 4.0 Readiness Evaluation for Manufacturing Enterprises (Schumacher et al., 2016)	DYAMM (van Steenbergen et al., 2010)
New technologies, assets, applications like Cloud, IOT, AI	9	-	SIMMI 4.0 (Leyh et al., 2017)	
Horizontal & vertical integration, connectivity, communication between departments, information islands	13	(Dallasega et al., 2020)	SIMMI 4.0 (Leyh et al., 2017)	DYAMM (van Steenbergen et al., 2010)
Alignment IT and OT	9	(Aldea et al., 2018)	SIMMI 4.0 (Leyh et al., 2017)	DYAMM (van Steenbergen et al., 2010)
Employees, HR	2	(Bauer et al., 2015)	Industry 4.0: Building the digital enterprise (Reinhard et al., 2016)	Gartner Enterprise Architecture model (Bittler & Kreizman, 2007)
Implementation of Enterprise Architecture	7	-		DYAMM (van Steenbergen et al., 2010)
Development of systems and architecture, improvement, innovation	6	(Aliee et al., 2019)	SIMMI 4.0 (Leyh et al., 2017)	DYAMM (van Steenbergen et al., 2010)
Data-driven decision making	8	(Bi et al., 2014)	Industry 4.0-MM (E. Gökalp et al., 2017)	MIT Enterprise Architecture guide (MIT, 2014)
Managerial influence, management, leadership	6	(Bauer et al., 2015)	Industry 4.0 Readiness Evaluation for Manufacturing Enterprises (Schumacher et al., 2016)	TOGAF ADM based MM (Proença & Borbinha, 2017)

Areas distinguished in literature	**Quantity of mentions**	**Distinguished as relevant area for the combination by:**	**Distinguished as capability for domain Industry 4.0**	**Distinguished as capability for domain Enterprise Architecture**
Roles, responsibilities, hierarchical structure	8	(Chehri et al., 2021)	Industry 4.0 Readiness Evaluation for Manufacturing Enterprises (Schumacher et al., 2016)	DYAMM (van Steenbergen et al., 2010)
Support and management processes	3	(Bousdekis et al., 2019)	APM Maturity model (Dennis et al., 2017)	TOGAF ADM based MM (Proença & Borbinha, 2017)
Control of processes and systems	3	-	Industry 4.0-MM (E. Gökalp et al., 2017)	
Cloud technology (as an initiator of Industry 4.0)	3	-	Industry 4.0-MM (E. Gökalp et al., 2017)	
Quality towards customers, relation with customers, customization	5	(Bi et al., 2014)	Industry 4.0 Readiness Evaluation for Manufacturing Enterprises (Schumacher et al., 2016)	DYAMM (van Steenbergen et al., 2010)
Flexibility, agility	11	(Bi et al., 2014)	Roadmap Industry 4.0 (Pessl et al., 2020)	TOGAF ADM based MM (Proença & Borbinha, 2017)
Standards, protocols, standardization	12	(Aliee et al., 2019)	APM Maturity model (Dennis et al., 2017)	MIT Enterprise Architecture guide (MIT, 2014)
Contextualisation, visualisation	6	(Gogineni et al., 2020)	Roadmap Industry 4.0 (Pessl et al., 2020)	Gartner Enterprise Architecture model (Bittler & Kreizman, 2007)

Table 5: Focus areas as distinguished in literature review

To develop the initial set of focus areas, all areas found in literature as shown in table 3 were considered. For completeness purposes, we aimed to add as much information from literature in the initial model, since we had the opportunity to remove focus areas after the first round of interviews when they were not deemed relevant. However, some focus areas were only scarcely mentioned, and they were subsequently reinspected to decide on their relevance. The merge or re-

moval of areas was done in discussion with Atos, as some topics were either similar or had different levels of granularity for the same construct. Firstly, cloud technology was sometimes mentioned as an initiator of Industry 4.0 technologies, but also as an element of it. Therefore, the 'cloud' focus area was integrated into the 'Industry 4.0 implementation' focus area. Secondly, 'people' or 'employees' were often named, but mostly as an overarching domain instead of an individual focus area. Therefore, the 'employees' focus area was removed, as more detailed focus areas for this domain exist in the model, namely skills, culture, and management. Thirdly, 'regulations' were mentioned scarcely, and are therefore removed as a relevant focus area. The area of 'security' was always mentioned in combination with data and data management. Therefore, this focus area was merged with the focus area of 'data warehousing and quality'. Fifthly, 'control' was often mentioned in the same area as management and leadership. Therefore, this focus area was merged with management and leadership. Finally, the area of 'support processes' was merged with 'process change management' due to its focus on processes surrounding the changes brought by implementing Industry 4.0 technologies. The focus areas of 'flexibility' and 'customization' were merged due to flexibility often relating to the extent to which enterprises are able to handle customized demand.

All remaining areas found in literature that were deemed as relevant aspects for the combination between Industry 4.0 and Enterprise Architecture, or for one of the two separately, are included in the initial set of focus areas. Hereby, we created a list of focus areas that are relevant for maturing in the field of Industry 4.0 and Enterprise Architecture. Focus areas are contributed to either Industry 4.0 or Enterprise Architecture, or both, which is highlighted in its definition. The first round of interviews subsequently verified both the quality, correctness of the areas, and the completeness, presence of all relevant areas, of the list.

The definitions of the focus areas were derived from the literature in two different ways. In the case that a paper directly mentions the relevance of a focus area in the combination between Industry 4.0 and Enterprise Architecture, the definition was then derived from how that paper phrases this construct. When no definition on specifically the combination was present, the focus area's definition is derived from papers separately mentioning its importance. When a focus area is relevant for just Industry 4.0 or Enterprise Architecture, its definition was derived from one of the papers mentioning this capability.

Finally, for clarification purposes, four over-arching domains were derived from Leavitt's Diamond model for change (Smith, Norton, & Ellis, 1992). Leavitt's Diamond postulates that it is rare for any change to occur in isolation. We similarly propose that the changes brought by Industry 4.0 affect the entire enterprise. Leavitt's Diamond model consists of four domains: structure, tasks, technology, and people. To better fit our model's purpose, we assigned each focus area to one of these four domains based on the definitions of these domains, as well as the definitions of the focus areas. To more clearly fit our context, the domain of 'structure' was renamed to 'organization', and the domain of 'tasks' was changed to 'processes'.

The initial set of domains, focus areas, and definitions as based on the systematic literature review is shown in table 6.

Domain	Focus area	Definition
Organization	Strategy and vision	The extent to which Industry 4.0 and Enterprise Architecture practices are incorporated in the company's vision and strategy.
	Alignment IT and business	The extent to which Information Technology is directly aligned with business goals and processes.
	Budget	The extent to which budget is available for both Enterprise Architecture practices and Digital transformation, including training and supporting tools.
	Contextualization	The extent to which the current status of both the company's Enterprise Architecture and Industry 4.0 efforts are contextualized and visualized, from corporate to the work floor.
	Communication	The extent to which both horizontal and vertical integration and communication takes place regarding both EA practices and Industry 4.0.
	Enterprise Architecture implementation	The extent to which an Enterprise Architectural approach is used to define the structure and operations of the organization.
People	Knowledge and skills	The extent to which both managers and employees have the necessary knowledge of Industry 4.0 practices and architecture.
	Culture and mindset	The extent to which throughout the organization employees share beliefs and attitudes regarding the benefits of Industry 4.0, and actively participate in this improvement.
	Management and leadership	The extent to which management actively monitors and controls the development of changes stemming from the transformation towards Industry 4.0, and supports employees in this.
	Roles and responsibilities	The extent to which the roles and responsibilities regarding Enterprise Architecture and Industry 4.0 within the company are clearly defined in the organizational structure.

Domain	Focus area	Definition
Processes	Innovation and improvement	The extent to which organizations innovate and improve upon their existing technological processes and architecture.
	Standardization and protocols	The extent to which business processes and technological implementations throughout the enterprise follow standardized rules and protocols.
	Data-driven decision making	The extent to which insights from Industry 4.0 technologies and data actually lead to (changes in) decision making.
	Flexibility and customization	The extent to which the business is able to adapt dynamically to changes in the environment, and is able to respond to custom demands.
	Process change management	The extent to which processes are in place which support and guide the transition towards Industry 4.0, for decision making, management and rewards procedures.
Technology	Data warehousing and quality	The extent to which a company's digital infrastructure and data quality is able to deal with the technological demands of Industry 4.0.
	Alignment IT and OT	The extent to which Information Technology is aligned with Operations (technology), both on a technical and procedural level.
	Data acquisition	The extent to which a company is able to acquire the correct data stemming from production processes, and is able to translate this in a useful way.
	Industry 4.0 implementation	The extent to which a company is implementing Industry 4.0 technologies like cloud and IoT.
	Supporting tools	The extent to which a company has supporting tools in place for both Industry 4.0 and Enterprise Architecture.

Table 6: Overview of domains and focus areas for the initial maturity model.

3.4 Interview round 1

The goal of Interview 1 was to firstly validate the content of the created focus areas, and secondly to gather information on dependencies between focus areas.

- We validated the individual focus areas by asking participants if they felt a focus area needed to remain in the model, be removed from the model, or be changed. Interviewees were able to comment on both the focus area itself, as well as its given definition.
- We validated completeness by asking if elements were missing in the current set of focus areas, for each overarching domain as well as at the end of the interview.

- Concurrent with asking about the area content, we asked the interviewees to rank every focus area on its importance in the process of growing to a new level of maturity. We asked participants to grade a focus area as either initially important, intermediately important, or important at later levels.

Interview 1 was performed with a set of experts that were identified both from Atos' and the author's networks. This includes experts in academic and advisory fields, as well as in industries directly working with and implementing Industry 4.0. For the latter, the focus lay on identifying experts in manufacturing industries.
When more than 50 percent of experts claimed a focus area needed to be removed from the model, it was removed from the model. Next to this, textually proposed changes were considered during the revision of the initial definitions. To guide the creation of initial dependencies between focus areas, every focus area received a dependency score based on the feedback of the experts.

3.4.1 Interview structure

A detailed version of the structure, information given to participants, and questions asked during Interview round 1 can be found in Appendix B.

First, the interviewees were asked whether the meeting could be recorded for note-taking purposes and if the interviewee consents to the data of the interview being used anonymously in this report. Next, interviewees were asked about their familiarity with Industry 4.0, Enterprise Architecture, and Maturity Models on a Likert scale, as used by Mukherjee, Lapre, and Van Wassenhove (1998). When required, additional information was provided. To ensure sufficient knowledge of interviewees, we asked the participants to grade their knowledge on each of the following three concepts on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), as used by Mukherjee et al. (1998). When interviewees indicated they were not familiar with a concept, a familiarity lower than neutral, additional information was provided.

- *I am familiar with the concept of Industry 4.0*
- *I am familiar with the concept of Enterprise Architecture*
- *I am familiar with the concept of Maturity Models*

Next, all focus areas and their definitions as derived from the systematic literature review were validated one by one, both on completeness and rigor. Every single focus area was discussed to confirm its validity regarding the topic, after which the completeness of the entire set of areas was verified. The results of this interview have guided the revision of the model by altering, removing, and adding focus areas, to create the second version of the model after this step in the research process. To quantitatively verify the focus areas, the interviewees were asked to grade every focus area with either one of the following three options: *change, remove, or keep.* Secondly, every focus area was graded by the interviewees on its dependencies to the other areas, and thus its chronological relevance. This was done by having each focus area graded as either being initially

relevant, intermediately relevant, or relevant in the final stages. Due to the abstract nature of this question, this was explained in detail to the interviewees together with an example. The practical experience of experts in different areas was able to help in creating initial maturity paths for each focus area, based on the progress of the other focus areas.

The following two questions were asked after the explanation of every focus area, to verify the constructs detailed above.

- "Should this focus area remain in this maturity model, or should it be changed or removed?"
- "Is this focus area initially relevant, intermediately relevant or relevant in later stages, and why?"

Lastly, the completeness of the set of focus areas was checked by asking if the interviewee felt that all relevant areas were covered. This question was asked after every main domain (organization, people, processes, and technology), as well as at the end of the interview.

- After every domain: "Do you feel these X focus areas cover all relevant elements for this domain?"
- At the end: "Do you feel this set of focus areas covers the entire relevant spectrum for Industry 4.0 and Enterprise Architecture?"

3.4.2 Panel selection interview round 1

Interviews were held with both experts in industry and advisory domains, preferably in different fields. Table 7 below highlights the interviewees that participated in the first round of interviews, including their area of expertise as well as the distinction between working in an advisory or industrial setting. Relevant individuals were recruited via the author's network, Atos' network, and the TU/e network.

#	Function	Type	Area of Expertise
1	Enterprise architect	Industry	Hi-tech manufacturing
2	Consultant	Advisory	ERP & MES systems
3	Head of IT dept.	Industry	IT
4	Architect	Industry	IT architecture
5	Architect	Industry	Enterprise architecture
6	Chief digital officer	Industry	Enterprise Architecture
7	Enterprise Architect	Industry	Utility
8	Consultant	Advisory	Enterprise Architecture
9	Consultant	Advisory	Enterprise architecture
10	Management	Advisory	Industry 4.0
11	Business developer	Advisory	Digital transformation
12	Director operations	Industry	Food, operations
13	Consultant	Advisory	Enterprise Architecture
14	Consultant	Advisory	Manufacturing
15	Business analyst	Industry	Hi-tech manufacturing
16	Chief information officer	Industry	Digital transformation
17	Enterprise Architect	Industry	Food, manufacturing
18	Management	Industry	Food, operations

Table 7: First round of interviews participants

3.4.3 Results Interview round 1

This section provides an overview of the results and corresponding changes after the first round of interviews. The first round of interviews consists of eighteen interviews, which all took approximately one hour to perform.

Domain familiarity

At the start of the interview, participants were asked to grade their familiarity with the topics of Industry 4.0, Enterprise Architecture, and Maturity Models, on a 5-point Likert scale. Table 8 gives an overview of the quantities of each familiarity level per topic. Except for one interviewee, all interviewees indicated being at least familiar to some extent with Industry 4.0 and Enterprise Architecture. Interviewees that responded as being neither familiar nor unfamiliar were provided with additional information on the corresponding domain. One participant (participant R) indicated not being familiar with maturity models, which prompted an additional explanation by the interviewer to the interviewee. Contextual knowledge of maturity models was not deemed necessary to progress through the interview, therefore the data of this participant was not removed.

Familiarity	1	2	3	4	5
Industry 4.0	0	0	1	11	6
Enterprise Architecture	0	0	1	9	8
Maturity Models	0	1	3	8	6

Table 8: Familiarity level quantities per topic

General feedback

This subsection summarizes the general feedback on the initial model that is not attributed to a single focus area. Such general feedback was indicated either during the key interview questions or as final remarks on the interview. This feedback was used to alter the titles and definitions of some of the focus areas, as well as the generic maturity level definitions, as specified in the next sections. Moreover, this feedback is used to add information to the individual maturity steps for each level.

Granularity of focus areas

An often-mentioned general feedback point is concerned with the granularity and type of focus areas. Some focus areas, like 'data acquisition', were indicated to cover more specific aspects, while other focus areas were indicated to be concerned with broader topics, like 'communication'. Multiple interviewees (participants H, I, and M) reported this difference in granularity and suggested combining or altering focus areas to have a more consistent overall level of granularity.

Moreover, a couple of interviewees (participants A, B, F, and K) commented on the differences in some of the focus areas described. The definitions of focus areas like 'budget' or 'supporting tools' were indicated to be closer to a requirement or condition, instead of a focus area that a company would aspire to be mature in. Similarly, one interviewee (participant F) indicated that the focus areas of 'flexibility' and 'innovation' are, even though important, not necessarily elements that one would want to improve its overall maturity in, but rather are (final) stages of maturity within other focus areas.

Assessments

Multiple interviewees (participants C, D, G, J, K, L, N, P, and Q) indicated the need for an addition of an initial assessment step in the first maturity level, for multiple focus areas. The reasoning behind this feedback point stems from a desire to have a basic view of the current status of a focus area, so the enterprise knows what needs to be changed accordingly, versus what is already on a desired level. The focus area of data acquisition is an example of this, for which it is required to assess where the company stands regarding data acquisition before being able to improve maturity. Questions in this specific assessment might be about how the current sensing technology works and about what is currently being measured. The need for assessment steps was, next to data acquisition, also mentioned for the focus areas of knowledge, culture, data quality, standards, and technological implementation. For the remaining focus areas, a full assessment was not deemed necessary. As a result, we added the execution of assessments to the maturity levels of the aforementioned focus areas.

Project-based implementation

The extent of implementation within the organization is an important element to consider in the maturity levels itself, according to the first round of interviews. Interviewees (participants K, L, N, and P) indicated that when a company is in the first level of maturity, it will be unable to implement technology in the entire organization. Rather, in lower stages of maturity companies should aim to implement Industry 4.0 technologies in a project-based manner. This kind of project-based implementation has the advantage of not having to establish alignment with the entire organization, while also reducing the financial risk might the project not perform up to expectations. According to the interviewees, this project-based implementation strategy should be considered not only in the first maturity level of the technological implementation focus area but in all focus areas that shape the way these implementations are conducted, like budget and management. This feedback was used to design the general maturity levels described in section 3.4.4.

Best practices

Since the purpose of the model is to specifically guide companies in combining Industry 4.0 and Enterprise Architecture, one interviewee (participant F) indicated that each requirement to reach a certain maturity level should contain best practices. Information on proven techniques, systems, or procedures will greatly increase the extent to which the model is able to provide guidance. According to the interviewee, there is a large difference between knowing what to do and how to do it, which a list of best practices might help with. As a result, the model design was extended to include best practices for each focus area maturity level.

Overall model clarity

Two interviewees (participants H and M) with expert knowledge of the creation of maturity models indicated the desire to reduce the number of focus areas, to increase the clarity and understandability of the model. Moreover, for companies using the artifact to assess their maturity, the model should be manageable, both in the number of focus areas and in the number of questions required to assess their maturity level. We reduced the number of focus areas, as further detailed in the next paragraph.

Changes in elements

The section below highlights all changes made to the initial list of twenty focus areas. Figure 8 shows the results of the first section of the interview which aims to assure inclusion validity for every focus area. Changes to the focus areas were made based on these results, together with the overall interpretation of observations of the interview.

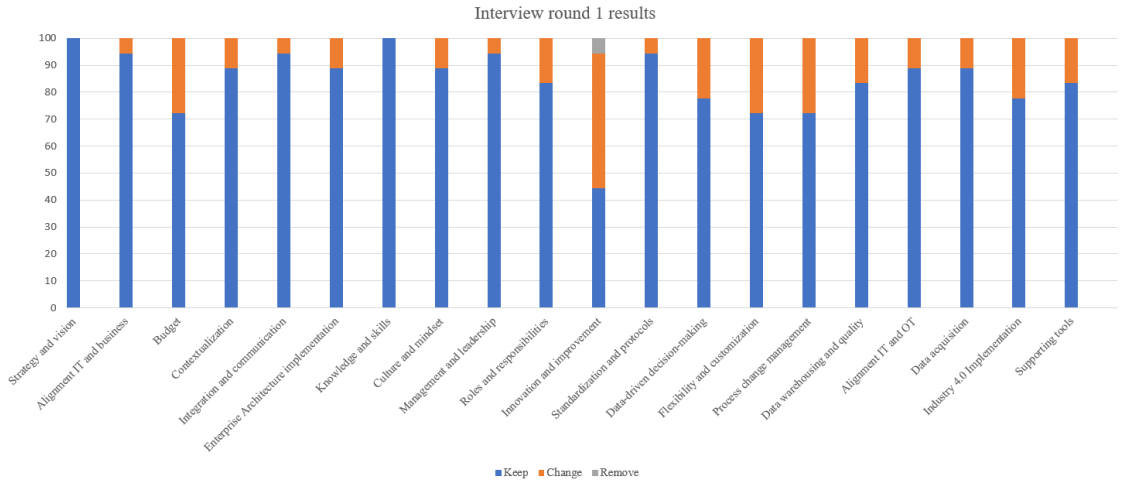

Figure 8: Interview round 1 results per focus area

- The 'alignment' focus area: Multiple interviewees (participants O, P, and R) indicated that two separate focus areas for alignment might hinder the overall alignment process since these two areas are two sides of the same coin. Moreover, interviewees indicated that the focus area of 'strategy and vision' is in fact the first step of the alignment process, where the overall aim is to ensure a strategy is translated into business goals, which are aligned with both IT and OT. The focus areas of 'strategy and vision', 'alignment IT and business', and 'alignment IT and OT' are therefore combined into a new focus area called 'alignment'.

- The 'change management' focus area: More than half of the interviewees proposed a change or removal of the 'innovation' focus area due to the claim that innovation in itself is not a focus area that a company would want to be mature in, but is rather the final step in how an organization deals with change. The same feedback was given for the 'flexibility and customization' focus area, where interviewees felt that the focus should lie on the extent to which a company is able to manage change in a flexible way. Therefore, as a result of the overall interpretation of the textual comments on the focus areas, the focus areas of 'innovation' and 'flexibility' are combined into a new focus area called 'change management'.

- The 'process management' focus area: As a result of the overall interpretation of observations of the interview, to prevent confusion, 'process change management' is renamed to 'process management'. This change better reflects the essence of the focus area, namely: the process management of processes relating to Industry 4.0 and Enterprise Architecture.

- The 'data quality' and 'data governance' focus areas: Multiple interviewees (participants H and M) indicated the difference in granularity between especially the focus area of 'data acquisition' and other more high-level focus areas. In essence, this focus area captures what the data processes look like, from data quality to data acquisition. Therefore, the focus areas of 'data quality' and 'data acquisition' are combined into a new focus area called 'data

quality'. However, multiple participants (participants B and Q) suggested adding a focus area concerned with the aspect of data governance. They indicated that the way data is governed and dealt with is a relevant area, distinctly different from data quality. The data governance focus area contains elements concerned with data managers, warehousing, and security. As a result, we added a new focus area concerned with 'data governance'.

- The 'embedding' focus area: Most interviewees indicated the relevance of the 'contextualization' and 'communication' areas, but two participants (participants G and K) specifically mentioned that these areas lie very close together. The main purpose of the 'embedding' focus area is to assess maturity to what extent Industry 4.0 is embedded in the organization, and how corresponding communication, regarding who and what needs to be updated, takes place. As a result, we combined the 'contextualization' and 'communication' focus areas into a new focus area called 'embedding'.

- The 'Enterprise Architecture' and 'Technology' focus areas: Multiple interviewees (participants B, I, and Q) indicated that the focus area of 'supporting tools' is not necessarily an area a company would want to aspire to be mature in. Rather, supporting tools are requirements for technical implementations to correctly work. Therefore, the focus area of 'supporting tools' has been removed. Instead, the information regarding supporting tools is provided under the different maturity levels of the focus areas for which these tools are relevant, 'Industry 4.0 implementation' and 'enterprise architecture implementation'.

- The 'Technology' focus area: Interviewees (participants J and O) indicated that the maturity level of a company's technical capabilities needs to be taken into account, as this dictates the extent to which Industry 4.0 projects can be implemented. The technical capabilities required to realize Industry 4.0 are acquired step-by-step as the company matures in this focus area. The 'Industry 4.0 implementation' focus area is therefore renamed to 'Technology implementation', to better reflect the overall maturity of the enterprise's technical capabilities.

- The 'governance' focus area: Participant P proposed to change the name of the 'roles & responsibilities' focus area to 'governance', to better reflect the overall level of granularity of the model. This change was made accordingly.

- The 'finance' focus area: Participant K proposed to broaden the 'budget' focus area to 'finance', to better reflect the overall level of granularity of the model. The 'finance' focus area covers more financial elements than just budget, for example, the return on investment (ROI) of projects.

- The generic maturity level definitions: As a result of the overall interpretation of observations of the interview, we noted the concern that the focus area of 'data-driven decision making' is closer to a final step in multiple focus areas, instead of a focus area in its own right. Even though almost 80% of the interviewees indicated it as a relevant focus area, qualitative data

suggests that being mature in data-driven decision-making is not an end goal, but a step in improving processes in different focus areas. Therefore, the focus area of 'data-driven decision making' is removed, and its elements are integrated into the generic maturity level definition of 'predict and optimize', as well as in the highest maturity level of individual focus areas.

- The 'standards' focus area: The 'standards' focus area is moved under the technological domain, due to its focus on technical standards and protocols.

Due to the changes in the focus areas above, the overarching 'process' domain was removed. This results in three over-arching domains consisting of 'organization', 'people', and 'technology'.

Additional feedback

This section covers a list of all additional feedback mentioned during the first round of interviews, which was in part used to derive the individual maturity levels per focus area.

- Generic 'optimized' maturity level definition: Multiple participants (participants A, I, L, and P) indicated that partnerships with external parties can be valuable tools in increasing maturity in Industry 4.0. These partnerships can help in fulfilling certain elements of the digital transformation, that the company itself is unable to do. This feedback prompted a change in the generic definition for the 'predict and optimize' maturity level to include an external view and partnerships, and subsequently for the level 4 requirements for all focus areas except 'change management' and 'leadership'.

- Definition of multiple maturity levels of the 'alignment' and 'finance' focus areas: Participants A and L suggested the addition of key performance indicators to the model specifically concerning Industry 4.0, to improve existing processes. The setting up and use of KPIs have been added to the requirements for multiple maturity levels in the focus areas of 'alignment' and 'finance'.

- Definition of the 'managed' level of the 'leadership' focus area: An important managerial aspect is to clarify to employees what the transition to Industry 4.0 brings for them, or, "What's in it for me", according to participant L. This element has been added to the second maturity level requirement of 'leadership'.

- Definition of the 'managed' level of the 'culture' focus area: According to participant R, to realize employee contribution, incentives need to be created that are specific to the transition to Industry 4.0. As long as the existing incentives are not about Industry 4.0 progress, but solely about already existing processes, it will be difficult to get employees on board. This element has been added to the second maturity level requirement of the 'culture' focus area.

- Definition of the 'managed' level of the 'process management' focus area: Participant I indicated that maintenance of new processes implemented through the transition to Industry 4.0 is an important aspect to ensure proper integration. This element has been added to the second maturity level requirement of 'process management'.

- Definition of the 'established' level of the 'technology' focus area and the 'optimized' level of the 'finance' focus area: Participant R suggested adding that when projects and solutions are implemented, reviews and validations are required afterward to verify if the solution fulfills its desired purpose. Therefore, solution validations and post-implementation reviews have been added to the third maturity level requirement of 'technology implementation' and to the fourth maturity level requirement of 'finance'.

- Definition of the 'established' level of the 'embedding' focus area: Participants D and J noted that the use of interfacing can be a valuable tool in communication and embedding efforts to get all hierarchical layers of the company involved. This element has been added to the third maturity level requirement of 'embedding'.

- Definition of the 'managed' level of the 'data governance' focus area: Two interviewees (participants B and O) indicated that due to the connected nature of Industry 4.0 technologies, security is an extremely important aspect to take into account when companies start implementing Industry 4.0 projects. This element has been added to the definition of the 'data governance' focus area and to its second maturity level requirement.

- Definition of the 'established' level of the 'process management' focus area: Participant O suggested adding version control as an important element to take into account under the process management focus area. This element has been added to the third maturity level requirement of 'process management'.

3.4.4 Development Model V2

This section details the development of Model v2, which consists of the changes to focus areas derived from Interview round 1, as well as the creation of the individual maturity levels for each focus area. Next, the derivation of the initial dependencies through Interview round 1 is illustrated. Lastly, a few textual changes were made to the definitions of the focus areas and their maturity levels to improve readability.

Model structure

The EAI4.0 maturity model is designed as a focus area-oriented maturity model with individual maturity paths for each focus area, similar to the DYA Maturity Matrix (Van Steenbergen et al., 2008). However, through discussion with academic experts, it was decided to structure the model in separate maturity levels instead of one individual matrix on which all levels are portrayed. The advantage of the DYAMM approach is that the model is able to indicate if a requirement for a higher level of maturity of one focus area should be achieved as a prerequisite for a requirement of a lower level of maturity of another focus area. However, through this approach dependencies need to be derived between all maturity levels for all focus areas, which was deemed as unrealistic and impractical. Moreover, depicting all dependencies between focus areas within each maturity level separately increases the structural clarity of the model. As a result, the EAI4.0 maturity model is structured as a focus area-oriented maturity model with individual maturity paths for

each focus area structured separately within each maturity level. In this structure, dependencies exist between all focus areas within each maturity level separately.

The EAI4.0 maturity model contains four columns, each representing a different level of maturity including a generic definition of that maturity level applicable to all focus areas, based on the Process Measurement framework for assessment of process capability (ISO 33020, 2019). This framework is used to assess Industry 4.0 maturity by E. Gökalp et al. (2017), and is used in a similar fashion in this study. The ISO33020 standard uses five levels of process capability. However, for the purpose of this study, the fourth, 'predictable', and fifth, 'optimized', levels are combined. This study aims to guide enterprises in maturing in Industry 4.0 and Enterprise Architecture regardless of their current maturity. However, interview results show that for the general purpose of implementing Industry 4.0, these two maturity levels are similar in requirements and accordingly combined. Therefore, the four different maturity levels derived from ISO33020 are as follows.

- Performed: Implemented processes achieve their purpose. Processes are performed in an ad-hoc fashion and are not standardized, controlled, or implemented in the organization, therefore processes cannot be repeated with confidence for the same outcome. There is no learning cycle.
- Managed: Processes are being implemented in a managed fashion (planned, monitored, and adjusted), and their documented information is appropriately defined, controlled, and maintained. Standardization has taken place, some level of intervention is visible, and some (unaware) learning cycles are in place.
- Established: Processes are being robustly implemented and integrated using a defined procedure, which is assured. Standards and protocols are consistently followed, and processes are vertically integrated on a full organizational level. Learnings are actively documented but improvements are not yet actively pursued.
- Predictable and optimized: The procedure of implementing processes is performed predictively and with a clear objective defined upfront. Quantitative management needs are identified, and measurement data are collected and analyzed to identify assignable causes of variation. Processes are continually improved through innovative approaches. There is not only vertical integration but also a complete horizontal integration with the supply chain and its surrounding value network.

Subsequently, each focus area explains the requirements to reach these levels of maturity specific to that focus area, in conformance with the generic definitions of the maturity levels detailed above. For example, to reach the level of 'managed process' in the focus area of 'finance', a company might be expected to have a central budget for Industry 4.0 practices and Enterprise Architecture, which is sufficiently implemented in the organization.

Focus area maturity levels

Maturity levels for each focus area were developed by combining literature on these individual

constructs with results from the first round of interviews. Subsequently, we altered definitions to align with the purpose of this thesis being in the field of Industry 4.0 and Enterprise Architecture, as well as aligning the definitions with the general definitions of the maturity levels derived in the paragraph above. As an example, the maturity levels for the focus area of 'data quality' were derived mainly from the MD3M master data management maturity model by Spruit and Pietzka (2015). Next, we added upon these definitions with specific requirements that were indicated by participants during the first round of interviews as being requirements for a specific level of maturity for that focus area, like the necessity to perform an assessment on the current level of data quality in the 'performed' level of maturity. Lastly, in case the direct link with our focus domains was missing and instead, a more general term was being used like 'technology' or 'structure' this was then clarified by adding the connection to specifically Industry 4.0 and/or Enterprise Architecture, while also making sure the definitions were in line with the general definitions of the maturity levels. All individual definitions developed for Model v2 can be found in Appendix N. More detailed explanations including sources can be found for each focus area separately in section 4 of this report where the final EAI4.0 maturity model is presented.

Best practices

In a similar fashion, the best practices were developed by combining literature on Industry 4.0 and Enterprise Architecture with results from the first round of interviews. Many maturity models used during the systematic literature review indicated some form of best practices or tips that we incorporated into the model. Also, the participants during the first round of interviews mentioned a lot of practices that they believed to work, or not work, well according to their experience.

The best practices available in the model are not exhaustive due to the way in which they were derived. Most best practices were mentioned once by a single participant and can therefore not be generalized. Accordingly, the role of the best practices is to inspire and give examples, instead of providing an exhaustive overview of all possibilities. To ensure participants are aware of the intended role of the best practices it is highlighted in the explanatory section in the full version of the model in section 4.5.

Initial dependencies

To guide and streamline the focus group sessions an initial setup was created for the dependencies between maturity levels. The goal is to reduce the time it takes the first focus group session to fill the entire model with dependencies, while also incorporating valuable knowledge from the first round of interviews. We derived this initial setup from the results of the first round of interviews, where for each focus area participants were asked to indicate at what stage or relative to what other area the focus area should be achieved. Participants differed in their approach here, and either kept their answers solely as 'first, intermediate, or last', or indicated all dependencies relative to the other focus areas. To create initial dependencies from these results, the interviewer translated these textual responses into numerical responses. In the former instance, we translated 'first' to the number 1, and thus the first focus area that should be achieved. Subsequently 'in-

termediate' was translated to 3, and 'final' to 5, or, the last focus area that should be achieved. In a similar fashion, results from participants that already indicated dependencies were translated into numbers relative to all other focus areas. All individual results of this section can be found in Appendix E.

To reach the initial dependencies, we calculated the average and rounded 'order' value for each focus area. Changes were made to the set of focus areas due to the results of the first round of interviews, which were taken into account by averaging out the 'order' values of focus areas that were merged. The specific merges that took place and guided this process can be found in the 'changes in elements' paragraph in this subsection. These steps led to all fourteen focus areas having an individual order value attributed to them, which subsequently created the initial dependency setup as shown below in figure 9, where each column within a maturity level corresponds to the distinguished 'order' value. Within the first round of interviews, there was no distinction made for the dependencies between the four maturity levels. Therefore, the initial dependencies between focus areas as derived from the results are the same for all four maturity levels. As an example, participants on average indicated that the 'culture' focus area should be achieved second; earlier than most focus areas but not as the first step. Therefore, the 'culture' focus area is placed in the second column of each maturity level.

	Perform				Manage				Establish				Optimize			
Alignment	X				X				X				X			
Embedding			X				X				X				X	
Finance		X				X				X				X		
Process management			X				X				X				X	
Governance			X				X				X				X	
Enterprise Architecture				X				X				X				X
Change management				X				X				X				X
Knowledge		X				X				X				X		
Culture		X				X				X				X		
Leadership		X				X				X				X		
Data governance		X				X				X				X		
Data quality			X				X				X				X	
Standards		X				X				X				X		
Technology				X				X				X				X

Figure 9: Initial dependencies between focus areas

Each focus area, e.g. 'alignment' or 'embedding', consists of four levels of maturity specific to that focus area, indicated by the X's. Each of these four levels contains the requirements to reach a certain level of maturity, specifically for that focus area. The maturity levels for specific focus areas are ordered on what levels need to be reached as prerequisites before maturity levels of other focus areas, within the same general maturity column (e.g., 'perform' or 'establish'). Through this, the model suggests a process to reach the next overall level of maturity. In figure 9, the model suggests that the 'perform' maturity level of the 'alignment' focus area should be reached before the 'perform' maturity level of all other focus areas. Maturity levels for focus areas can

be ordered in the same column, which indicates that the model suggests that these levels can be reached independently, given all prerequisites are achieved.

The dependencies between focus areas are suggestions and should therefore not be seen as necessarily black and white, similar to the dependencies in the DYAMM (Wagter et al., 2005). Each organization's or industry's context is different which in turn might influence the dependencies. Therefore, the role of the dependencies is to guide and suggest an order between the maturity levels, instead of creating an absolutist ranking. To ensure participants are aware of the intended purpose of the dependencies it is highlighted in the explanatory section in the full version of the model in section 4.5, by emphasizing that the organization's specific context should always be taken into account.

3.5 Validation round

3.5.1 Validation round structure

To verify the content of the second version of the model developed above, a validation round was held with both Enterprise Architecture and Industry 4.0 experts. The aim of this step is to sharpen the definitions of the general maturity levels, the general focus areas, and most importantly, the individual focus area maturity levels since the content of the maturity level definitions is a crucial element of the maturity model. Participants were prompted to focus their evaluation of the model on two design science evaluation criteria: completeness, by asking if any requirements were currently still missing, and fidelity with practice, by asking if the requirements derived through literature and the first round of interviews are logical in practice.
The next step after the validation round is the focus group session in which the dependencies between the focus area maturity levels were established. For this to be properly executed all definitions are required to be correct and concise, prompting the need for this validation round. Moreover, the people participating in the validation round were the same people participating in the focus group session, which greatly increased their knowledge of the subject which in turn reduced the time required during the focus group sessions.

3.5.2 Panel selection validation round

The panel selection for the validation round is guided by their participation in the focus-group session, as these two consist of the same participants. Two separate focus group sessions were performed to reach a consensus on focus-area interdependencies. The first focus group session contained a group of experts focused mainly on the field of Industry 4.0, working in advisory roles for different clients in the manufacturing domain. The second focus group session contained experts focused mainly on Enterprise Architecture, encompassing decades of experience in different organizations. Table 9 gives an overview of the experts participating in the validation round and present at the different focus group sessions.

Session	Function	Area of Expertise
1	Consultant	Industry 4.0 (manufacturing) & IT
1	Researcher and architect	Digital business, Industry 4.0
1	Sr. Consultant	Business analysis, MES, Industry 4.0, IT-OT integration
1	Sr. Consultant	Industry 4.0, PLM
1	Architect	Enterprise Architecture
2	Architect	Enterprise Architecture, digital
2	Architect	Enterprise Architecture, business transformation
2	Consultant	Enterprise Architecture, integration
2	Chief technology officer	Enterprise architecture, information management
2	Manager	Digital IT, IT strategy & architecture
2	Domain architect	Enterprise architecture, information systems
2	Solution architect	Enterprise architect, information management

Table 9: Validation round and Focus group session participants

3.5.3 Results Validation round

This section details the major changes made to the definitions of the general focus areas, general maturity levels, and focus area maturity levels based on the validation round before the focus group sessions. The definitions validated in this section were derived from literature, as well as from the results of the first round of interviews. Seven members participating in the focus group sessions participated in the validation round due to time constraints and gave comments both on content and readability.

As an overall feedback point, one participant (participant 2) mentioned the need for additional explanatory information at the beginning of the model, to clarify the purpose of the focus areas versus the maturity levels. The following sentence was added to improve upon this: “Each maturity level, ‘performed’ to ‘optimized’, represents a coherent stage where all focus areas are in balance regarding the maturity of an enterprise which successfully integrated Industry 4.0 and Enterprise Architecture.”.

General maturity level definitions

For visibility purposes we shortened the titles of the general maturity level definitions by removing the word ‘process’ from all of them, e.g. ‘performed process’ was changed to ‘performed’. As a result of comments by participant 7, all general maturity level definitions were extended by adding information on the extent to which learning cycles are present in general, as this captures the level to which an organization is able to improve in a structured manner. As a result of comments from participant 3, we removed the assessment section of the ‘performed’ general maturity level definition, as this is not a general theme for all focus areas, but rather a specific step in certain focus areas. Finally, a few minor changes were made based on the focus group comments to improve clarity.

General focus area definitions

Based on the feedback from participants 2 and 6, we shortened the 'finance' focus area definition to increase simplicity, by removing information about specific budgets and KPIs. As a result of feedback from participant 3, we extended the 'data quality' focus area to better reflect the intention of this focus area being concerned with not only data quality itself but also data acquisition. Finally, a handful of minor changes were made to the general focus area definitions to improve clarity and add nuance.

Focus area maturity level definitions

This section covers a list of changes to the individual focus area maturity level definitions based on the feedback from the validation round.

- The 'performed' definition of the 'embedding' focus area was extended to better reflect the link with the company's strategic Industry 4.0 goals due to comments by participants 1, 5, and 6. The 'managed' definition of the 'embedding' focus area was changed from a "communication plan" to a realization of embedding through the appointment of stakeholders due to comments by participant 6, as this is a more concrete step.

- The 'managed' definition of the 'governance' focus area was extended due to comments by participant 3, to include active execution in the organization through the defined governance structure, instead of solely the presence of one.

- The 'established' definition of the 'enterprise architecture' focus area was extended to include the presence of a reference architecture due to comments by participant 1, as this is seen as a relevant requirement for this level of maturity.

- The 'established' definition of the 'knowledge' focus area was extended due to comments by participant 3, to include an active use for the personal growth of budget for people development, instead of solely the presence of one.

- The 'managed' definition of the 'culture' focus area was changed due to comments by participant 3, by removing the "separate department or start-up" information and instead changing this to "organizational measures in specific cases of cultural assessment", as the decision to set up a separate department or start-up was felt too specific a decision. The 'optimized' definition of the 'culture' focus area was extended due to comments by participant 7, to include the active sharing of knowledge with external parties as participants saw this as an integral part of a highly mature Industry 4.0 organization.

- The 'optimized' definition of the 'leadership' focus area was changed due to comments by participant 4, by removing "managers have the flexibility to innovate" and instead changing this to "managers pursue innovation", to better reflect an internal managerial drive to improve the organization.

- The 'performed' definition of the 'standards' focus area was extended due to comments by participant 6, by adding that at this level of maturity, no choices are yet enforced through standards and protocols, to better show the extent to which companies need to be concerned with rigidness in the form of standards. The 'established' definition of the 'standards' focus area was extended due to comments by participant 4, by adding that systems and procedures adhere to standards accordingly, as participants noted that a company could, at this level, deliberately not follow standards when applicable.
- The 'managed' definition of the 'technology' focus area was extended due to comments by participant 4, by adding information about removing redundant or legacy technology when applicable, as this is seen as a relevant requirement to reach higher levels of technological maturity.

3.5.4 Development Model V3

The changes presented in the section above were made to ModelV2 to create ModelV3. Next to these changes, multiple minor changes were made to the focus area maturity level definitions to improve clarity and readability and to add nuance. The results of these changes can be found in Appendix O detailing the third version of the model.

3.6 Focus group round

After the definition validation round, a focus group session took place with the goal of deriving incremental dependencies between the focus area maturity levels. An initial setup for these dependencies was used in the focus group sessions based on the results of the first round of interviews, where every maturity level is ordered relative to the maturity paths of the other focus areas. During the focus group sessions, an open discussion took place to verify the exact placement of every maturity level. Due to the complicated and extensive content of this task, a focus group session was deemed preferable over an interview. For the focus group sessions, experts in the advisory domain were invited that are highly knowledgeable in both Enterprise Architecture and Industry 4.0. Moreover, these experts all have experience working with such models.

A Delphi method was implemented through the focus group sessions, to solicit expert opinion without bias, with the aim to reach a consensus on the focus area interdependencies (Dalkey & Helmer, 1963). Two focus group sessions were conducted, with a different set of experts. For the first focus group, participants were selected from experts with expertise mainly in Enterprise Architecture, whereas for the second focus group, participants were selected from experts with expertise mainly in Industry 4.0. The inclusion of experts in both areas of expertise ensures sufficient content input from both domains. The first focus group received an initial order between the maturity levels for focus areas based on the first round of interviews, with the aim to guide the focus group participants. During the first focus group session, the participants reached a consensus on the dependencies between maturity levels. The second focus group, in a different session, used

the consensus of the first group as input to reach a final consensus. Next, the final consensus was shared with the first focus group participants to ensure overall consensus. All focus group members were sent a document containing the final definitions of the focus areas and their requirements beforehand to ensure knowledge of the topic. Two different focus group sessions were held due to temporal and geographical constraints.

The 'iterative development' and 'controlled feedback' features of the Delphi method are used to design the focus group process (Rowe & Wright, 1999). The focus group session is guided by a facilitator who assures all feedback is incorporated in a controlled manner. Within each focus group session, participants reached a consensus on the dependencies between the focus area maturity levels through an iterative process, which allowed participants to make changes to previously identified dependencies, based on each new round of additional maturity levels. Moreover, participants were informed of the other participants' perspectives each round, which provided the opportunity for the participants to refine their views in light of the opinions of the other participants (Skulmoski, Hartman, & Krahn, 2007). Participants started with identifying the dependencies within the first general maturity level, 'perform', for the first domain, 'organization', which consists of the first seven focus areas. All participants followed the same method for this identification, by using the provided individual grid and post-it notes, which they could use to indicate the dependencies according to their judgment. By following this approach, participants are less prone to initial bias, which should lead to a balanced consensus. After every participant decided on the dependencies individually, an overall discussion took place to reach a consensus among the participants for that specific round. Following this, the next three focus areas, the areas of the 'people' domain', were ordered via the same procedure. Finally, the four focus areas of the 'technology' domain were ordered. This process was repeated for all four general maturity levels until twelve rounds have taken place and all dependencies were identified. After each round, participants are guided to look back at the previously established dependencies and reflect if this is still correct or needs changing, as dependencies among focus areas across domains might change with each addition of the remaining maturity levels. Progress was documented after each round to reflect on the entire process of reaching a consensus.

Participants of a Delphi study should meet four requirements. Knowledge and experience, capacity and willingness to participate, sufficient time to participate, and effective communication skills (Adler & Ziglio, 1996). Experts were chosen based on the first and fourth requirements to ensure a valid content-wise consensus. All participating experts received a short explanation of both the content and the procedure prior to the interview. To facilitate the second and third requirement, a date, location, and time was chosen in consultation with all experts.

3.6.1 Focus group structure

First, a short personal introduction of all members commences. Next, the setup of the focus group session is explained, as well as general information regarding the topic. When everything is clear

for the participants, the twelve rounds commence in order from 'performed' to 'predicted and optimized', per domain separately.

After every participant has filled in their individual grids, the facilitator identifies the commonalities first and places these focus area maturity levels on the whiteboard when applicable. Next, all remaining focus area maturity levels are discussed one by one until a consensus is reached. This discussion is guided by the facilitator, in turn asking one of the participants to deliberate on the reasoning behind their identified dependencies. When a consensus is reached, applicable changes are made on the whiteboard. To keep track of the changes after each of the twelve rounds, a picture of the whiteboard will be taken containing the overall consensus. Through this, changes in dependencies in each round will be documented.

After each of the 12 rounds, we look back at the previously placed letters and discuss if the order needs to be changed based on the newly added letters. After all 56 maturity levels have been defined, the model is complete. The participants are asked separately if they are content with the consensus, or if there are still dependencies that need to be altered. Finally, participants are thanked for their input.

A detailed version of the structure, information given to participants, and questions asked during the Focus Group can be found in Appendix H.

3.6.2 Panel selection focus group round

Participants of the focus group sessions are the same participants that took part in the validation round and can be found in table 9.

3.6.3 Results focus group round

This section details the results of the focus group sessions split into two parts. Firstly, minor changes to some of the focus area maturity level definitions are introduced, which are made based on the discussions during the focus group sessions. Secondly, this section details the reached consensus on the dependencies between the focus area maturity levels.

Changes and comments from session 1

- Definitions of the 'managed' and 'established' levels of the 'technology' focus area: By mutual agreement the participants commented that the removal of redundant technology in the 'managed' level is too early. Rather, at the 'managed' level obsolete technology should be identified and subsequently removed at the 'established' level. Therefore, we changed the 'managed' definition to identification and the 'established' definition to the removal of redundant technology.

- Definition of the 'optimized' level of the 'finance' focus area: By mutual agreement, the participants noted that in the definition of the 'optimized' level of the 'finance' focus area, project budgeting was solely based on financial KPIs, instead of company-wide KPIs, while company-wide KPIs are in fact present as a result of implementing Industry 4.0. We extended this definition to also incorporate non-financial KPIs.

- Definition of the 'optimized' level of the 'process management' focus area: It was agreed by all participants that the link between Industry 4.0 and the supply chain network in the 'optimized' level of process management needed to be more explicitly mentioned. The definition was changed to better reflect the intended purpose of the maturity level.

- Definition of the 'optimized' level of the 'leadership' focus area: By mutual agreement, the participants suggested removing the section: "instead of being required to forcefully include employees", because they felt that this information is often mainly situation-specific, and therefore not an addition to the core purpose of the 'optimized' level of the 'leadership' focus area. We subsequently removed this section from the definition.

- Definition of the 'established' level of the 'standards' focus area: Participant A commented that all relevant applications should adhere to established standards, instead of solely new applications. Logically also existing applications, systems and procedures need to adhere to the defined standards in the 'established' level of maturity. The definition was changed to cover all relevant applications.

- Definition of the 'optimized' level of the 'standards' definition: Participant C suggested renaming the section: "external standards and open-source information" to "emerging standards", with the goal of generalizing the definition. This definition was updated accordingly.

- Definition of the 'optimized' level of the 'data quality' focus area: By mutual agreement, the participants decided that milestones and metrics should be regularly reviewed by all relevant stakeholders, not just by executives. We updated the definition to include all relevant stakeholders.

- Best practice for the 'performed' level of the 'change management' focus area: Participant A suggested that organizations can benefit from starting a prototypical project as a precursor to a full-on project in which all rules have to be followed. This ensures innovation is not flattened, while it might also feel like a lower threshold for employees and thus seem more appetizing. We added the use of (technical) prototypical projects as a best practice as a result.

- Best practice for the 'established' level of the 'knowledge' focus area: Two participants (participants B and D) suggested adding the appointment of thought leaders as a best practice for the 'established' level of the 'knowledge' focus area with the goal to create knowledge leaders for specific subjects relevant to Industry 4.0. As a result, we added the appointment of thought leaders to the best practices for this level.

Changes and comments from session 2

- Definition of the 'optimized' level of the 'change management' focus area: By mutual agreement, the participants noted that a company cannot go from a situation in which they only include their own organization, to a situation in which the complete value network is integrated. In line with this, we added a requirement for the 'optimized' level of 'change management', which states that companies need to have a structured plan on how to incorporate their supply chain.

- Best practice for the 'performed' level of the 'change management' focus area: Participant H and participant I highlighted the importance of starting small when beginning with projects in the 'performed' phase. For most focus areas, it is unrealistic to address the entire organization at once. Also on a project level, companies should remember to keep it simple. For example, a project with the aim to increase operational excellence through artificial intelligence should not start with the entire production facility at once, but rather with a single production line. This feedback was added as a best practice for the focus area of 'change management'.

- Best practice for the 'optimized' level of the 'change management' focus area: In line with the previous remark and subsequent definition change, participant H noted that a best practice to achieve this requirement on value network integration is to focus first on integrating the company's most important customer or supplier in the value network, before integrating other organizations. We added this best practice to the 'optimized' level of the 'change management' focus area.

- Best practice for the 'managed' level of the 'standards' focus area: Participant J suggested mentioning system-focused best practices in the 'standards' focus area, like ERP or MES systems since they are already utilizing existing standards but can also limit possibilities for future new standards. We added a best practice to the 'managed' level of the 'standards' focus area suggesting to evaluate the way in which currently in-use systems deal with standards.

- Maturity model explanation: By mutual agreement the participants indicated that some focus area maturity levels require attention earlier than their proposed order within the dependencies. An example of this is the 'finance' focus area in the 'performed' stage, which, according to the model, is the last to be reached in the 'performed' maturity level. However, while reaching the 'performed' maturity levels for the other focus areas, finance should not be completely ignored. We extended the maturity model explanation in accordance with this feedback, by stating that users of the model should be wary that some areas require attention earlier than the proposed moment of achievement of that maturity level.

Dependencies

The reasoning behind the dependencies between the maturity levels for the focus areas is based on expert consensus. For each maturity level, the achievement is either dependent on the achievement of other maturity levels, a prerequisite for other maturity levels, independent of other maturity

levels, or required to be achieved together at the same time. As a result of the focus group session, all dependencies between maturity levels of each focus area were derived and placed together in a tabular format as can be seen in figure 10. Figure 10 below shows the final reached consensus on the dependencies between focus areas, after both focus group sessions. Here, each X represents a maturity level for a single focus area, the ordering of which indicates the dependencies. Thus, the model is to be read from left to right, ideally reaching each level of maturity per column before moving on to the next column. The dependencies in figure 10 suggest that the 'perform' maturity level for the 'finance' focus area should not be achieved before all other focus areas other than 'Data quality' reach their respective maturity level of 'perform'. An individual example of such a dependency is the 'perform' level of 'change management' (column 3), which requires the first Industry 4.0 project to be delivered, being dependent on the 'perform' level of, among others, the 'knowledge' focus area (column 2), which requires the relevant knowledge for this project to be acquired. These dependencies are subsequently used in the final 'EAI4.0 maturity model' in section 4.

	Performed				Managed				Established				Optimized			
Alignment	X				X				X				X			
Embedding			X			X					X			X		
Finance				X			X					X			X	
Process management		X			X				X					X		
Governance			X			X			X				X			
Enterprise Architecture	X					X				X			X			
Change management			X					X				X			X	
Knowledge		X					X				X					X
Culture		X						X				X		X		
Leadership	X				X						X				X	
Data governance			X				X			X					X	
Data quality				X				X			X			X		
Standards		X				X						X				X
Technology			X			X						X		X		

Figure 10: Final dependencies between focus areas

Four changes were made to the consensus of the first focus group by the second focus group, and are highlighted below. The dependencies as derived from the first focus group session, before the second session, can be found in Appendix I.

- Relative dependency of the 'performed' level of the 'knowledge' focus area: By mutual agreement the participants opted that the 'performed' level of knowledge is a requirement for the 'performed' levels of the 'change management' and 'technology' focus areas, instead of a maturity level that should be achieved at the same time. Participants noted that without the required knowledge, technical capabilities cannot be properly acquired, nor can the project be delivered. As a result, we changed the placement of the 'knowledge' focus area to the second column within the 'performed' maturity level, to be a prerequisite for 'change management' and 'technology'.

- Relative dependencies of the 'managed' levels of the 'standards' and 'technology' focus areas: It was agreed by all participants that the maturity levels for standards and technology in the managed level of maturity need to be achieved in parallel. More specifically, the definition of specific standards and protocols is required to go hand in hand with the definition of Industry 4.0 supporting tools and capabilities, as these requirements shape each other. As a result, we changed the placement of these two focus areas to the second column within the 'managed' maturity level.
- Relative dependency of the 'established' level of the 'leadership' focus area: By mutual agreement, the participants decided that the requirements for the 'established' level of leadership are prerequisites for the 'established' level of change management. Participants noted that the 'change management' requirement demanding a standardized change management process within Enterprise Architecture cannot function properly without the 'leadership' requirement for a standardized management framework. Moreover, participants indicated that the requirements for the 'leadership' focus area should be achieved in parallel with the 'embedding' focus area, as a fully defined embedding and communication process should be set up hand in hand with a standardized management framework. As a result, we changed the placement of the 'leadership' focus area to the third column within the 'established' maturity level.

The sections below show the results of the focus group sessions, from which the dependencies in figure 10 were derived. These dependencies are based on the reached mutual agreements between all participants. This consensus subsequently led to the positions of the Xs for the final dependencies between focus areas.

Dependencies among focus areas for the performed level of maturity

Dependencies for the 'alignment', 'Enterprise Architecture', and 'leadership' focus areas: The first focus areas to reach the 'performed' maturity level are 'alignment', 'EA', and 'leadership', as they are prerequisites to the 'perform' maturity levels of the other focus areas. These focus areas contain the basic requirements for all other focus areas to be performed, namely: a basic view of what the goal is (the 'why' and 'what'), an appointed project architect, and a responsible manager with the willingness and skills to push the digital transformation.

Dependencies for the 'process management', 'knowledge', 'culture' and 'standards' focus areas: The next three focus areas to reach the 'performed' maturity level are 'process management', 'knowledge', 'culture', and 'standards', who all require the three focus areas before being performed. Moreover, these four focus areas are prerequisites for the remaining focus areas, as they all have assessments in common that will guide the requirements at later levels. An assessment of the company's culture is required to take place before focus areas like embedding, governance, and change management since it dictates how these focus areas elicit change in the organization. The assessment of current (Industry 4.0) processes (process management) is also required for further

levels, as they decide what governance is required, what needs to be embedded, for what data governance is required, and what technical capabilities are required. The same holds for the assessment of current standards and protocols, as they drive data governance, technical capabilities, and embedding. Finally, an assessment of the current knowledge is required to take place before focus areas like technology, as it defines what technical capabilities are able to be utilized.

Dependencies for the 'embedding', 'governance', 'change management', 'data governance', and 'technology' focus areas: The focus areas that should reach the 'performed' maturity level next should all be reached in parallel. embedding, governance, change management, and data governance at this level rely on one another to be correctly implemented in the organization. Also, the focus area of technology should reach its requirements at the same time, regardless of the four other focus areas in this stage. All five focus areas in this stage should achieve their requirements before the final two focus areas of the 'performed' maturity level, 'finance', and 'data quality'.

Dependencies for the 'finance' and 'data quality' focus areas: The finance focus area requires project budgets for Industry 4.0 and Enterprise Architecture, for which sufficient knowledge and implementation in the organization are required. The first level of data quality requires an idea to be present about what data quality requirements are, which can only take place after the (data) governance and technology focus area 'perform' maturity levels are reached.

Dependencies among focus areas for the managed level of maturity

Dependencies for the 'alignment', 'process management', and 'leadership' focus areas: The first focus areas that should reach the 'managed' level of maturity are 'alignment', 'process management', and 'leadership'. In a similar fashion as in the 'performed' maturity level, 'alignment' and 'leadership' are important drivers of digital transformation. In this level of maturity, clear leadership is required to ensure the effectiveness of the other focus areas. The 'managed' level of alignment describes relevant steps for most other focus areas and should thus be achieved first. The 'process management' focus area needs to be achieved at a similar moment, as a defined process architecture is a requirement for Industry 4.0 requirements in other focus areas.

Dependencies for the 'embedding', 'governance', 'Enterprise Architecture', 'standards', and 'technology' focus areas: Next, the 'embedding', 'governance', and 'enterprise architecture' focus areas should achieve the 'managed' level with the similar goal of managing the established plans and projects within the organization, which is a prerequisite for requirements of the 'knowledge' and 'finance' focus areas. In parallel, the 'standards' and 'technology' focus areas need to achieve the 'managed' level of maturity and need to take place in parallel since their requirements rely on one another to function properly.

Dependencies for the 'finance', 'knowledge', and 'data governance' focus areas: The 'finance',

'knowledge', and 'data governance' focus areas should reach the 'managed' level of maturity next, as they all require a 'managed' maturity level of earlier areas. For example, the 'finance' 'managed' level requires financial information to be monitored, which requires a 'managed' level of embedding and governance.

Dependencies for the 'change management', 'culture', and 'data quality' focus areas: Finally, the organization should achieve the 'managed' level for 'data quality' since at this level the company is working with rules and criteria for which a managed level of 'standards' and 'technology' is required. In parallel, the 'culture' focus area should achieve the 'managed' level since cultural change measures and incentive structures require the company to have clearly defined structures in focus areas like 'leadership', 'governance', and 'data governance'. The 'change management' focus area states that Industry 4.0 projects are performed in a controlled and planned manner, which requires all other focus areas, except 'culture' and 'data quality', to be managed.

Dependencies among focus areas for the established level of maturity

Dependencies for the 'alignment', 'process management', and 'governance' focus areas: Within the established level of maturity, the focus lies on integration in the organization through defined procedures and standardization. In line with this, the first focus areas to reach the 'established' level of maturity are 'alignment', 'process management', and 'governance'. Firstly, the alignment process is fully defined and in line with IT and OT is a requirement for the remaining focus areas. In parallel, a fully integrated process architecture is a prerequisite for the established level of other focus areas like 'knowledge', 'data quality', and 'technology'. The 'governance' focus area is also required to reach its 'established' level of maturity before the remaining focus areas, since a fully embedded governance structure is a prerequisite for organizational integration, in line with the general 'established' maturity level definition.

Dependencies for the 'Enterprise Architecture, and 'data governance' focus areas: Next, the 'Enterprise Architecture' and 'Data Governance' focus areas should reach the 'established' level of maturity. A fully integrated and standardized Enterprise Architecture follows from the 'established' levels of 'process management' and 'governance', and is required for the remaining focus areas to mature. Similarly, an integrated and standardized data governance framework follows from 'established' levels of 'process management' and 'governance', and should be set up in parallel with the established level of Enterprise Architecture.

Dependencies for the 'embedding', 'knowledge', 'leadership', and 'data quality' focus areas: To have a fully defined embedding process, all governance processes need to be taken care of. Therefore, the 'embedding' focus area should reach its 'established' level next. The 'leadership' focus area should reach its 'established' level of maturity in parallel with the 'embedding' focus area, as they are prerequisites for one another to function properly. In parallel, the 'knowledge' and 'data

quality' focus areas should reach their 'established' level of maturity, as they in a similar fashion require all governance and processes to be established and known.

Dependencies for the 'finance', 'change management', 'culture', 'standards', and 'technology' focus areas: Lastly, the 'finance' focus area should reach its 'established' level of maturity, since a fully integrated financial measurement structure is dependent on the 'knowledge' and 'embedding' focus areas, through the defined personal development budgets and established embedding process. In parallel, the 'standards' and 'technology' focus areas should reach their 'established' level of maturity, as the requirements for their levels are dependent on large-scale integration of focus areas like 'knowledge', 'data governance', and 'data quality'. The 'change management' and 'culture' focus areas reach their 'established' levels of maturity in this stage as well. A cultural shift can only have happened when the 'embedding' process is fully established. Similarly, a standardized change management process requires an established maturity of the 'embedding' and 'leadership' focus areas.

Dependencies among focus areas for the optimized level of maturity

Dependencies for the 'alignment', 'governance', and 'Enterprise Architecture' focus areas: Within the optimized level of maturity, the focus lies on optimization, predicting, improvement, and integration with the supply chain and value network. In line with this, the focus areas of 'alignment', 'governance', and 'enterprise architecture' should achieve the 'optimized' level of maturity first. The alignment focus area dictates the way in which the value network is integrated within the company and its Industry 4.0 efforts, and is therefore a prerequisite for the remaining focus areas. Similarly, the governance structure concerning this inclusion is a prerequisite for the focus areas which require clear roles and responsibilities. In parallel, the Enterprise Architecture focus area should reach its 'optimized' level of maturity, as reaching this level greatly benefits the ease with which the other focus areas can improve their maturity.

Dependencies for the 'embedding', 'process management', 'culture', 'data quality', and 'technology' focus areas: After the first three focus areas have achieved the 'optimized' level of maturity, the plan, the 'who', and the 'how' is defined. Next, the focus shifts to the embedding and inclusion of the value network on a content level. Consequently, the focus areas of 'embedding' and 'process management' should improve next, which integrates processes within the Industry 4.0 structure of the organization. In parallel, the 'data quality' and 'technology' focus areas should achieve their 'optimized' level of maturity, as these need to be known and clear at the same time as the 'embedding' and 'process management' focus areas. At this stage, the company is able to learn from different company cultures and is, therefore, able to harbor an innovative culture.

Dependencies for the 'finance', 'change management', 'leadership', and 'data governance' focus areas: When the value network is fully embedded and integrated, the organization is able to per-

fectly balance and optimize the finances, thus having the 'finance' focus area reach its 'optimized' level of maturity. In parallel, managers are now change leaders and are able to disrupt existing processes, which can only be achieved when the previous focus areas have reached the 'optimized' level of maturity. Similarly, the organization is now in a state of maturity where it is able to evaluate external data governance frameworks for best practices.

Dependencies for the 'knowledge' and 'standards' focus areas: Finally, the organization looks towards the future and deliberates where they aim to be in the coming years, on a technological capability level, as well as on a 'standards' and 'supporting tools' level. At this stage, the company is able to deal with and possibly utilize emerging technologies and standards, which can be integrated on short notice through the defined Enterprise Architecture.

Horizontal dependencies

Next to the dependencies between focus areas within maturity levels, the results of the focus group session also contain logic behind relative maturity to other areas within focus areas. These paragraphs provided additional input to derive the final set of dependencies between focus areas.

Horizontal dependencies for the 'leadership' focus area: In the leadership focus area, the 'performed' and 'managed' levels should be achieved first in their respective levels of maturity. However, in the 'established' and 'optimized' levels of maturity, the requirements for leadership are less of a prerequisite for other areas and have changed to requirements that require achievement of other focus areas which steer the 'leadership' focus area. In other words, at lower levels of maturity leadership has to proactively push the digital transformation and its focus areas, but as the organization matures leadership gradually reaches a more supportive role which evolves as a result of other focus areas.

Horizontal dependencies for the 'knowledge' focus area: A similar logic exists for the 'knowledge' focus area which gradually changes from a prerequisite or precondition in lower levels of maturity to an area that builds on other focus areas the more mature the organization becomes. To start a first Industry 4.0 project, a sufficient level of knowledge is required. However, when the organization has an integrated knowledge framework, the goal of the focus area changes from being about ensuring the required knowledge capabilities to evolving knowledge capabilities based on learnings from other processes.

Horizontal dependencies for the 'standards' focus area: A similar logic exists for the 'standards' focus area which also gradually changes from a prerequisite or precondition in lower levels of maturity to an area that builds on other focus areas the more mature the organization becomes. In the 'performed' level of maturity, standards are required to guide and steer the first Industry 4.0 projects. However, when the organization has defined and controls standards, the goal for the

focus area becomes less about ensuring processes follow standards and protocols, and more about evolving standards based on learnings from other processes.

Horizontal dependencies for the 'governance' focus area: The 'governance' focus area evolves contradictory to the three dependencies mentioned above, gradually changing from a focus area that requires other focus areas to have matured, to an area that is a prerequisite for and subsequently steers other focus areas. In the early stages of the 'performed' level of maturity, there should be no limiting roles and responsibilities as this might inhibit innovation. However, as the organization matures in Industry 4.0 the requirement for clear roles and responsibilities increases due to the complexity of the topic, prompting earlier achievement of the focus area relative to other areas.

Horizontal dependencies for the 'data quality' focus area: The 'data quality' focus area evolves similarly to the 'governance' focus area mentioned above, gradually changing from a focus area that requires other focus areas to have matured, to an area that is a prerequisite for and subsequently steers other focus areas. In the early stages of the 'performed' level of maturity, there are no defined processes from which to extract data. However, as the organization matures in Industry 4.0 data quality evolves into a requirement for other processes to reach their respective requirements.

Horizontal dependencies for the focus areas not mentioned above: A specific logic within the evolution of the focus areas while reaching higher levels of maturity was not identified for the remaining focus areas.

3.6.4 Development Model V4

The changes presented in the section above were made to ModelV3 to create ModelV4. Next to these changes, a few textual changes were made to the definitions of the focus areas and their maturity levels to improve readability. The results of these changes can be found in Appendix P detailing the fourth version of the model. The fourth version of the model has subsequently been sent to the participants after they completed the maturity assessment.

3.7 Maturity assessment

This section details the protocol for the EAI4.0 maturity assessment that was used as input for the final round of interviews. Companies performed the assessment in their own time through an extensive survey containing an explanation of the procedure and the relevant questions. After the maturity assessment took place, the results were discussed in an in-person interview. The goal of the maturity assessment is to assess the maturity level of an enterprise for each of the established fourteen focus areas. Each focus area is assessed based on defined requirements that correspond to the established levels of maturity, from 'performed' to 'optimized'.

To verify if the information at the start of the assessment was sufficient two participants completed the questionnaire in pilot format. Moreover, this pilot was used to assess if the time it took participants to complete the assessment was acceptable and if any other problems arose.

After participants completed the maturity assessment for their organization a subsequent interview was planned. Before the interview took place, participants were sent the full maturity model, including its explanations and definitions, the requirements per focus area maturity level, and the corresponding best practices, without the assessment results. Covering the entire model during the interview itself is infeasible, but it is important that participants receive all the required information if they were to use the model to improve their maturity. The model was sent before the interview to give participants the opportunity to read through it before the interview and use it as correspondence during the assessment results during section the interview. The assessment results were deliberately not shared before the interview to ensure questions about the assessment would be asked during the interview itself and no subsequent insights would be lost.

3.7.1 Maturity assessment structure

Organizations participating in the maturity assessment received a summarized explanation of the goal of the maturity model, combined with definitions of terms used in the assessment as an addition to the questionnaire. Participants were chosen from the set of participants that participated in the first round of interviews, to ensure sufficient knowledge and validity of the subject. A detailed version of the structure, information given to participants, and questions asked during the Maturity assessment can be found in Appendix J.

Next to information about the model, participants received a survey containing 115 questions. The aim of the assessment is to check for each of the 4 maturity levels for 14 focus areas if a company has reached this level. Each focus area maturity level consists of between one and four requirements to reach that level, based on the established definitions for the maturity levels. Each individual requirement was assessed through a yes/no question that verified whether a company has or has not achieved that step. After each question participants were able to comment if they were unsure about their answer, or if they would like to add additional information. These questions were not mandatory and participants were instructed to only use these questions in case of doubt or when they felt more context was required.

3.7.2 Panel selection assessment and final interview

The set of participants for the maturity assessments and subsequent final round of interviews consists of interviewees from the first round of interviews, as well as newly acquired participants. An overview of participants is given in table 10.

#	Function	Type	Area of expertise
1	Director operations	Industry	Food, operations
2	Enterprise Architect	Industry	Manufacturing
3	Management	Industry	Food, operations
4	Architect	Industry	Enterprise Architecture
5	Enterprise Architect	Industry	Mobility
6	Enterprise Architect	Industry	Utility
7	Consultant	Advisory	Industry 4.0
8	CIO	Industry	Industry 4.0
9	Technology lead	Industry	Digital transformation
10	IT lead	Industry	Digital transformation
11	Consultant	Advisory	Industry 4.0
12	IT Strat consultant	Both	Hi-tech and IT

Table 10: Maturity assessment and second round of interviews participants

3.7.3 Pilot results

Two participants completed the assessment questionnaire in a pilot format, with the aim of verifying whether the explanatory information was sufficient, as well as checking if the questions were clear and sufficiently extensive.
The time it took the pilot participants to fill in the questionnaire was between twenty and thirty minutes, which was deemed a perfect time investment for the remaining participants.

Both participants indicated that for certain questions the phrasing was too general and that an extension would be required to better show specifically the link between the subject of the requirement and Industry 4.0 and/or Enterprise Architecture. As a result of this, we slightly altered seventeen questions, mostly in the 'optimized' level of maturity, to better reflect the purpose of the requirement and thus improve the structural validity of the assessment. The following questions were altered, of which the resulting questions can be found in Appendix Q: #10, #26, #39, #53, #55, #58, #65, #66, #67, #73, #80, #97, #98, #102, #103, #114, #115.

Moreover, participants noted that in the pilot setup, they were unable to give comments in a convenient way, being only possible in the final question. To resolve this issue, we added a non-mandatory open-field question after each requirement-based question in which participants are able to indicate if they want to add additional information or if anything was unclear.

When evaluating the assessment results we realized that the initial way of presenting maturity did not show progress within a focus area maturity level until all requirements were completed. In other words, when an organization has completed three out of four requirements for a focus area maturity level, the subsequent assessment for that level would be white. This leads to the overall assessment not giving the true picture of progress, while in cases of low maturity also looks rather depressing.

Lastly, the pilot assessments showcased an unexpected effect of organizations achieving requirements in later maturity stages, without achieving the earlier requirements in the same focus area. What we however noticed was that many of the requirements achieved in later maturity stages were often relatively stand-alone requirements that a company could have sensibly achieved separate from the Industry 4.0 transition. An example of this is the requirement for data warehousing in the 'managed' maturity level of the 'data quality' focus area. Most organizations indicated to have achieved this requirement due to it being inherently required for their organization to function, separate from Industry 4.0. To ensure the relevant progress of organizations within our domain was correctly captured, no changes were made as a result of this finding.

3.7.4 Maturity assessment presenting strategy

The maturity assessment as originated from the survey results subsequently highlights what focus areas require attention and what steps need to be taken next to evolve, in addition to displaying the overall maturity of the company in combining Industry 4.0 and Enterprise Architecture. When a company has achieved all requirements that comprise a focus area maturity level, the company has reached that maturity level as a whole. The same holds for the four general levels of maturity, in the sense that a company has reached the 'performed' maturity level when all fourteen focus areas have individually reached the 'performed' maturity level. Each achieved focus area maturity level is indicated in dark green, compared to the non-reached maturity levels indicated in white. When a company has achieved at least one but not all requirements of a maturity level, it is indicated in light green. An example of an assessment overview can be found in section 4.5.

The steps an organization can take to improve its maturity are presented by means of a roadmap that is prepared in advance of the interview. This roadmap contains two or three sections, depending on the number of requirements per section, where each section consists of maturity levels of focus areas that should be achieved in parallel. Therefore each section of the roadmap is a set of requirements companies can achieve at the same time as the next step to improve their maturity. Through this approach, the roadmap consists of between ten to fifteen requirements that the organization should achieve next. The goal of this roadmap is to specifically provide guidance next to the assessment. In other words, the assessment shows organizations which areas they are and are not mature in, while the roadmap visualizes in what steps the company should improve its maturity. An example of a roadmap presented to participants during the interview can be found in Appendix R.

4 EAI4.0 Maturity Model

This section details the final EAI4.0 maturity model and includes changes made as a result of the second round of interviews detailed in section 5. The EAI4.0 Maturity Model aims to guide organizations in maturing in Industry 4.0 and Enterprise Architecture by visualizing their maturity and subsequently indicating what steps to take to improve their maturity. The EAI4.0 Maturity Model consists of the following elements:

1. Information on the goal and structure of the maturity model
2. Definitions of the focus areas and general maturity levels
3. Information on how to read and use the maturity model
4. A table with all maturity level definitions per focus area
5. Best practices for each focus area maturity level
6. Requirements for each focus area maturity level
7. An assessment questionnaire based on the focus area maturity level requirements
8. A procedure on how to derive the maturity assessment from the questionnaire, and how to derive the roadmap from the maturity assessment

The first five elements of the model can be found in subsection 4.5 which highlights the complete model. Elements six and seven are depicted in Appendix Q. Element eight is detailed in subsection 4.4.

4.1 Scope and basic model information

The application domain of the EAI4.0 Maturity Model covers Industry 4.0 projects and Industry 4.0 improvement combined with high-level Enterprise Architecture, for which the relevant sub-elements are specified, thereby providing a holistic model covering the entire domain. The target group of the model and assessment are organizations aiming to start with or mature in Industry 4.0 and Enterprise Architecture, and aim to integrate this into their organization. The EAI4.0 model is due to the natural combination with Industry 4.0 (Möller & Möller, 2016) tailored to and mainly evaluated by organizations in the manufacturing domain, however, companies in different domains also indicated positive evaluations of the model. The model will be useful for larger companies mostly by means of a way to check their progress within these domains. On the other hand, it will also be useful for SMEs who are looking to begin embarking on this journey, and can thereby use the model to guide them in where to start (Orzes, Poklemba, & Towner, 2020). The EAI4.0 Maturity Model has been developed and refined through different types of validation rounds, together with academic, consulting, and industrial experts.

4.2 General structure and elements

The structure of the EAI4.0 Maturity Model consists of three over-arching domains, 'organization', 'people', and 'technology, which cover the fourteen main elements of the model. These over-arching domains aim to structure the model and give additional clarity to the purpose of the focus areas. The focus areas are the main elements of the model and cover areas that are relevant in maturing Industry 4.0 and Enterprise Architecture, of which the definitions can be found at the start of the EAI4.0 Maturity Model. Each focus area can reach four levels of maturity, 'performed', 'managed', 'established', and 'optimized, of which the definitions can be found at the start of the EAI4.0 Maturity Model. Every focus area maturity level contains its own definition and corresponding best practices, which can be found in the table at the end of the EAI4.0 Maturity Model. Lastly, each focus area maturity level contains requirements to reach this level and corresponding questions that make up the maturity assessment questionnaire. All questions and requirements can be found in Appendix Q.

4.3 Sub-elements

All focus areas were developed by combining relevant literature on these constructs with results from the first round of interviews into the structure of the four defined general levels of maturity, and subsequently where necessary clarified the link between Industry 4.0 and Enterprise Architecture.

Every focus area provides multiple best practices for specific maturity levels on how to achieve certain requirements or examples of models or technologies to utilize in achieving these requirements. All best practices were derived from the results of the first round of interviews, the focus group session, and the second round of interviews.

Alignment
Alignment refers to the extent to which strategy, IT, and OT are all coherently aligned with one another. The maturity levels are focused on translating business goals to Industry 4.0 and Enterprise Architecture, how this relates to the company strategy and vision, and how this aligns with the existing IT and OT of the organization (E. Gökalp et al., 2017; Pessl et al., 2020; Wagter et al., 2005).

Embedding
Embedding refers to the extent to which the digital transformation is embedded in the organization as a whole and in Enterprise Architecture. The maturity levels are focused on the communication of progress, stakeholder management, contextualization, and visualization (Wagter et al., 2005; Bittler & Kreizman, 2007).

Finance
Finance refers to the extent to which financial management processes are in place regarding In-

dustry 4.0 and Enterprise Architecture. The maturity levels are focused on budgeting, financial KPIs, and value addition (Ross, Weill, & Robertson, 2006; Wagter et al., 2005).

Process management
Process management refers to the extent to which processes surrounding Industry 4.0 and Enterprise Architecture are being managed. The maturity levels are focused on process architecture, maintenance processes, and version control (E. Gökalp et al., 2017; Proença & Borbinha, 2017).

Governance
Governance refers to the extent to which roles and responsibilities concerning Industry 4.0 and Enterprise Architecture are defined and governed. The maturity levels are focused on responsible managers and sponsors, governance structure, and top-level management and stakeholder inclusion (Wagter et al., 2005; Schumacher et al., 2016).

Enterprise Architecture
Enterprise Architecture refers to the extent to which an Enterprise Architecture approach is used to define the structure and operations of the organization. The maturity levels are focused on project architecture, Enterprise Architectural structure, supporting tools, and the link with decision-making (Wagter et al., 2005).

Change management
Change management refers to the extent to which the organization is able to make changes regarding digital transformation. The maturity levels are focused on the level of innovation that the organization is able to execute within the organization (Pessl et al., 2020; Dennis et al., 2017).

Knowledge and Skills
Knowledge refers to the extent to which the required skills for Industry 4.0 and Enterprise Architecture are present within the organization. The maturity levels are focused on knowledge capabilities, knowledge management, and training (Dennis et al., 2017; Wagter et al., 2005).

Culture
Culture refers to the extent to which the company culture is open to digital transformation, and the extent to which employees are actively involved in its improvement. The maturity levels are focused on cultural assessment, improving culture, incentives, and technology ownership (Schumacher et al., 2016; Wagter et al., 2005).

Leadership
Leadership refers to the extent to which managers are able to guide employees through digital transformation. The maturity levels are focused on exemplary behavior, management framework, and management capabilities (Proença & Borbinha, 2017; Schumacher et al., 2016).

Data governance
Data governance refers to the extent to which a data governance process is in place, concerned with data ownership, security, and policies. The maturity levels are focused on data ownership, security, and data governance (Spruit & Pietzka, 2015)

Data quality
Data quality refers to the extent to which the organization is able to deal with the data demands of Industry 4.0 and Enterprise Architecture. The maturity levels are focused on data requirements, acquisition, data management, and data quality improvements (Spruit & Pietzka, 2015).

Standards
Standards refers to the extent to which the organization manages a standardization process that makes implementations throughout the enterprise follow standardized rules and protocols. The maturity levels are focused on assessments of standards, protocols, and regulations (Dennis et al., 2017; MIT, 2014).

Technology
Technology refers to the extent to which the organization has the technical capabilities in place to implement (Industry 4.0) technologies. The maturity levels are focused on technological capabilities, acquirement of technology, supporting tools, and portfolio/asset management (Leyh et al., 2017; Schumacher et al., 2016).

4.4 Practical application and assessment

The EAI4.0 Maturity Model can be used by organizations to assess their maturity regarding Industry 4.0 and Enterprise Architecture, infer relevant focus areas in the domain, infer what focus areas should be improved next, and what requirements they subsequently need to achieve.

In case an organization utilizes the EAI4.0 Maturity Model, the first step is to complete the maturity questionnaire which is detailed in Appendix Q. The questionnaire consists of 115 questions that are one by one derived from the list of requirements for each focus area maturity level. Each question can be answered as either yes or no, which is subsequently coded as a one or zero. Every focus area maturity level is subdivided into between one and four requirements. These requirements directly correspond to the questions asked in the maturity assessment questionnaire. All requirements and corresponding questions can be found in Appendix Q.
The results of the questionnaire are used to create the maturity assessment overview, visualized in a colored table highlighting the organization's maturity. When all requirements of a certain focus area maturity level are achieved, the model visualizes this level as completed. An example of the assessment can be found in section 4.5. The maturity assessment is to be read from left to right, ideally achieving all 'performed' levels of maturity for all focus areas before moving onto

the 'managed' levels. In dark green, the model indicates for which focus area maturity levels the organization has achieved all requirements. In light green, the model indicates the focus area maturity levels for which the organization has achieved one but not all requirements, highlighting additional progress. The X's in the model highlight the dependencies between the maturity levels, which can be used to infer a roadmap for what maturity levels to achieve first.
The roadmap is a direct result of the maturity assessment, as it shows the first requirements that should be achieved based on the established dependencies. An example of this process can be found in section 4.5.
During the interview, organizations were presented with their assessment results, together with a roadmap containing the first ten to fifteen requirements to achieve based on their assessment. However, as part of the presenting strategy, this was enhanced by a summarizing storyline prepared in advance. The goal of this storyline was to add logic behind why certain requirements should be achieved in parallel, and why other requirements were prerequisites of one another. An example of the roadmap shown to participants in the second round of interviews can be found in Appendix R

Subsection 4.5 below shows the EAI4.0 Maturity Model in full, presented identically to how organizations participating in the maturity assessment received it. The model is presented in landscape format to improve its ease of reading. The EAI4.0 maturity model first introduces the goal of the artifact and states the definitions used for general terms in the model. Next, the model structure is explained, after which a table shows all individual maturity levels per focus area, including the corresponding best practices. For readability purposes, the requirements and questions corresponding to each focus area maturity level are depicted separately in appendix Q.

4.5 Complete EAI4.0 Maturity Model

Maturity model initial information

Goal: The goal of the EAI4.0 maturity model is to guide companies in the digital transformation through Industry 4.0 through the use of Enterprise Architecture. Industry 4.0 projects and applications require the integration of technological implementations into the existing infrastructure of the company, which can be achieved by Enterprise Architecture.

Structure of model: The EAI4.0 maturity model is structured as a focus-area oriented maturity model, consisting of fourteen focus areas relevant to the implementation and growth of Industry 4.0 and Enterprise Architecture. Each focus area can be placed in four subsequent levels of maturity, ranging from the first stage of 'performed', to the final stage of 'optimized'. This leads to 56 focus area maturity levels that a company can achieve. Every one of these 56 maturity levels contains a handful of requirements to reach this level, including a couple of best practices to do so. The achievement (or non-achievement) of these requirements is what composes the assessment of the organization through the questionnaire. Note that the available best practices are not exhaustive, but should be used as examples or as inspiration.

Industry 4.0: Industry 4.0 requires a digital transformation where companies integrate new technologies, such as IoT, cloud computing, and AI, into their production facilities and throughout their operations. Industry 4.0 focuses on connectivity between the entire factory, which, through advanced sensors and data analytics, allows for quicker and better decision-making. In an ideal state, production data is combined with operational data from ERP and customer service, but also data from the surrounding supply chain When Industry 4.0 technologies are correctly integrated, they can lead to highly positive operational excellence results.

Enterprise Architecture: By nature, Industry 4.0 technologies rely heavily on adjacent processes and technology and must therefore be integrated into the company's architecture. The EAI4.0 maturity model proposes the use of Enterprise Architecture to manage these technological implementations. Enterprise Architecture is defined as "the consistent set of rules and models that guide the design and implementation of processes, organizational structure, information flows, and the technical infrastructure within an organization". The use of Enterprise Architecture for Industry 4.0 ensures that the alignment and integration of new technologies align with the already existing infrastructure.

Definitions of focus areas

Alignment: The extent to which business goals, IT, and OT are all in sync and coherently aligned with one another, and the extent to which Industry 4.0 is a part of the company's strategy.

Embedding: The extent to which the digital transformation towards an Industry 4.0 organization is embedded in the organization as a whole, and in the Enterprise Architecture, and the extent to which a process is in place that informs all employees on the progress of the transformation.

Finance: The extent to which a financial management process is in place facilitating Industry 4.0 and Enterprise Architecture initiatives, concerned with available budget and financial KPIs.

Process management: The extent to which a process architecture or structure concerning Industry 4.0 and Enterprise Architecture is in place and being managed.

Governance: The extent to which decision-making power as well as roles and responsibilities concerning (the transformation towards) Industry 4.0 and Enterprise Ar-

chitecture are clearly defined, implemented, and actively executed within the organizational structure.

Enterprise Architecture: The extent to which an Enterprise Architecture approach is used to define the structure and operations of the organization, and the extent to which EA guides the change toward Industry 4.0.

Change management: The extent to which level the organization is able to define and implement changes concerning digital transformation in the organization.

Knowledge: The extent to which the required skills for Industry 4.0 and Enterprise Architecture are present in the organization, and the extent to which knowledge as a whole is being managed.

Culture: The extent to which the company culture is open to digital transformation, and the extent to which employees are actively involved in its improvement.

Leadership: The extent to which managers guide employees through the digital transformation, and in which manner.

Data governance: The extent to which a data governance process is in place, concerned with data ownership, security, and policies.

Data quality: The extent to which the organization is able to comply with the data demands of Industry 4.0 and Enterprise Architecture, and the extent to which the organization is able to manage its own data quality and the acquisition of external data.

Standards: The extent to which the organization manages standards to guide implementations throughout the enterprise via standardized rules and protocols.

Technology: The extent to which the organization has the technical capabilities in place to implement (Industry 4.0) technologies.

Definitions of general maturity levels

Performed: Implemented processes achieve their purpose. Processes are performed in an ad-hoc fashion and are not standardized, controlled, or implemented in the organization, therefore processes cannot be repeated with confidence for the same outcome. There is no learning cycle.

Managed: Processes are being implemented in a managed fashion (planned, monitored, and adjusted) and their documented information is appropriately defined, controlled, and maintained. Standardization has taken place and some level of intervention is visible, some (unaware) learning cycles are in place.

Established: Processes are being robustly implemented and integrated using a defined procedure that is assured. Standards and protocols are consistently followed and processes are vertically integrated on a full organizational level. Learnings are actively documented but improvements are not yet actively pursued.

Optimized: The procedure of implementing processes is now performed predictively and with a clear objective defined upfront. Quantitative management needs are identified, and measurement data are being collected and analyzed to identify assignable causes of variation. Processes are continually improved through innovative approaches. There is not only vertical integration but also a complete horizontal integration with the supply chain and its surrounding value network.

How to read and use the EAI4.0 maturity model

As a result of the assessment, each focus area's maturity level is colored either white, light green or dark green. When a level is white, this means no requirements for this level have been achieved. When a level is dark green, this means all requirements for this level have been achieved. When a level is light green, this means at least one requirement for this level has been achieved, however, not all of them. The model is to be read from left to right, ideally achieving the levels of maturity for all focus areas in the 'performed' stage first, before working on the 'managed' stage, and so on. Thus, when some of the focus areas in the 'performed' stage have reached this level of maturity, the remaining focus areas should also reach their 'performed' level of maturity, before working on requirements in the 'managed' stage.

Within each maturity stage dependencies between focus areas are depicted by means of X's in different columns. These dependencies are to be used as guidelines for the ideal order in which maturity levels should be achieved, as the completion of certain requirements are prerequisites for the correct execution of others. The dependencies should be read from left to right, ideally achieving the left-most X in white or light green first, before moving one column to the right. In the example below, the 'performed' maturity level of the 'process management', 'change management', 'leadership', 'standards', and 'technology' focus areas should be achieved first (the X's in red), as they are the focus areas in the 'performed' maturity level for which not all requirements have yet been completed and are thus either white or light green. With regards to the dependencies, the 'leadership' focus area should achieve the 'performed' level before the 'process management' and 'standards' focus areas, which in turn should be achieved before the 'change management' and 'technology' focus areas, as this is the order depicted by the X's. These dependencies serve as suggestions and as such, the specific context of your organization should always be taken into account.

	Performed				Managed				Established				Optimized			
Alignment	X				X				X				X			
Embedding			X			X					X			X		
Finance				X			X					X			X	
Process management		X			X				X					X		
Governance			X			X			X				X			
Enterprise Architecture	X					X				X			X			
Change management			X					X				X			X	
Knowledge		X					X				X					X
Culture		X						X				X		X		
Leadership	X				X						X				X	
Data governance			X				X			X					X	
Data quality				X				X			X			X		
Standards		X				X						X				X
Technology			X			X						X		X		

Figure 11: Example maturity assessment

Note that the X's depicting the dependencies give information about the order in which focus area maturity levels should ideally be achieved, not started with. An example of this is the 'finance' focus area in the 'performed' stage, which according to the model is the last to be reached in the 'performed' maturity level (the X most to the right). However, while reaching the 'performed' maturity level for the other focus areas, finance should of course not be completely ignored.

Individual maturity level definitions per focus area, including requirements and best practices

Focus area	Level	Definition	Best practices
Alignment	P	An understanding of Industry 4.0 and Enterprise Architecture within the company is present, based on business goals. The current situation is known and a future plan has been drafted regarding the "why" and "what" of Industry 4.0 and Enterprise Architecture.	A fully integrated strategy and vision are not required here, but make sure a basic view is present for where your organization wants to go. Business should be the driving force, not the technology.
	M	Alignment between strategy, business goals, OT, and IT is monitored and documented through the use of Enterprise Architecture. According to the alignment between the initial plan and the intended goals of the digital transformation, its development can be adjusted accordingly.	Give context to what Industry 4.0 means. Clearly distinguish between vision, strategy, and mission.
	E	Full vertical alignment is in place through a defined process within the Enterprise Architecture, which ensures alignment between strategy, business goals, IT, and OT elements across the organization (are we still on the right track?). KPIs are set up based on business goals.	Often revisit the company's strategy and vision by creating a revision loop with periodical reviews of business plans and alignment. Let different departments sit at the same table to ensure they sustain feeling with one another.
	O	Industry 4.0 and Enterprise Architecture are fully integrated into the company strategy, vision, and mission. The alignment process is continually improved through KPIs to respond to change through identified innovation. New Industry 4.0 projects are defined in an agile/flexible fashion. Research takes place with the aim of accelerating the execution of strategic goals through external partnerships.	Utilize data analytics to visualize these KPIs.
Embedding	P	There is embedding by periodical top-down communication of the strategic I4.0 company goals, setting the expectations of individuals participating in the digital transformation.	Utilize monthly updates to communicate the progress of the digital transformation to relevant individuals.
	M	Embedding is realized by having appointed transformation stakeholders participating in smaller projects. Industry 4.0 practices are partly integrated in Enterprise Architecture.	Think about the difference in contextualization between shopfloor and corporate, and how to deal with this. Avoid information islands between different departments.
	E	A fully defined embedding and communication process is in place within the Enterprise Architecture, consisting of who and what needs to be updated and involved, which assures relevant decisions are communicated across the entire business. Contextualization and/or visualization take place to enhance communication and integration.	Designate a specific embedding role for large projects, concerned with steering groups, advisory groups, and sponsors.
	O	Horizontal embedding and communication take place also outside of company boundaries through the entire value network. Digital transformation and Enterprise Architecture as a vision are shared by employees and do not need a top-down push. Multiple groups of talented people are striving towards common goals, and the opportunity for bottom-up pull is present.	

Focus area	Level	Definition	Best practices
Finance	P	Individual project budgets are defined for applications concerning Industry 4.0 and supporting Enterprise Architecture.	Start small, even when starting a project.
	M	A central Industry 4.0 and Enterprise Architecture budget is available for a portfolio of I4.0 projects. Financial information regarding digital transformation is monitored and documented.	Do not overlook 'invisible' money like licensing and software.
	E	A financial management structure for Industry 4.0 and Enterprise Architecture is fully integrated and standardized. Industry 4.0 projects are measured with established financial KPIs like return on investment, to verify added value to the business.	Utilize data analytics to visualize these KPIs.
	O	Budgeting of projects is optimized through companywide KPIs (data-driven) and projects are chosen and/or guided based on these KPIs. Post-implementation reviews take place on existing projects. The company looks externally for new customers or new markets to improve its financial situation.	Utilize data analytics to visualize these KPIs.
Process management	P	A basic view of relevant (business) processes, both existing and required, concerning Industry 4.0 and Enterprise Architecture is present.	Start small, even when starting a project. A project with the aim to get a view of relevant business processes does not have to be the complete company-wide process architecture at once.
	M	A process architecture is defined for Industry 4.0 and Enterprise Architecture. A maintenance process is defined to update the process architecture based on new technology implementations.	
	E	The process architecture is fully integrated and follows defined standards and protocols, and is able to be adjusted based on feedback. A process for version control of the architecture is defined and in place.	Establish a specific reactive "process management end support department" for digital transformation processes, assisting other departments with mapping, describing, and maintaining processes.
	O	Process architecture is horizontally integrated through the inclusion of the supply chain network, including inclusion in and contribution to the Industry 4.0 framework. Process architecture is continually optimized through identified innovative approaches.	Evolve the process management end support department from a reactive to a proactive department.
Governance	P	A group of project experts is assigned to guide the digital transformation. A responsible manager and sponsor are defined for both Enterprise Architecture and Industry 4.0.	These roles do not necessarily have to be fulfilled as FTEs but ensure end responsibility.
	M	The required specific roles and responsibilities concerning Industry 4.0 and Enterprise Architecture are described and documented and actively executed in change guidance through a governance structure within the Enterprise Architecture, for the entire organization.	An exemplary model to be used: the Raci model. Check what tasks can go to existing roles.
	E	The governance structure is fully standardized and embedded in the organization by capturing all relevant stakeholders and corresponding responsibilities. Top-level management has defined roles in the digital transformation.	
	O	The governance structure includes roles and responsibilities for horizontal integration with value network and innovation and is continually optimized through quantitative measures.	

Focus area	Level	Definition	Best practices
EA	P	Enterprise Architecture is recognized by appointing a project architect, responsible for the architecture of digital transformation projects.	The first steps of an Enterprise Architecture can be achieved quickly, but incorporating the entire organization takes time. You don't need to wait with this, start with an initial plan and initial setup, and slowly build and incorporate the entire enterprise. Deliberate to what extent the organization wants Enterprise Architecture. Enterprise Architecture is enabling, not an end goal.
	M	An Enterprise Architecture structure is defined, which includes Industry 4.0 endeavors within the enterprise architecture. Required supporting tools for Enterprise Architecture are consistently used.	Supporting tools might include: ArchiMate.
	E	The enterprise architecture is fully standardized and integrated into the organization, and is being used in decision-making processes. A reference architecture is defined and used.	Example of an Industry 4.0 reference architecture: RAMI4.0.
	O	The enterprise architecture steers the (development of) the organization, is continually improved and updated to respond and adapt to changes stemming from innovations or changes in business goals. The full supply chain is incorporated into the company's enterprise architecture and is actively contributing to improvement.	
Change management	P	The organization innovates on a project-based level with individual participants and business cases. The first Industry 4.0 project has been delivered.	Start with technical initiatives if projects are too big/daunting. Start small, even when starting a project. A project with the aim to increase opex through AI should not start with the entire production facility at once, but rather with a single production line.
	M	The organization performs Industry 4.0 projects in a controlled and planned manner. Multiple Industry 4.0 projects are implemented, documented, and maintained.	Start small, even when starting a project. A project with the aim to increase opex through AI should not start with the entire production facility at once, but rather with a single production line.
	E	A standardized change management process is present and embedded within the Enterprise Architecture, to change or transform existing processes throughout the entire organization. An innovation plan is defined for future projects.	
	O	The organization is able to disrupt and enhance existing processes to make data-driven optimizations. A plan is in place on how and in what steps the value network is to be integrated.	Do not try to integrate the entire value network in one go, rather, start with your most valuable supplier or customer first.

Focus area	Level	Definition	Best practices
Knowledge	P	The current in-house knowledge is assessed, and a basic view of required knowledge is present. External knowledge is hired when necessary.	Start small, even when starting a project. Knowledge and skills are important, but not everyone needs to exactly know what is going on for every project, especially at this stage of maturity. Execute a gap analysis as part of the assessment.
	M	The enterprise has the required knowledge capabilities for the digital transformation. A knowledge management framework is defined and present in the Enterprise Architecture. Need-based training consistently takes place.	Check the feasibility of skills for every new project.
	E	A fully integrated knowledge management framework is present. An overview of future knowledge is present (what capabilities do we aim to have in the future). A budget for people development is available and actively being used for personal growth.	Establish thought leaders with the goal to create knowledge leaders for specific subjects relevant to Industry 4.0.
	O	Industry 4.0 and Enterprise Architecture knowledge is optimized by dedicated training based on future goals and quantitative measures. Periodic measurements of required knowledge take place. An innovation lab or external partnerships are deliberated to expand the knowledge base and implemented when deemed beneficial.	
Culture	P	An assessment of the current culture in the organization has taken place to answer to what extent our organization is able to pursue Industry 4.0, or, with what ease can technologies be adopted in our organization.	Involve employees as much as possible. Execute a gap analysis as part of the assessment.
	M	Measures are in place to alter culture regarding the digital transformation, based on the cultural assessment of the company. An incentive mechanism is created (monetary or non-monetary). Organizational measures for digital transformation are implemented in specific cases of cultural assessment.	Personality types can play a role here and could be utilized to steer the cultural change. Incentive goals might not fit the company culture. As such, utilize incentives in a way that fits the company culture.
	E	An organizational culture shift has taken place; ownership of technology is present. The company makes conscious decisions in deliberately hiring people that have an affinity with Industry 4.0 when applicable.	
	O	An innovative culture is present in the company where employees are bottom-up contributing to innovation, which is continuously being improved. The company learns from other organizations to reach this level and actively shares knowledge.	
Leadership	P	Responsible manager(s) has the willingness and skills to lead and push the digital transformation.	Involve employees as much as possible.
	M	Management is setting a planned vision and examples for employees and is able to clearly define to employees "what's in it for me". The management structure is controlled.	Think about the difference in contextualization between shopfloor and corporate, and how to deal with this. Give context to what Industry 4.0 means and what the advantage is for employees.
	E	A management framework for digital transformation is fully integrated and standardized in the Enterprise Architecture. A management development program is in place with the goal to improve management capabilities to lead the digital transformation.	Ensure acceptable adoption of new projects before regarding the project to be landed.
	O	Managers are now change leaders for the digital transformation and are able to pursue innovation without restrictions.	

Focus area	Level	Definition	Best practices
Data governance	P	Data ownership and data stewardship are defined and ad hoc executed.	When purchasing new assets, verify if your organization is eligible to extract data from this asset.
	M	A data governance framework is defined within the Enterprise Architecture, including policies on how data is dealt with. A data/technological security plan is defined.	An exemplary model to be used: the Raci model. Check what tasks can go to existing roles.
	E	Data governance framework is fully integrated and standardized in the Enterprise Architecture. Adjustments to data governance activities and structure can be made.	Assure a single source of truth across your data landscape.
	O	External governance frameworks and industry case studies are evaluated for best practices and lessons learned, providing ideas for improvements and subsequently utilizing these lessons when beneficial. Data governance processes are continually refined and improved.	
Data quality	P	An assessment of current data quality and (external) data acquisition has taken place, showing which data (overviews) are currently present. A basic idea is present of what the data quality requirements are.	In the first stages, acquire as much data as you can get but check if it is correct. Execute a gap analysis as part of the assessment.
	M	The required data quality and acquisition is defined through objectives, rules, and criteria. A data architecture, within the enterprise architecture, and corresponding data models are defined, and data warehousing and sensory technology are managed.	This includes also computing power, are our computers able to deal with these data demands. Think about in what timeframe data should be acquired, for example, real-time every second or an inventory count at the end of the day? Visualize data quality to show what the organization's data quality currently is but also where possible mistakes are.
	E	A data quality and acquisition process is integrated and standardized in the organization through the Enterprise Architecture. Periodic data quality assessments are conducted through defined metrics and improvements are being followed up. Required data quality and acquisition goals are reevaluated and adjusted accordingly.	
	O	Industry 4.0 data is continuously used to optimize data quality. Analyses and visualizations are used to drive company improvement. Data quality program milestones and metrics are regularly reviewed, and continuous improvements are implemented.	

Focus area	Level	Definition	Best practices
Standards	P	An assessment of current standards and protocols regarding Industry 4.0 and Enterprise Architecture has taken place. No choices are yet enforced.	Think about ERP, MES, and PLM systems and how Industry 4.0 integration would operate. Execute a gap analysis as part of the assessment.
	M	Required standards and protocols are defined, keeping possible external regulations in mind. "What do we want to and should we want to standardize".	Utilize defined ERP, MES, and/or PLM systems when required. A possible standard to utilize is: isa95.
	E	All relevant applications, systems, and procedures are checked to the defined standards and protocols and adhere accordingly.	Standards are important but leave room for your own core process.
	O	Standards and protocols are evaluated through quantitative metrics and changes are made where necessary. Emerging standards and means to standardize are being evaluated for new opportunities.	
Technology	P	A basic view of current technological capabilities is present. Specific technological capabilities are acquired project based.	Start small, even when starting a project.
	M	(Required) technical capabilities are defined and documented, through modeling of the desired IT solutions by the use of Enterprise Architecture. Obsolete technology is identified. New technical capabilities are being acquired based on requirements in a planned fashion. The required supporting tools for Industry 4.0 are defined.	Evaluate the extent to which cloud technology should be utilized as an enabler. Design technological applications in a way that shopfloor workers cannot make mistakes.
	E	A plan for future technical capabilities is present, and a technical capabilities management framework is implemented in the Enterprise Architecture. When applicable obsolete technology is removed. Portfolio management and procurement processes related to Industry 4.0 technologies are established.	Explore cyber-physical systems and when beneficial utilize these. Explore predictive technologies like predictive maintenance and when beneficial utilize these.
	O	Technical capabilities are continuously improved. Company capabilities are extended by the addition of capabilities of other organizations in the value network in the Enterprise Architecture.	

Table 11: The EAI4.0 Maturity Model Definitions and Best Practices

5 Evaluation of EAI4.0

This section covers the final demonstration and evaluation stage of the research process followed in this Thesis. Participants in this interview are the same people that filled in the maturity assessment for their organization or for an organization in their customer network. The final round of interviews is, similar to the first round of interviews, deliberately held with both people working in industry, as well as with people working in advisory domains. Participants joining to assess the maturity of their own organization have in-depth knowledge of their organizational ins and outs and are therefore able to give detailed assessments of to what extent certain elements of the model would or would not align with real life. On the other hand, participants working in advisory domains filling in the assessments for customers might be more experienced with using similar models, while also having a deeper understanding of how and if such a model would realistically operate in practice, through having seen different organizations execute similar transformations.

The second interview follows after companies have completed the maturity assessment for their organization. The goal of this interview is to evaluate the designed artifact, while simultaneously offering organizations insight into their maturity regarding Industry 4.0 and Enterprise Architecture. March and Smith (1995) have proposed evaluation criteria for different types of DSR artifacts, able to be used in each evaluation step in the DSR process (Sonnenberg & Vom Brocke, 2012). March and Smith (1995) differentiate between a DSR artifact being either a 'construct', 'model', 'method' or 'instantiation', with each type of artifact being paired with different evaluation criteria. As the artifact designed in this study is a maturity model, the 'model' evaluation criteria will be assessed in the second interview. The maturity model additionally consists of a method to assess an organization's maturity, as well as a methodology to utilize the model. Therefore, also the 'method' evaluation criteria as proposed by March and Smith (1995) are assessed during the second interview. The 'internal consistency' and 'level of detail' evaluation criteria have been assessed at an earlier stage, during the definitions validation round before the focus group sessions. The evaluation criteria assessed during the second interview are as follows.

- Completeness
- Fidelity with practice
- Robustness
- Perceived ease of use
- Intent to use
- Generality
- Perceived usefulness (operationality)

The interview consists of three parts. First, the maturity assessment is discussed through questions to verify to what extent the assessment is deemed correct and in line with their view of the organization's maturity. Through this assessment, we are able to provide companies with a direct roadmap

consisting of focus area maturity levels and corresponding requirements which they should achieve to improve their overall level of maturity on Industry 4.0 and Enterprise Architecture. Next to this, a number of questions are asked with the goal to evaluate the model's completeness, fidelity with practice, level of detail, and robustness. Secondly, the interview utilizes a technology acceptance model questionnaire to verify the perceived ease of use, perceived usefulness, and intent to use the model. Thirdly, the interview consists of questions regarding general digital transformation KPIs to assess the generality of the model by verifying the effects of maturity in our model versus the general digital transformation process.

5.1 Interview structure

Introduction
A short personal introduction commenced, after which the goal and structure of the interview were explained. Interviewees that did not participate in the first interview received a short recap of the research process up until this point.

Maturity assessment
Before talking about the maturity assessment in detail, we asked the participants to what extent their organization utilizes Enterprise Architecture. Through this, we aim to infer the level of necessity of using an Enterprise Architecture approach for Industry 4.0 and thereby evaluate the robustness of the model in light of ways to structure the digital transformation. When a participant indicated that their organization does not work with an Enterprise Architecture approach, we questioned if there is a different approach used.

Next, we showed the participants their maturity assessment based on the filled-in questionnaire. A short explanation followed which highlights how the assessment is to be read, and subsequently what steps we recommend them to take to improve their general level of maturity. Moreover, participants were urged to consider the level of maturity they have versus the level of maturity they aspire to reach. Not every organization will or has to want to reach the optimized level of maturity in this domain, which impacts the next maturity levels to be achieved.

To evaluate the 'fidelity with practice' of the model, we asked the participants to discuss for each focus area if they feel the maturity assessment is in line with their view of the company's maturity in that area. In other words, the extent to which the real-world maturity regarding each focus area in their organization corresponds to the presented assessment. Any comments participants might have about their organization's maturity assessment could be shared here. To evaluate the 'completeness' of the model regarding ways in which maturity levels can be reached, we asked participants about possible (best) practices used in reaching their achieved levels of maturity, to find out if there are (best) practices that are currently not present in the model.

Technology acceptance model questions

To evaluate the acceptance of the maturity model we used a Technology Acceptance Model questionnaire. More specifically we evaluated the model's 'perceived usefulness', 'perceived ease of use', and the participants 'intent to use the model', of which the latter has been derived from the original construct of 'operationality' (March & Smith, 1995). The questions to evaluate these criteria are derived from literature on these constructs, as well as research using these questions with a similar goal (Davis, 1989; Erasmus et al., 2020; Gilsing et al., 2021). The goal of this section is to evaluate whether users would prefer to use our artifact as a method to assess their organization's maturity, as well as the model itself as a method to subsequently improve their organization's maturity. All questions were measured on a 5-point Likert scale, ranging from 'extremely likely' to 'extremely unlikely'. Perceived usefulness consists of questions regarding the effectiveness and facilitative role of the artifact, as well as the extent to which the model is found to be useful in guiding enterprises in taking the right steps. Perceived ease of use consists of questions regarding the clarity and understandability of the model, as well as the extent to which the model is seen as easy to use by both advisors and companies. Lastly, intention to use is concerned with the extent to which experts are likely to use the artifact both for maturity and guidance purposes in the domain of Enterprise Architecture and Industry 4.0. Questions asked in this section can be found below in table 12.

Variable	Nr.	Statement
Perceived usefulness	1	Using the model would facilitate me to reflect on our organization's current level of maturity regarding I4.0 and EA.
	2	Using the model would improve the way in which our organization operates with I4.0 and EA.
	3	Using the model would be an effective way to assess and improve maturity regarding I4.0 and EA.
	4	Using the model would make it easy to improve maturity regarding I4.0 and EA.
	5	Using the model would be a useful way to assess and improve maturity in I4.0 and EA.
Perceived ease of use	6	Learning how to read the model to evaluate and improve our organization's maturity regarding I4.0 and EA would be easy for me.
	7	I would find it easy to use the assessment questions to assess our organization's maturity.
	8	The assessment questions and model information would be clear and understandable to me.
	9	I would find it easy to use the model to improve our organization's maturity.
Intention to use	10	I would intend to use the model to improve our organization's maturity in Industry 4.0 and Enterprise Architecture

Table 12: TAM Questionnaire Interview round 2

General digital transformation KPIs

Finally, we asked participants to answer four questions on general digital transformation KPIs. The

aim of this section is to evaluate if a high overall level of maturity in the EAI4.0 model relates to an organization benefiting more from a digital transformation in a general sense. An organization's digital transformation is not only influenced by the use of Industry 4.0 and Enterprise Architecture but also comprises other elements. Therefore, this section verifies if our maturity model comprising an element of the digital transformation is generalizable to the digital transformation in general. Literature on general digital transformation success by Barthel (2021) differentiates success into four clusters that are not mutually exclusive. The first cluster is concerned with overall company value and performance as a result of the digital transformation. However, in our context, we are not interested in general company value and performance, but rather in the value and performance of the digital transformation specifically. The second cluster is concerned with the performance of the digital transformation itself which is often a financial affair and can be measured through different financial KPIs (Kuntsman & Arenkov, 2019). The measurements for this cluster are summarized by Barthel (2021) as the extent to which an organization generates profit through the deployment of digital technologies, which drives the first KPI of this section. The third and fourth clusters focus on evaluating the progress of the digital transformation and innovation process itself, not the economic output resulting from the process (Barthel, 2021). These two clusters differ in the realization of the transformation internally and externally. External measures are concerned with the digitization of market offerings, customer interaction, and partner networks, which are argued to be central to the digital transformation (Barthel, 2021; Wessel, Baiyere, Ologeanu-Taddei, Cha, & Blegind-Jensen, 2021). These measurements evaluate similar aspects at different points in the supply chain and are therefore summarized within the second and third KPIs in this section. The fourth cluster is concerned with the realized digital transformation within the organization, of which the underlying premise is that successfully realizing a digital transformation leads to a transformed organization (Barthel, 2021). Similar to the third cluster, these measures are concerned with the extent to which processes are digitized, however, in this instance regarding internal processes like strategy, culture, and IT. These measurements are summarized within the fourth KPI in this section. We hypothesize these KPIs are influenced by combinations of focus areas, as they all require different facets of the company to perform (Kuntsman & Arenkov, 2019). In line with this reasoning, we combined the proposed measurements by Barthel (2021) in the four KPIs below to ensure we are measuring the general effect of maturity instead of specific focus areas.

- KPI1: Our organization is generating profit through the deployment of digital technologies, either by reducing costs or improving revenue.
- KPI2: Our organization has digitalized products & services or processes related to these.
- KPI3: Our organization has digitalized customer & partner network interaction channels.
- KPI4: Our organization has digitalized general internal processes, not only concerned with Industry 4.0.

A detailed version of the structure, information given to participants, and questions asked during Interview round 2 can be found in Appendix L.

5.2 Results

This section provides an overview of the results and corresponding changes after the second round of interviews. The second round of interviews consisted of twelve interviews, which all took approximately one hour to perform, not including the time it took participants to fill in the questionnaire beforehand. In general, the evaluation of the EAI4.0 Maturity Model and corresponding assessment was found to be positive. Levels of maturity varied among the organizations assessed, with the most mature organization achieving 109 out of 115 requirements, and the least mature organization achieving seven requirements.

Usage of Enterprise Architecture

At the start of the second interview, participants were asked to reflect on the extent to which their organization utilizes Enterprise Architecture, or if different approaches are used to achieve a similar purpose. The answers given to this question vary, from organizations indicating that Enterprise Architecture steers the organization by being in the company DNA, to organizations indicating that they have just started setting up solution architectures. The paragraphs below assess the robustness of our model regarding using Enterprise Architecture as a means to structure the digital transformation.

All organizations that participated in the interview indicated to either use or plan to use Enterprise Architecture. Therefore no organizations were removed from the dataset based on their answers to this question.

All five organizations that scored high in maturity, both in the EAI4.0 maturity model as well as in the questions regarding general digital transformation KPIs, indicated explicitly using Enterprise Architecture. One participant (organization H), whose organization completed close to all 115 requirements, explained that Enterprise Architecture is in the DNA of their organization and through this continuously influences and is being influenced by changes and innovations in the company. Moreover, two participants (organizations I and L) argued that due to the size of their organization, it is impossible to manage Industry 4.0-like changes without an Enterprise Architecture approach and setup. Similarly, interviewees from organization K noted Enterprise Architecture to be a basic element throughout the organization, from solution and domain architectures at lower levels of abstraction linked with business-focused Enterprise Architecture at a higher level.

Organizations lower in maturity that show to be at the start of their digital transformation journey employed either a rudimentary form of architecture or no architecture yet. Two organizations (organizations C and D) indicated to have made initial starts with ISA standards and data architecture but noted that their organization is not yet ready for a full-scale Enterprise Architectural approach. Other organizations (organizations A and E) indicated that using Enterprise Architecture throughout the company is an end goal, but that they are currently in an exploratory

phase. Three organizations (organizations A, B, and F), all active in the manufacturing domain, mention their need to properly implement ERP before considering a company-wide architecture. They indicate performing many changes in an ad-hoc fashion instead of being guided by a defined architecture.

These findings suggest that the usage of Enterprise Architecture is seen as the predominant way to guide digital transformation innovations, mainly within IT, in a structured fashion. Therefore, based on these findings, we can positively evaluate the robustness of our model regarding using Enterprise Architecture as a means to structure the digital transformation to Industry 4.0. However, the necessity for a highly detailed Enterprise Architecture with subsequent lower levels of domain architecture is found to be higher for larger organizations (Wagter et al., 2005). Instead, for smaller companies, a simple architectural overview linking business goals to IT seems sufficient.

Assessment results

Figure 12 shows the percentage of total achieved requirements per organization. This figure visualizes the large differences that are present between organizations that participated in the interviews.

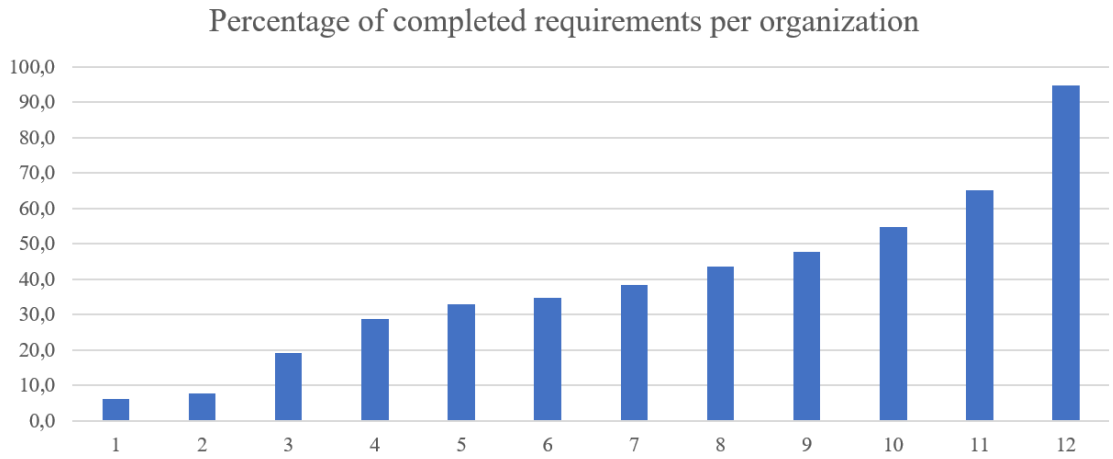

Figure 12: Percentage of completed requirements per organization

The difference in maturity between organizations was found to be beneficial to the diversification of the evaluation of the model, as the assessments and road maps differed greatly between participants. Hereby we were able to assess the usefulness of the model both for organizations that just started their digital transformation journey, as well as for organizations that are already quite mature ($> 50\%$).

Large differences in maturity between organizations were present in the interviews, but also in between focus areas themselves. Figure 13 shows the average percentage and standard deviation of completed requirements per focus area, indicating which areas are the most mature across all

participants. These results show quite large differences in maturity between different focus areas, with the biggest difference being the 'data governance' focus area being on average almost 30% more mature than the 'standards' focus area. However, figure 13 also shows large deviations within each focus area between the achieved requirements for different organizations. In the next paragraph of the results section, each focus area is evaluated on its fidelity with practice, in which both the 'data governance' and the 'standards' focus area score similarly with eight participants indicating the assessment is perfectly in line with the actual situation in the company. If we include only the participants that noted the fidelity with practice of these two focus areas to be perfect, a similar difference in maturity between the two areas remains. In comparing the textual comments on the 'fidelity with practice' questions for the 'standards' and 'data governance' focus areas we noticed that participants indicate that data governance, as well as data quality, are often requirements for the organization to perform its core processes, independent from Industry 4.0, whereas standardization is seen as less of a core and required element. Nevertheless, due to the relatively small number of participants, it is difficult to derive robust conclusions from these results.

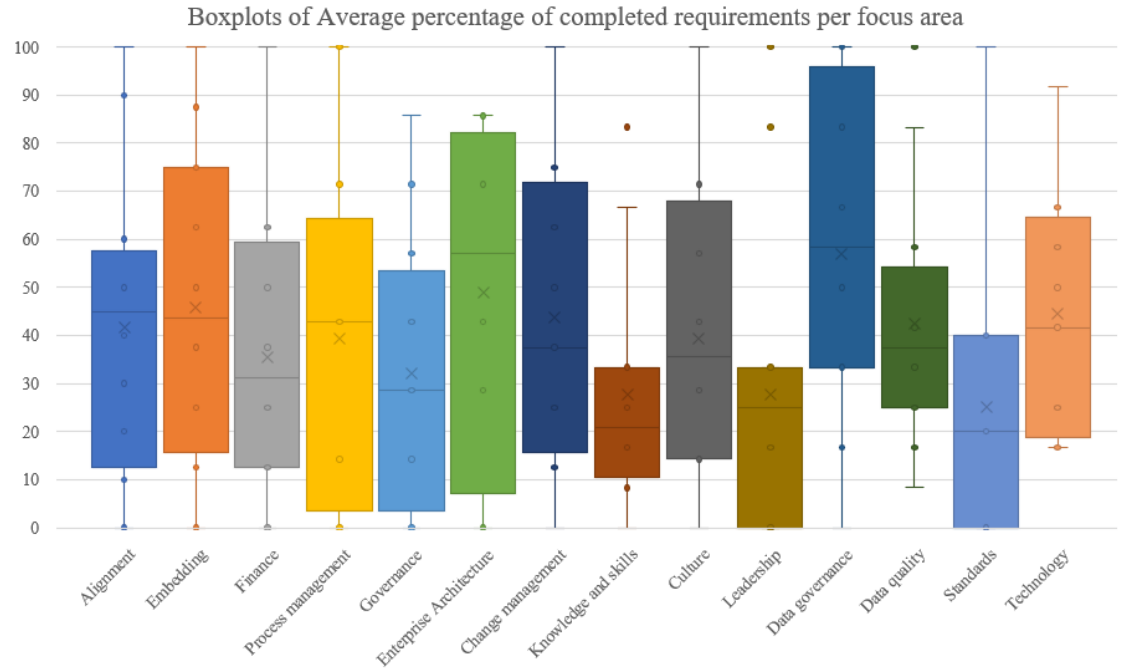

Figure 13: Average percentage of completed requirements per focus area

Assessment and roadmap evaluation

Participants evaluated the overview of the assessment of their maturity as well as the corresponding roadmap positively, both on a content-level as well as on a thought-provoking level. Participants of Organization D indicated being positively surprised by how well a *"seemingly randomly connected"* set of questions led to a roadmap fitting very well to their goals for the coming period. Similarly, five interviewees (organizations A, E, F, G, and K), noted a high level of general recognition be-

tween what the roadmap suggests as points of improvement and the current situation of innovation in their organization.

Moreover, most organizations (organizations A, B, C, D, F, I, J, K) indicated experiencing the assessment and roadmap as inspiring, discussion-starting, or eye-opening. Organization A noted that the roadmap challenges the user to also emphasize relevant subjects surrounding the digital transformation that currently receive little attention. Organizations B and D specifically positively evaluated the clear and concrete steps the assessment and roadmap provide. Similarly, organization J indicated an appreciation for the concrete and pragmatic handles the model provides.

The main research objective of this thesis is to create a model that not only assesses maturity but also guides in achieving higher levels of maturity, which is re-stated in the solution requirements. The responses to the roadmap and assessment during the second round of interviews suggest that the created maturity model suffices in its solution requirement (6) of being able to guide users in how to improve maturity, by providing a concrete roadmap including best practices as an addition to the assessment.

Fidelity with practice evaluation

To evaluate the 'fidelity with practice' criterium, we asked participants to indicate to what extent they felt the maturity assessment is in line with the real situation in their organization. For each focus area, participants indicated if the assessment was perfect, close to, or not at all in line when comparing their progress to the assessment of the general maturity definitions. As an example, organization B reached the 'performed' level for the 'finance' focus area and subsequently had to indicate whether the financial progress of the organization regarding Industry 4.0 and Enterprise architecture is in line with the definition of a 'performed' level of maturity.

Figure 14 below shows how many times each fidelity with practice score was given for each focus area. Only one participant (organization A) indicated that the assessment was not at all close to the organization's actual situation, specifically for the 'process management' focus area. When asked to reflect on this decision, the participant noted that the assessment was too mature, especially in the managed and established level of maturity, for their true status regarding process management of Industry 4.0 and Enterprise Architecture, and instead focused too much on process management in a general sense. As a result, the requirements for the 'managed' and 'performed' levels were updated to better reflect the purpose of assessing process management specifically regarding Industry 4.0 and Enterprise Architecture. Participants indicated that for all focus areas, except for the 'culture' focus area, the assessment was perfectly in line with the actual situation at the company in more than half of the cases. In cases where the focus area was scored to be 'close' to the real-life progress of the organization, comments by multiple organizations stated that the 'optimized' definition of the focus area needed sharpening. Minor changes were made as a result of these comments and can be found in the paragraph below. However, due to the largest portion

of answers being perfectly in line with practice, 72% across all areas across all participants, we conclude that the 'fidelity with practice' of the model is evaluated positively. Moreover, we expect this number to be evaluated higher when a new assessment including the minor changes mentioned above would take place.
The 'culture' focus area was more often than not indicated to be 'close' to the actual situation instead of perfectly in line. Two participants (organizations B and D) noted that they experienced difficulty in rating their company's culture with regard to the general maturity definitions. Similarly, organization E noted that during the questionnaire the questions about organizational culture were the most difficult to answer, especially in a yes/no format. Changes were made to the 'culture' focus area requirements based on the textual comments from participants which can be found in the paragraph below.

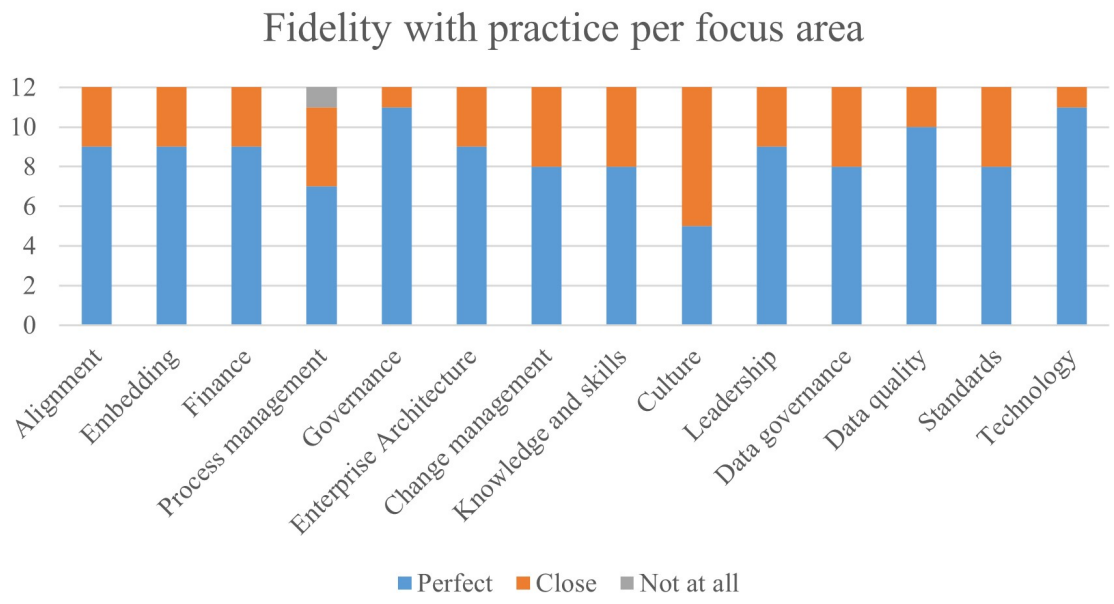

Figure 14: 'Fidelity with practice' score per focus area

The following changes were made to the requirements of maturity levels based on participant feedback during this section of the interview.

- Requirement 2 of the 'managed' level and requirement 2 of the 'established' level of the 'process management' focus area: Organization A noted that the link with Industry 4.0 was missing in the second requirement of both the managed and established level of the process management focus area. We updated the requirement definitions to better reflect the purpose of assessing process management specifically regarding Industry 4.0.
- Requirement 1 and 2 of the 'managed' level and requirement 1 of the 'established' level and requirement 1 and 2 of the 'optimized' level of the 'culture' focus area: By overall agreement among the participants some requirements in the 'culture' focus area needed

further explanation. We concretized five requirements as a result, to better explain the purpose of the requirement in line with the digital transformation.

- Requirement 1 and 2 of the 'optimized' level of the 'process management' focus area: Three organizations (organizations C, E, and J) indicated that the requirements for the highest embedding maturity level needed to be better in line with the general definition of the 'optimized' level of maturity. We sharpened the requirement definitions to better align with the intended purpose of an optimized Industry 4.0 embedding process.
- Requirement 1 of the 'managed' level of the 'governance' focus area: Organization B proposed to extend the managed level definition for the governance focus area to include that the mentioned "Industry 4.0 and Enterprise Architecture roles and responsibilities" applies to the entire organization. We extended the requirement definition to incorporate this feedback.
- Requirement 3 of the 'optimized' level of the 'Enterprise Architecture' focus area: Organization D proposed to extend the optimized level definition for the Enterprise Architecture focus area to better detail what it means to incorporate the full supply chain within a company's Enterprise Architecture. We extended the requirement definition to incorporate this feedback.
- Requirement 1 of the 'optimized' level of the 'Leadership' focus area: Two organizations (organizations C and D) indicated that the final leadership maturity level should be more strict, especially since this maturity level consists of only one requirement. As a result, we extended the requirement to include the intended purpose of managers being change leaders specifically within the digital transformation, instead of on a general level.
- Requirement 1 of the 'optimized' level of the 'Data governance' focus area: Three organizations (organizations C, D, and L) indicated that the first requirement of the final data governance maturity level should be more strict. They claim that evaluating external governance for best practices is a necessary but relatively easy step, whereas incorporating these best practices is the more difficult part. As a result, we extended the requirement to include the ability to utilize external best practices, instead of just evaluating if they would be a valuable fit.

Lastly, a handful of new best practices were mentioned by six participants (organizations B, C, D, I, K, and L), and are highlighted below. Nevertheless, many best practices mentioned by participants in the second round of interviews were to some extent already present in the model.

- Best practice for the 'performed' level of the focus areas that include an assessment: participant B proposed to add the execution of a gap analysis to the best practices for assessment requirements. As a result, we added gap analyses to the 'knowledge', 'culture', 'data quality', and 'standards' focus areas' best practices.
- Best practice for the 'established' level of the 'alignment' focus area: participant K proposed to extend the alignment best practice concerning revisitation of the company's strategy and

vision with a periodical review of business plans and alignment between business, IT, and OT. Here, the focus lies on having these different departments sit at the same table to ensure they keep in contact with each other and have a basic view of each other's progress. We extended the 'established' best practice to include a more detailed plan for alignment revisions.

- Best practice for the 'established' level of the 'embedding' focus area: participant C noted the advantage of having specific people at large projects that are focused on embedding through the active setup and inclusion of steering groups, advisory groups, and sponsors. This information was added as a new best practice for the 'established' level of the 'embedding focus area'.

- Best practices for the 'established' and 'optimized' levels of the 'process management' focus area: One organization (organization K) highlighted the positive effects of establishing a specific "process management end support department" for digital transformation processes. Within their organization, this department assists other departments with the mapping, describing, and maintaining of processes, which started as a reactive instrument in the company's 'established' level of maturity and has since evolved into a more proactive instrument in the company's current 'optimized' level of maturity. We added the creation of such a reactive department as a best practice to the 'established' level of maturity, and the evolution to a proactive department to the 'optimized' level of maturity, with the sidenote that larger organizations will benefit more.

- Best practice for the 'established' level of the 'Enterprise Architecture' focus area: One participant (organization B) proposed to add a best practice to the Enterprise Architecture established level of maturity which gives an example of a reference architecture, instead of only demanding to use one. As a result, we added RAMI4.0 as an example of a reference architecture to use for Industry 4.0.

- Best practice for the 'managed' level of the 'culture' focus area: Organization C indicated that the use of incentives to reach digital transformation goals does not work in every organization, and is thus dependent on the type of company. We added a best practice that suggests utilizing incentives in a way that fits the organizational culture.

- Best practice for the 'established' level of the 'leadership' focus area: One participant (organization L) indicated from a management point of view that when an innovation project is introduced in a department, it can be risky to assume the department to be accountable prematurely before the project has sufficiently landed. As a result, we added a best practice to the established level of leadership which advises managers to ensure acceptable adoption of a new project before regarding it as landed.

- Best practice for the 'performed' level of the 'data governance' focus area: Organization D noted that it is important to verify when purchasing new technology or machinery if your organization is eligible to extract the data from this asset. Often, especially for SMEs, asset

management is performed by an external party. Therefore, we added a best practice to the data governance performed maturity level concerned with verifying if the organization is eligible to utilize data from their assets.

- Best practice for the 'managed' level of the 'data quality' focus area: One participant (organization B) noted the advantage of not only visualizing data but also visualizing data quality itself, more specifically, building dashboards to show what the organization's data quality is, but also visualizing where mistakes are. We added a best practice accordingly.

- Best practice for the 'established' level of the 'technology' focus area: Organization I proposed to add the exploration of cyber-physical systems as a general term to the best practices for the established level of the technology focus area, indicating that an organization is ready to reap sufficient benefits from CPS at this level of maturity. A best practice was added to cover the exploration and possible usage of cyber-physical systems.

Organization D indicated that some of the best practices available in the model are not always relevant for their type of organization, illustrating through experience that different types of companies require different types of best practices. The generalizability of the model regarding different types of industries should therefore be revised in future research, possibly through the creation of different versions of the model depending on the type of industry or the type of organization. Moreover, not every focus area maturity level in the model is accompanied by a best practice due to a lack of conclusive best practices specifically for our purpose in the literature. Additionally, the best practices were not evaluated as rigorously in this thesis compared to the focus areas and maturity levels. Following these results, the best practices section of the model was evaluated as valuable, but incomplete in its current form.

TAM

A Technology Acceptance Model (TAM) has been used as a means to assess the following three evaluation criteria for an artifact as suggested by DSR (March & Smith, 1995): 'perceived usefulness', 'perceived ease of use', and 'intent to use'. Every participant in the second round of interviews answered all ten statements. Table 13 shows the average rating for each individual statement, where the model was evaluated with a value over 3 for every statement on a Likert scale ranging from 1 to 5.

Variable	Nr.	Statement	Average rating
Perceived usefulness; Average rating of 3.97	1	Using the model would facilitate me to reflect on our organization's current level of maturity regarding I4.0 and EA.	4.25
	2	Using the model would improve the way in which our organization operates with I4.0 and EA.	3.83
	3	Using the model would be an effective way to assess and improve maturity regarding I4.0 and EA.	3.67
	4	Using the model would make it easy to improve maturity regarding I4.0 and EA.	3.92
	5	Using the model would be a useful way to assess and improve maturity in I4.0 and EA.	4.17
Perceived ease of use; Average rating of 3.69	6	Learning how to read the model to evaluate and improve our organization's maturity regarding I4.0 and EA would be easy for me.	3.92
	7	I would find it easy to use the assessment questions to assess our organization's maturity.	3.67
	8	The assessment questions and model information would be clear and understandable to me.	3.75
	9	I would find it easy to use the model to improve our organization's maturity.	3.42
Intention to use; Average rating of 4.33	10	I would intend to use the model to improve our organization's maturity in Industry 4.0 and Enterprise Architecture	4.33

Table 13: TAM Questionnaire Interview round 2 with average ratings by participants

Usefulness

The 'perceived usefulness' evaluation criterium, consisting of the first five questions, is scored as an average value of 3.97 across all participants. Participants that added textual comments to their ratings of usefulness reported positively about the extent to which they felt the model would be a useful tool for its intended purpose, based on our overall interpretation of the observations and textual comments during the interview. Organization D indicated that the concreteness and practicality of the model contribute highly to the model's usefulness, by giving a pragmatic approach to assess and roadmap to improve maturity. Similarly, one participant (organization H) noted the positive impact of clear and concrete steps as valuable to companies that might not have the time to explore such an assessment in great detail. Based on these results, we conclude that the model is evaluated as a useful artifact to assess and improve maturity regarding Industry 4.0 and Enterprise Architecture.

The third question pertaining specifically effectiveness of the model scored the lowest average rating. Four participants (organizations G, H, J, and L) indicated that particularly the length of the questionnaire decreased the effectiveness of the assessment, due to the time and effort it takes to complete. Nevertheless, they also noted the necessity of the number of questions to realize

a well-funded assessment. Organization G proposed to structure the questionnaire in different sections, possibly per focus area or per maturity level, to reduce the negative feeling of the questionnaire being very long.

One of the most common comments by organizations was that even though the model gives positive guidance, achieving requirements is still challenging. Organization A indicated that the model does a good job of showing the company what needs to be achieved, but of course, the organization still needs to perform these steps itself. This participant recognized the advantage of the best practices, especially for this concern, but proposes to extend the best practices into larger storylines on how to improve maturity instead of the current bullet-point setup. Best practices give hints on what to do to achieve requirements, but not necessarily how to do it. Therefore, a more detailed storyline might help in increasing the level of guidance the model can provide even further, by also providing information on how to utilize these best practices. Nevertheless, we argue that the generality of the model might be decreased by incorporating this proposal.

Lastly, one participant (organization D) noted that even though this person itself evaluated the model as very useful, the usefulness does depend partly on the amount of effort an organization wants to put into working with the model. More specifically, an organization is required to have a certain positive mindset toward digitization and the usage of such models to utilize the model to its full potential.

Ease of use

The 'perceived ease of use' evaluation criterium, consisting of questions six to nine, is scored as an average value of 3.69 across all participants. Participants that provided textual comments to their ratings of ease of use reported positively about to what extent they experienced the model as clear and straightforward to utilize, based on our overall interpretation of the observations and textual comments during the interview. Organization B indicated that even though the model content is of a high level, the assessment and corresponding roadmap feel like a logical result due to the detailed explanation at the start of the EAI4.0 maturity model, as well as during the interview itself. Similarly, one participant (organization I) specifically positively evaluated the understandability of the model due to the detailed table containing all definitions in a structured manner. Lastly, organization A indicated the advantages brought by the best practices for the last 'ease of use' criterium question pertaining to how easy the model is to improve maturity. Based on these results, we conclude that the model is evaluated as an artifact that is easy to use to assess and improve maturity regarding Industry 4.0 and Enterprise Architecture.

One of the most common comments by participants was that the assessment questionnaire requires a high level of knowledge to be sufficiently complete. Organization D similarly indicated that a deep understanding of the content is required, after which additional information is still necessary during the interview itself. Overall, this leads to the time investment to completely un-

derstand and utilize the model being quite high, slightly decreasing the 'ease of use' of the model. Similarly, organization E noted that the model can be quite abstract, which can complicate the extent to which the model is easy to use inter-company. This person indicated that they felt the knowledge required to utilize the model is rather high and diverse, which might not be present among other employees within the organization. Therefore, organization E proposed the creation of a short high-level summary as an addition to the roadmap, concretely explaining the next steps to take.

The responses to the 'perceived usefulness' and 'perceived ease of use' questions during the second round of interviews suggest that the created maturity model suffices in its solution requirement (5) of being deemed both useful and easy to use by practitioners, by providing a concrete and practical model with clear information for users.

Intent to use

Lastly, the 'intent to use' evaluation criterium, consisting of the last question, is scored as a value of 4.33 out of 5 averaged over the twelve participants. Participants that provided textual comments to their ratings of 'intent to use' reported positively about wanting to continue using the model after the interview to increase their maturity, based on our overall interpretation of the observations and textual comments during the interview. Organizations A and B specifically indicated that the concrete actions combined with the storyline presented to them during the roadmap section of the interview insured their intention to utilize the model. Furthermore, three participants (organizations D, I, and K) contacted the researcher after the interview with the request to plan an additional brainstorming meeting on how to further develop the roadmap for their organization specifically. Based on these results, we conclude that the model is evaluated as an artifact that participants intend to use to assess and improve their maturity regarding Industry 4.0 and Enterprise Architecture.

General digital transformation KPIs

This paragraph assesses the 'generality' evaluation criterium of the EAI4.0 maturity model by evaluating if a high overall level of maturity in our model focused on Industry 4.0 relates to an organization's performance in digital transformation in a general sense. The level of overall maturity of an organization is graded by the total amount of requirements achieved in all focus areas, which ranges from 0 to 115 and is depicted as the variable "maturity score" in the paragraphs below. The distribution of the achieved maturity scores can be found as a percentage of the total in table 12. Subsequently, Pearson's correlation coefficient was calculated between the organizations' overall maturity scores and the four different KPIs, to evaluate if correlations exist between these variables. Pearson's correlation is chosen as the primary measure of correlation for a linear relationship between quantitative variables (Schober, Boer, & Schwarte, 2018). The four KPIs together are, in this report, used as a means to evaluate an organization's digital transformation maturity. As such, an average value of the four KPIs is used pertaining to the overall general

digital transformation performance of the organization. Table 14 shows the correlation matrix between the aforementioned variables.

	Maturity score	KPI $\overline{X}$	KPI1	KPI2	KPI3	KPI4
Maturity score	-	0.78	0.53	0.76	0.49	0.70
KPI Average		-	0.83	0.79	0.61	0.91
KPI1			-	0.52	0.31	0.65
KPI2				-	0.22	0.70
KPI3					-	0.57
KPI4						-

Table 14: Correlations between general digital transformation KPI variables

Large correlations are present between the organization's maturity scores and the variables for 'KPI Average', 'KPI2', and 'KPI4', next to medium correlations between the maturity scores and the variables for 'KPI1' and 'KPI3' (Schober et al., 2018). We can conclude based on these results that a high correlation exists between the average KPI value and the maturity score. In other words, these results suggest there is a high correlation between general digital transformation maturity and maturity in the EAI4.0 Maturity Model.

To examine the relationship between a high maturity level in the EAI4.0 Maturity Model and a high general digital transformation maturity the method of Partial Least Squares Structural Equation Modelling (PLS-SEM) is used. The presence of this effect could similarly be evaluated by the use of a linear regression model. However, due to the digital transformation maturity being measured as a combination of data from a Likert scale, this is undesirable. Lastly, PLS-SEM is found to be applicable with small sample sizes (Davari & Rezazadeh, 2013). Before the PLS-SEM analysis, general assumptions were checked on data distribution using the respective skewness and kurtosis values. The results of this assessment can be found in Appendix M, in which none of the variables exceeded the thresholds for these values as defined by Byrne (2013).

An initial path model was created in SmartPLS 4 using the general digital transformation score as the independent variable, consisting of the four measured KPI values, and the maturity score in the EAI4.0 model as the dependent variable. First, the model was checked for validity and reliability through a bootstrapping approach with 5000 sub-samples (Sarstedt, Ringle, & Hair, 2021). The consistency reliability of the KPI construct was evaluated with both Cronbach's Alpha (0.797) and the Composite Reliability method (0.820). Both these values should be equal to or greater than 0.6 in an exploratory model (Sarstedt et al., 2021), which they both satisfy. Next, the Average Variance Extracted value (0.518) was calculated for the KPI construct to test for convergent validity, which should be equal to or greater than 0.5 (Fornell & Larcker, 1981), which the value satisfies. We tested the discriminant validity of the KPI construct versus the Maturity construct through the Heterotrait-Monotrait Ratio (0.879) which should be smaller than a value of 1.0 (Sarstedt et al., 2021), which the value satisfies. To additionally verify the discriminant validity, we checked the cross-loadings between the individual variables and the main constructs. The cross-loadings

of the individual KPI variables to the KPI construct are larger than their loadings to the Maturity construct, which is desirable (Fornell & Larcker, 1981). Finally, the VIF values are checked to assess multi-collinearity among the KPI indicators for general digital transformation. All VIF values are smaller than the benchmark value of 5.0 (KPI1:1.78, KPI2:2.15, KPI3:1.64, KPI4:3.67) (Sarstedt et al., 2021), and thus no multicollinearity problem was found among the indicators. In conclusion, all indicators are valid and reliable measures.

Table 15 shows the outer weights, outer loadings, and p-values of the indicators that make up the 'KPI' construct. Since all indicators have an outer loading of above 0.5, all indicators can remain in the model (Sarstedt et al., 2021).

Indicator	Outer weights	Outer loadings	P-values
KPI1	0.265	0.601	0.000
KPI2	0.383	0.870	0.000
KPI3	0.244	0.555	0.000
KPI4	0.354	0.805	0.000

Table 15: Outer weights, outer loadings, and p-values per indicator to the main 'KPI' construct

Figure 15 shows the graphical output of the model. The path coefficient between the 'KPI' and 'Maturity' values is found to be highly significant and positive ($\beta = 0.874, p < 0.05$). The R^2 (0.765) and adjusted-R^2 (0.741) values are both evaluated as substantial being larger than 0.7 (Sarstedt et al., 2021), measuring how much variance is explained by the 'KPI' construct on the 'Maturity score' construct. Based on these results we can conclude that there is a positive significant relationship between the general digital transformation KPIs and the Maturity score in the EAI4.0 model. In other words, if an organization's general digital transformation maturity is higher, this positively influences maturity in our model.

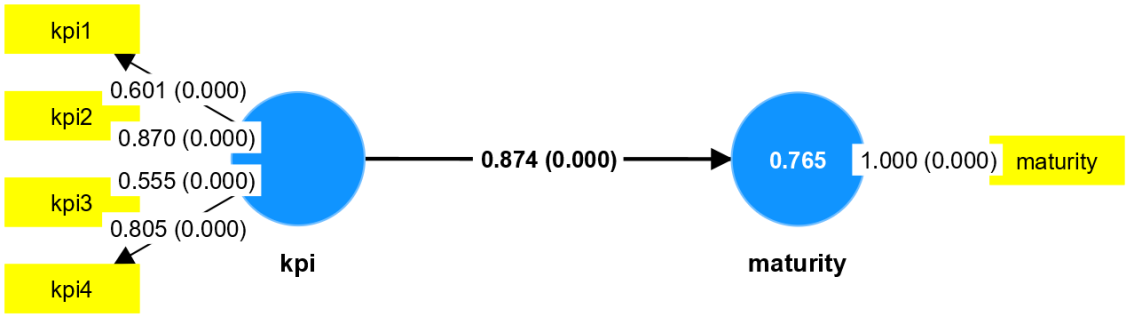

Figure 15: PLS-SEM Analysis graphical output

The correlation results and significant effect of the average KPI value suggest that organizations that are more mature in the digital transformation tend to be more mature in the Industry 4.0 and Enterprise Architecture domain. However, due to the low number of participants we cannot, based on these results, conclusively positively evaluate the 'generality' of the EAI4.0 Maturity Model,

such that our model comprising an element of the digital transformation is generalizable to the digital transformation in general.

Presenting strategy results
Finally, a clear result stemming from the second round of interviews is the positive evaluation of the presenting strategy during the interview. The logic behind this storyline was based on the logic behind the dependencies as derived from the focus group session results as detailed in section 3.6.3, and was evaluated as a useful addition to the roadmap based on the overall interpretation of the observations and textual comments of the interview.

5.3 Development of final model

The changes highlighted in the paragraphs above were introduced to create the fifth and final version of the model, together with a few textual changes made to the definitions of the focus areas and their maturity levels to improve readability. The final version of the model is displayed in section 4.5.

5.4 Discussion of the model

Through general observations of the assessment results, we noticed that for the 'change management' focus area some requirements are not depicted as requirements that should be achieved, but rather as a status of change management. Specifically, the first requirement of the 'performed' level of maturity and the first requirement of the 'managed' level of maturity both explain the way an organization is innovating, instead of the achievement of a requirement. Because the 'change management' focus area is setup like this, the assessment could show that these two highlighted requirements are not achieved while this is not an issue if the organization has achieved all requirements at the 'established' level, as then the organization has evolved to a higher level of how they innovate. Nevertheless, the 'change management' focus area was specifically added to capture the extent of innovation of the enterprise, and therefore no changes were made as a result of this observation. For an updated version of the model, this matter can be resolved by updating the logic which creates the assessment overview so that these two requirements specifically are shown to be completed when the organization has achieved the 'established' level of maturity for the 'change management' focus area.

Organization E noted the sometimes difficult task of grading a requirement as either 'yes' or 'no' with the requirement being not necessarily a black or white statement. This result was primarily found in the 'culture' focus area and subsequently, we sharpened the requirements in this area. Nevertheless, future research might explore a different way of assessing the organizations' maturity through the use of scales. The current EAI4.0 Maturity Model revolves around the achievement of individual requirements which makes the assessment robust and straightforward. However, this setup also reduces the room for nuance and therefore sometimes pushes a gradual phenomenon

into a binary format. Still, we feel the straightforward approach to the achievement of requirements and the one-to-one resulting assessment are critical to the positively evaluated practicality and concreteness of the model, which therefore outweigh the possible advantages of using a more gradual approach to assess maturity.

Organization H indicated that they believed it to be difficult to go from the assessment to the roadmap and corresponding storyline by themselves, without the presence of the interviewer. This comment establishes the positive addition of the storyline to the assessment and roadmap. However, future research might explore how to create this storyline in a more structured way less reliant on interviewer knowledge, as this can help in generalizing and broadening the use of the model.

A limitation of the setup for the maturity assessment is that there currently is no way to indicate if the person who completed the questionnaire was unsure about one or more answers. For example, it could be the case that the assessment is completed by one individual who commented on the 'optimized' level of maturity questions for the 'data governance' focus area that he or she did not possess the required knowledge to give a sufficient answer to these questions. In case this participant would still want to utilize and show the assessment, it would be a good addition to have the option to visualize when certain focus area maturity levels were not completed sufficiently. For future research, we propose to resolve this matter by either adding a small marker or crossing at the focus area maturity levels that were deemed as not sufficiently answered.

6 Conclusion

The main research objective of this thesis was stated as follows: "The development of a maturity model which can guide companies in their transformation towards Industry 4.0, by combining Industry 4.0 with the Enterprise Architecture practice". To achieve this objective, the EAI4.0 Maturity Model has been created consisting of relevant focus areas in the domain of Industry 4.0 and Enterprise Architecture, including relative maturity paths for each area and a corresponding assessment and roadmap.

Six solution requirements were established in section 3 to guide the development of the model, and are shortly concluded in this paragraph. The first requirement states that the artifact should be designed as a focus area-oriented maturity model, including focus areas, their definitions, and corresponding maturity levels, which has been achieved by designing the model as a focus area-oriented maturity model, including all required elements. The second solution requirement states that the artifact should contain all focus areas that are deemed as relevant, by both literature and industry, for implementing Industry 4.0, Enterprise Architecture, and its combined use. This requirement has been achieved through the execution of the systematic literature review, and subsequent validation of the focus areas in all validation rounds, specifically the first round of interviews. The third requirement states that the artifact should contain relative dependencies between focus areas and their maturity levels, depicted on a scale that highlights ordering between areas. This requirement has been achieved by deriving these dependencies through the focus group sessions. This requirement includes that a scale should be available to highlight the ordering between areas. Through the addition of the four general maturity levels, a literal scale was not deemed necessary. The fourth solution requirement requires the model to be categorized under over-arching general domains, which was achieved through the addition of the 'organization', 'people', and 'technology' domains and was subsequently positively evaluated in the results section of this report. The fifth requirement states that the model should be deemed both useful and easy to use by practitioners, which was achieved through the positive evaluation of the model on these constructs, during the final round of interviews, shown in section 5. The last solution requirement requires the model to contain an assessment procedure able to guide users in the company's maturity assessment. This requirement has been partly achieved by the creation of an assessment protocol including a questionnaire and corresponding roadmap and has been positively evaluated in section 5. However, the assessment protocol currently assumes a too-perfect situation and lacks flexibility, as there are no guidelines for irregular situations. As highlighted at the end of subsection 5.4, the current protocol assumes the participant has all of the required knowledge to complete the questionnaire, which might not always be the case. Similarly, a more concrete link between the maturity assessment and roadmap and the corresponding storyline should be added to the assessment protocol.

Overall, we conclude that the main research objective of this thesis has been successfully achieved, both through the achievement of the solution objectives and through the overall positive evaluation of the artifact mainly during the last round of interviews.

6.1 Contribution to theory

This research contributes to the academic literature on Industry 4.0 maturity, the connection between Industry 4.0 and Enterprise Architecture, and maturity models in general in several ways. First, it responds to the demand for a model which has the ability to guide organizations in maturing in Industry 4.0 combined with Enterprise Architecture, as similarly suggested by Nowakowski, Häusler, and Breu (2018), who claimed that an appropriate guideline for Enterprise Architecture application in the Industry 4.0 domain in the form of a dedicated planning process is needed. To fill this gap in the literature, this study provides the EAI4.0 Maturity Model which identifies relevant focus areas in the combinatory domain specifically by highlighting what areas organizations should focus on regarding Industry 4.0 and Enterprise Architecture. Moreover, the model defines individual maturity paths for these focus areas highlighting when to achieve what level of maturity. Lastly, the model provides an additional roadmap which, due to its positive evaluation, contributes to research on how to present maturity assessment results to users.

In the background section of this report, we discussed two frameworks that function in the same domain. The RAMI4.0 functions as a reference architectural model and therefore focuses mainly on the technological element of Industry 4.0 integration (Kornyshova & Barrios, 2019). We propose that our model provides a more broad approach to increasing general maturity in Industry 4.0 and Enterprise Architecture, by including extensive focus areas not only concerned with the technical integration of Industry 4.0 but also the areas surrounding it. In turn, the RAMI4.0 can be a valuable tool as an addition to the EAI4.0 Maturity Model by providing technical support when organizations reach the level of maturity in which they would require this. Therefore, the RAMI4.0 has been added as a best practice, but, future research might explore if a more detailed connection between the two models can be achieved to reach greater levels of guidance. The HORSE framework was developed to act as a reference architecture of a cyber-physical system to integrate various Industry 4.0 technologies (Erasmus et al., 2020). Similar to the RAMI4.0, this framework focuses on technological integration and could therefore be explored in future research as a lower abstraction level addition to the EAI4.0 Maturity Model.

The EAI4.0 Maturity Model contributes to the literature on Industry 4.0 maturity by suggesting substantial differences in maturity between focus areas. Literature highlights that many difficulties of implementing Industry 4.0 are concerned with integration in the current organization (Aldea et al., 2018). When we compare these findings with the focus areas that were found to be the least mature in the EAI4.0 Maturity assessments, shown in figure 13, we find the focus areas of 'knowledge', 'culture', and 'standards'. These focus areas are concerned with relatively peripheral and integrational matters to the direct technological implementation of Industry 4.0, which suggests that our findings are in line with research on general difficulties found within Industry 4.0. Future research might specifically investigate organizational maturity in these focus areas, in an attempt to improve overall maturity in Industry 4.0.

The EAI4.0 Maturity Model contributes to the literature on maturity models in general by creating and utilizing a new type of maturity model, set up as a focus area-oriented maturity model but structured in separate maturity levels. This setup combines maturity model practices of the continuous level maturity model, which portrays one set of requirements for each maturity level, with a dependencies-focused approach found in the DYAMM. The advantage of this new type of model over the focus area-oriented maturity model as used in the DYAMM is that our model has an increased level of structure, which improves readability and logic. The advantage of this new type of model over a regular continuous level maturity model is the addition of dependencies which can help organizations in guidance on when to achieve what level of maturity. However, this also increases the difficulty and decreases the simplicity of the model. Moreover, a limitation of the EAI4.0 Maturity Model is that its design has to our understanding not been evaluated previously which makes it a less validated approach to structuring a maturity model.

Lastly, the EAI4.0 Maturity Model contributes to theory through its results suggesting that when organizations are more mature in digital transformation in general, this positively influences their maturity in the EAI4.0 Maturity Model which focuses on Industry 4.0. This information is in line with research by (De Carolis et al., 2017) and might guide future research in distinguishing participants for Industry 4.0 research.

6.2 Contribution to practice

This research contributes to practice by containing several practical implications for practitioners, such as managers, architects, IT directors, and innovators. Firstly, it identifies all relevant focus areas surrounding Industry 4.0 and Enterprise Architecture for practitioners. Research suggests that an overview of areas influenced by Industry 4.0 and Enterprise Architecture is helpful in maturing in this domain (Rogers, 2016). As an extension, the set of focus areas creates awareness for affairs surrounding digital transformation that are less prominent but equally important. In general, the EAI4.0 Maturity Model can be used by practitioners as a means of communication to increase awareness among employees.

For each focus area, the EAI4.0 Maturity Model provides a set of requirements that when achieved increase the organization's maturity in that area. The results of this thesis suggest that a concrete list of requirements is evaluated as very useful by giving practical handles to practitioners, instead of an abstract overview of goals. The best practices provided in the model as an extension to the requirements were similarly evaluated as useful in the model evaluation section 5. These best practices suggest concrete tips on how to achieve certain requirements, and therefore add specific value to practice.

A large contribution to practice of the EAI4.0 Maturity Model is the corresponding assessment and especially the subsequent roadmap. The assessment can pinpoint the maturity of organizations for each individual focus area, which has the following advantages. Firstly, suchlike assessments

show the current situation, and can subsequently be used to develop and improve implementation (Pöppelbuß et al., 2011). Moreover, by highlighting the maturity of further developed focus areas, organizations also get an idea of what areas might require less attention or be used as a specific capability.
Most importantly, the EAI4.0 Maturity Model provides a roadmap that organizations can use to improve their maturity regarding Industry 4.0 and Enterprise Architecture by prioritizing requirements that are prerequisites for later levels of maturity. Roadmaps are seen as valuable in research (Pöppelbuß & Röglinger, 2011), and are similarly evaluated as very positive in this research and thereby provide a valuable addition to practice.

6.3 Limitations and future research

As a result of the first round of interviews, an initial order between focus area maturity levels was created with the aim of guiding and streamlining the focus group session. Participants in the first focus group session were prompted to make changes to the initial dependencies that were presented to them on a whiteboard. However, during the focus group session, we learned that the participants were very eager to build the dependencies from the ground up, instead of making individual changes to an initial setup. Participants noted in unison that they believed this approach to be better since every focus area's maturity levels depend on one another which thereby creates a storyline of achieving higher levels of maturity. Similarly, the participants felt that this setup was easier, as it helped in thinking about the logic behind why specific dependencies should or should not exist. Therefore, if future research were to recreate the model from the ground up including new focus areas, we suggest removing gathering data on dependencies during the first round of interviews and letting the focus-group session build the dependencies from the ground up.

Two focus-group sessions were held with the aim of establishing the dependencies between all focus area maturity levels. Both groups had different areas of expertise and were planned at other moments in time due to planning and location constraints. According to the Delphi method, a consensus between these two groups is required to confirm the end result (Dalkey & Helmer, 1963). However, reaching a consensus between participants in two different groups during different sessions posed to be inconvenient. The consensus was eventually reached by verifying changes made by each group via e-mail. For future research, we, therefore, propose to conduct focus group sessions with one single group of individuals. Nevertheless, multiple sessions can still be had when consensus is not reached after the first session. Having the same group of people in every session will both improve consensus quality (Dalkey & Helmer, 1963), and reduce the effort it takes to coordinate this process.

During the second round of interviews, most interviewees indicated that they completed the assessment questionnaire on their own, occasionally asking colleagues for help when they were uncertain if a requirement had or had not been achieved. In an ideal world, the assessment for the EAI4.0 maturity model would be carried out by multiple people within the same company but in different

departments. When an employee was to fill in the assessment on their own, the risk exists that either insufficient knowledge is present to complete the questionnaire which leads to an incomplete assessment, or, that the employee wrongly believes they have sufficient knowledge, which might be even worse. Having people from different departments in the organization complete the questionnaire ensures not only sufficient knowledge but also removes potential bias from a singular employee by averaging beliefs throughout the company, which is especially important for qualitative requirements like the existence of an innovative culture. Moreover, a questionnaire filled in by multiple people increases involvement in the digital transformation as a whole, which is shown to be an important element (Auth, 2021), while also ensuring that possible outcomes of the assessment reach the right people.

The advantages of diversification can be extended by broadening the types of industries or organizations that participate in the interview rounds. In the current study, a handful of different industries are explored, which suggested the effects of diversification within this domain. Nonetheless, a more structured differentiation between different types of industries might be executed in future research, to understand the differences between industries specifically in this field. An example visible in the results of this thesis concerns the 'standards' focus area, which was deemed of relatively higher importance in organizations working within the food domain. Interview results show that in this branch regulations and protocols from governmental institutes are a much bigger driving force behind business goals and corresponding Industry 4.0 executions than in other industries. Similarly, interview results indicate a difference in how organizations treat the 'finance' focus area. Most companies, especially SMEs (participant D in interview 2), imply financial elements to be inhibiting factors to innovation and change, and subsequently boundaries to what projects can achieve. However, one interviewee (participant J in interview 2) deliberately stated that impactful Industry 4.0 and digital transformation changes can only be fully achieved when they are tackled based on, sometimes optimistic, business goals and strategy, instead of on a limiting factor like a budget. Another example of industry differentiation was mentioned by participant E in interview 2, who stated that in industries where supply chain integration is part of the core process of the organization, the subsequent requirement that stated this integration should be achieved significantly earlier than in the 'optimized' level of maturity. These results highlight the demand to further investigate differences between industries, both through exploring additional industries to the ones explored in this thesis, and through assessing more similar types of industries to ensure well-founded conclusions can be made on this front. In an ideal world, the maturity model can be tailored to the type of industry, giving a more accurate assessment for a specific type of branch. To achieve this, definitions and best practices should be altered to fit better with the general core processes of each type of industry, while also changing dependencies based on which focus areas are found to relate differently to each other compared to the current dependencies. When done correctly, the model would in this case be able to give more direct and precise feedback and anchors for organizations to improve their maturity, which was explicitly mentioned by one of the interviewees (organization B) in the evaluation round to be a very useful addition.

A limitation of the current model design was found in line with the diversification of the model in different industries. The best practices that were derived for the maturity model were mainly taken from textual comments and input from the first and second rounds of interviews, and are therefore not exhaustive. Even though these best practices were deemed useful by participants in the second round of interviews, participant D noted that some best practices could be worked out in more detail, while participant C indicated that some best practices were too specific. Moreover, the overall interpretation of the observations in the interview suggests that differences between industries are big in the extent to which a certain best practice is useful or not. This identifies a key limitation of our study, which is the thin line between generality and detail, which arises due to the relatively large scope of the model. A specific example of this is the construct of 'supporting tools' for Enterprise Architecture and Industry 4.0, which we found to be a relevant topic in these domains in the systematic literature review. One participant (organization I) in the second round of interviews suggested giving specific examples of supporting tools that could be used and that were deemed useful by the researcher. We argue however that this hurts the generality of the model, as there is a large scale of supporting tools, of which many are tailored to certain industries (Ilin et al., 2021; Xu et al., 2018). As stated above, future research might explore creating different versions of the model for different types of industries. In this case, the model could highlight specific best practices in more detail, and thereby improve the extent to which companies can directly follow the roadmap, as suggested by participant E in section 5. In line with this, future research might explore performing a systematic literature review combined with validation rounds with practitioners to create an exhaustive but general set of best practices for this domain.

During the interviews after the maturity assessments, some participants (organizations G, H, J, and L) commented that the length of the questionnaire is rather large, sometimes feeling there was no end in sight. A possible solution for future research would be to make the assessment shorter and more focused by not continuing with questions for a certain focus area when a previous level of maturity has not been reached. For example, if an organization did not achieve a single requirement of the 'performed' level in the 'finance' focus area, then the questionnaire does not ask questions pertaining to 'finance' requirements in the 'managed', 'established', and 'optimized' levels. However, the results of the interview also show the advantage of organizations indeed filling in the entire questionnaire. Multiple maturity assessments show organizations having completed requirements for later maturity levels while having neglected earlier requirements. One might argue that this should not be possible in the setup of a maturity model, but we feel neglecting to ask all questions does not give the full overview of an organization's progress in this domain. Moreover, we argue that also showing the areas in which an organization has not yet completed any requirements is a useful addition by showing where the organization has yet to improve.
Future research might explore structuring the questionnaire in different sections as proposed by participant G in interview 2, possibly per focus area or per maturity level, to reduce the unfavorable feeling of the questionnaire looking lengthy.

As stated above quite a few organizations indicated having completed requirements in later maturity levels while not having achieved the requirements of the same focus area in less mature levels. During the interviews, different reasons for this were mentioned, most commonly that the organization achieved a 'more mature' requirement on an ad-hoc basis for single instances, but not in a general structured sense. Answers to these kinds of questions often seem to be dependent on interpretation by the participant, which is why some questions should be sharpened in future iterations. The question remains however if this is negative, as there is some merit in showing organizations also the things they did progress to a lesser extent, albeit not in the most perfect way. An example of this is one of the requirements of the process management focus area concerned with version control. This requirement focuses on the version control of the Industry 4.0 process architecture, which not many organizations indicated they have achieved in full. However, some participants did answer 'yes' to the corresponding question, including a comment that version control of many Industry 4.0 processes is in place, but not for the entire process architecture. Even though we still propose to sharpen some definitions to make sure an organization has really achieved what the model claims, future research could investigate a way to show progress within single requirements. A possibility would be to change the assessment questions from binary to a Likert scale so that participants can indicate requirement progress in more detail. This would however increase the time it takes to complete the questionnaire, as well as complicate the corresponding assessment.

Two participants (organizations B and H) indicated that they completed certain requirements at later levels of maturity without achieving the prior requirements in the same focus area because certain requirements are always performed at projects due to the way their organization operates. They indicated that for every project that is started, they execute a standardized project portfolio management process which includes, among others, a financial structure with KPIs and means to assess the performance of the project. Therefore, since they do this for every project, they also perform this for Industry 4.0 projects. Similar to the example above, we argue that indicating this in the maturity assessment is valuable, even though this decreases the observable logic of the assessment. When organizations do eventually arrive at this higher level of maturity, it means the requirements corresponding to this level will be more easily achieved. Importantly, due to it being displayed in the assessment, they will be aware of the fact that the organization is already working with these requirements which we argue might increase visibility surrounding this process. For example, if an employee that is working on improving Industry 4.0 maturity within the organization is unaware that the organization is in fact already achieving the financial KPIs requirements, this will be made visible to this employee when the organization reaches the corresponding level of maturity through the EAI4.0 Maturity Model.

One participant (organization G) in the second round of interviews proposed if, for future research, a workshop setting might be better suited to gather the results for the maturity assessment than an online questionnaire. This participant argued that many questions required additional

information due to the questions being in a binary format and that this additional information can be better expressed in a more open workshop setting instead of in the current setup of a comment format under each question. Moreover, this participant argued that a workshop setting is a great way to have multiple people contribute to the maturity assessment in a meaningful way, which was also proposed by other participants (organizations D and L). In a workshop setting with multiple people, individual bias is countered and possible gaps in knowledge are filled by inviting participants with different roles having relevant know-how and experience. However, such a setting can also have disadvantages like groupthink or fear of speaking honestly about how a person assesses a certain requirement, which might be critical for requirements in, for example, the 'culture' focus area. Such group issues that might arise in a workshop setting are non-existent in the use of a questionnaire, assuming results are not shared among participants. Nevertheless, future research might explore the advantages of a workshop setting as this might increase both the quality of the assessment and the behavior of the outcome, through discussions with the relevant actors compared to an average value of separately completed questionnaires. A possible way to counter groupthink within a workshop setting is to use the method of Planning Poker which originated as a means to elicit team-member opinions in Agile development (Sudarmaningtyas & Mohamed, 2020). Extensions to this method have been proposed with the aim of utilizing this method as a means to reach a consensus in an unbiased manner (Sudarmaningtyas & Mohamed, 2020). In our research, this method could be used during the assessment in a workshop setting, where each participant grades the maturity of a focus area maturity level with a playing card ranging from ten to ace, for a 5-point Likert scale, or ace to two, for a binary-format. These cards are placed face-down in front of the participants to remove groupthink and are only shared with the rest of the group after everyone has made a decision. Through this method, all participants can give their honest opinion on the maturity of a focus area, while also giving a starting point to the discussion on the consensus.

Another example of why utilizing a workshop setting to gather the results for the organization's maturity assessment would be beneficial is highlighted by comments by organization D. This participant indicated a limitation of the current assessment design, as during the questionnaire many questions might be interpreted differently and are thus dependent on nuance and how they are explained and written down. An example of this is the requirement and corresponding question number 110 which reads: "Is a plan for future technological capabilities present?". Participant D mentioned that they were doubtful about what to answer to this question, as they argued that their organization knew to a large extent which technological capabilities they would want to acquire in the coming months, however, there was no plan present on how to achieve this and no specifics worked out. By using a workshop design certain complications can be prevented by having an open discussion with the assessor on what exactly is meant by each question and requirement. Moreover, in case the assessor possesses the knowledge the two parties can discuss openly, keeping in mind the current company situation, if they feel that this question is sufficiently complete or not. In other words, it might be the case that through a discussion the organization believes they are confident this type of plan is sufficient for the goal the assessor detailed, which can subsequently

steer the answer to the question. The opposite might similarly alter the result of the assessment when after the addition of details by the assessor, the organization feels this question requires more work.
It should be noted that the addition of nuance and additional information to each question can be achieved through the addition of content within the questionnaire's general information section, as well as in the questions separately. However, we argue that based on the results for the 'ease of use' criterium in section 5 this is not desirable, as this would increase the negatively evaluated questionnaire length.

A limitation of the research design is that there is currently no means to utilize a company's ideal 'end-maturity' within the assessment itself. One participant (organization A) indicated during the interviews that some of the requirements in especially the 'optimized' level of maturity are requirements that their organization does not necessarily want to achieve, at least in the foreseeable future. This results in organizations partly filling in the questionnaire for elements they deem less useful, which we feel is nevertheless not a big issue. It would however be a great addition to the assessment and corresponding roadmap to include the level of maturity a company strives for, either on a general level, e.g. 'managed', or even on a focus-area specific level. As an example, some companies will be more reliant on 'data quality' or 'standards' than others. Inquiring about this information during the assessment questionnaire would not only improve the specificity of the road map for the organization in question but could also reduce the overall size of the assessment result making it more manageable.

An important conceptual element of our model design is the decision to use focus areas as a means to distinguish between relevant domains. Other maturity models often instead employ more specific ways to indicate the different elements such as capabilities like the CMMI design (CMMITeam, 2001), or processes as described in the ISO33020 standard for process capabilities (ISO 33020, 2019). The advantage of the focus area-oriented design used in this thesis is the ability to define a more general area of emphasis, instead of specific capabilities, processes, or limiting factors (Wagter et al., 2005). However, this design choice therefore also reduces the structural clarity of the model and makes it more difficult to compare focus areas with one another, especially when deriving dependencies between when to achieve certain maturity levels. Future research might explore constructing the model as a process capabilities maturity model as we feel this would fit our purpose best. Nevertheless, some focus areas currently identified, like the 'culture' focus area, seem difficult to quantify as a specific process.

Another limitation of the current research design is the way in which the 'fidelity with practice' evaluation criterium was validated. Participants were asked to grade for each focus area the extent to which the maturity assessment was in line with the actual situation in their organization, by grading the assessment of each focus area as either 'perfect', 'close', or 'not at all' in line. However, we feel that the scaling on these three points should be revisited, as the 'perfect' and 'close' grades

appear to lie more closely together than the 'not at all' grade. Moreover, such qualitative grading might leave unnecessary room for interpretation. Therefore, we propose future research to label these options more neutrally and quantitatively. An exemplary way to solve this issue is to ask participants for each focus area whether the assessment is in line with the actual situation at their organization and in case the answer is negative ask what maturity level they deem more fitting. Subsequently, the differences between the assessment and participant answers can be calculated to reach a quantitative result for the 'fidelity with practice' for each focus area (either 0, 1, 2, 3, or 4 maturity levels away). This solution can be extended further by asking participants to grade their organization's maturity for each focus area on the five general maturity levels, including zero maturity, before showing the organization's assessment. By doing this, participants are not influenced by the assessment and might therefore give a more correct, and possibly more honest, answer which would increase the quality of the 'fidelity with practice' evaluation criterium. However, doing so on the spot might be difficult for organizations, and might thereby also increase the length of the interview.

Future research might consider the temporal aspect of the model, which is currently not present. Organizations could benefit from information on how long certain requirements on average take to achieve, as was shortly mentioned in a general sense in interview round 1, which could assist in long-term planning of strategy and vision. However, adding suchlike temporal information to the model is very dependent on the type of organization, the size and means of the organization, the extent to which they possess a digitalized culture, and the type of industry (Agostini & Filippini, 2019). Nevertheless, by adding temporal information the model could change to a Gantt chart-like structure, which would remove the current limitation of the model that we based the dependencies on when to achieve a certain maturity level instead of when to start it. For example, the fact that the 'performed' maturity level requirements of the 'finance' focus area are dependent on all other focus areas in the performed level, does not mean finance should be completely ignored until all other focus areas have reached the performed level of maturity. We see this as a big limitation to our current design. Portraying the model as a Gantt chart would remove this limitation. However, the design of such a model would require a revision of the dependencies since each focus area maturity level would in this situation have two critical moments, a starting and ending point, of which dependencies to the other focus areas need to be derived. Moreover, adding temporal components to each focus area maturity level increases the difficulty of aligning these dependencies, while also requiring data from many organizations in order to make well-founded statements on the average time it takes to complete certain requirements. Nonetheless, we view this as the ideal end goal and design of our model. This goal could be achieved by following the organizations that completed the assessments in this thesis for the coming years, to see if and how they mature, which would yield valuable data to improve the model. Next, data could be gathered on how long requirements take to achieve on average which would be used to add an indication of time to the model, in case a sufficient number of organizations participate. In an ideal world, the temporal component of the model can be altered to the type of Industry, but also to the input of the or-

ganization itself. For example, if the organization decides to take one year to sufficiently achieve a requirement, the model should be able to update the other focus area maturity levels based on this decision. Through this, an interactive model with built-in dependencies and averages could help in building a detailed roadmap, including a temporal element, specifically for the organization.

A limitation of the current research design is that we did not validate the final changes to the model as a result of the last round of interviews. Even though the structure and setup of the model were not altered, a few textual changes to the focus area maturity levels were made together with the addition of new best practices. Since these changes were proposed by participants in the second round of interviews with the specific aim of improving the model, we argue that this did not negatively impact the evaluation criteria results as highlighted in section 5.

In the current study, we evaluated the effects between maturity in the EAI4.0 Maturity Model versus maturity in general digital transformation. In addition to this research, future work might explore if similar effects exist between maturity in our model versus different maturity models that lay on the edge of our domain. For example, verifying if there exists a significant effect between maturity in the DYAMM and our model, or, verifying if there exists a significant effect between maturity in an Industry 4.0 maturity model and our model. Of course, many parts of these maturity models will be similar. However, the results could shine a light on the necessity and effectiveness of Enterprise Architecture within Industry 4.0 (Van Steenbergen, 2011). For example, if no significant effect would exist between maturity in the DYAMM and our model, this might suggest that Enterprise Architecture is less necessary for Industry 4.0 maturity than we previously proposed.

Within the first and second rounds of interviews, participants might have suffered from cognitive biases due to the presence of the interviewer.
In the first interview, participants were asked to grade their familiarity with the concepts of Industry 4.0, Enterprise Architecture, and Maturity Models. Participants were invited for the interview on the premises that they possessed subsequent knowledge about Industry 4.0 and Enterprise Architecture to partake in the interview. When asked about their familiarity with these topics, it might have been the case that participants gave an answer claiming a higher familiarity than what is actually true because that answer is desirable to the interviewer. The social desirability bias refers to the tendency of research subjects to choose responses they believe are more socially desirable or acceptable rather than choosing responses that are reflective of their true thoughts or feelings (Grimm, 2010), and is found to be a common bias in qualitative research (Bergen & Labonté, 2020). This effect might have influenced the grades participants gave regarding their familiarity with the topics. However, based on the overall interpretation of the observations we believe this effect to have been negligible or nonexistent during the first round of interviews.
A similar risk of response bias has been present during the second round of interviews. Participants were asked to evaluate the 'usefulness' and 'ease of use' of the model, as well as their 'intent to use'

the model. Social desirability bias, or in this case even courtesy bias (Hallihan, Cheong, & Shu, 2012), might have influenced the answers participants gave to the ten questions in the TAM, in an effort to be polite toward the interviewer by giving a socially desirable answer, as all participants were aware of the fact that the model was created by the interviewer itself. Based on the overall interpretation of the observations we believe that there might have been a small effect of courtesy bias in the responses of the individuals during the second round of interviews.

Another bias that could possibly have had an effect on part of the results is the so-called question-order bias or response-order effect. This phenomenon might induce measurement error by the order in which questions are posed and/or responses are given (Israel & Taylor, 1990). In the first round of interviews, all focus areas were evaluated on their correctness regarding their relevance to the topics of Industry 4.0 and Enterprise Architecture. The order of evaluation was the same for each participant, starting with the 'strategy' focus area and ending with the 'technology' focus area. The response-order effect might have influenced the results due to participants having a better grasp of the average granularity level of each focus area after evaluating a couple of areas. We tried to limit this effect by showing the participants all focus areas at the start of the interview before evaluating the areas one by one. However, due to time constraints, this overview was presented without the definitions which could have been an inhibiting factor in limiting the response-order effect. We feel that this effect has been negligible due to the participants being prompted to evaluate the set of focus areas as a whole after each overarching domain. Nevertheless, future research could explore randomizing the evaluation order between focus areas since a specific order is not relevant for the purpose of the interview.

Lastly, one participant (organization H) in the second round of interviews mentioned a phenomenon, more substantial than a best practice, which future research might explore as an addition to the assessment presenting strategy. This participant indicated from experience that organizations focus on either specifying or generalizing their capabilities in a pendulum-like fashion, which falls together with the highs and lows of profit. The participant argued that in times of profit, an organization should not overtly focus on making more profits and specifying their business, but should instead use this period of wealth to generalize their capabilities throughout the organization by the use of Enterprise Architecture. When done correctly, the organization will be ready and in order for when eventually the organization is in a less profitable period. If future research were to extend the EAI4.0 model with a temporal element, this addition of constantly keeping the architecture up to date might be further explored.

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Appendices

A Systematic Literature Review

Table 16 gives an overview of how many times certain elements were mentioned in the set of papers explored during the systematic literature review. All individual mentions can be found in Appendix B.

Identified element	Count in literature
Strategy and vision	11
Alignment IT and business	7
Budget	8
Contextualization	6
Communication	13
Enterprise Architecture implementation	7
Knowledge and skills	12
Culture and mindset	12
Management and leadership	6
Roles and responsibilities	8
Innovation and improvement	6
Standardization and protocols	12
Data-driven decision-making	8
Flexibility	11
Process change management	5
Data warehousing and quality	10
Alignment IT and OT	9
Data acquisition	6
Industry 4.0 implementation	9
Supporting tools	9
Security	4
Employees	2
Support processes	3
Control	3
Cloud	2
Customization	5
Regulations and other legalities	1

Table 16: Elements identified during Systematic Literature Review

B Systematic Literature Review details

Papers can either refer to Industry 4.0, Enterprise Architecture, or both, which is highlighted in the third column.

Author	Paper	Paper refers to	Mentioned key-word(s)	Context in which key-words are mentioned	Coded in SLR as:
(Aldea et al., 2018)	"Enterprise architecture 4.0-A vision, an approach, and software tool support"	Both	"IT-OT alignment"	The core problem of Industry 4.0 related to IT-OT alignment could be addressed by Enterprise Architecture, which is an enhancement on EA with operational data and model-based advanced analytics.	Alignment IT and OT
			"New skills required", "Domain knowledge"	New skills are required to deal with the usage of advanced analytical techniques that come with I4.0 and EA, and that these can either be fulfilled by training existing employees, or hiring employees with the required skills	Knowledge and skills
			"Dynamic nature", "Dynamic changes"	With the addition of Industry 4.0 into EA, the EA behaves no longer isolated, but rather as a living organism, reflecting the dynamic changes in all the layers of the organization.	Flexibility
			"Quality of the data", "Data architecture", "Central repository database"	Interpretation of analysis results requires quality of the data, as well as of the related processes generating/using the data. One of the challenges of Industry 4.0 is heterogeneous unreliable big data. Integration of models and data is facilitated by a central database.	Data warehousing and quality
			"Methods and tools", "Tooling support"	To achieve the vision of EAI4.0 (an integration of Industry 4.0 into an EA environment), methods and tools are needed to seamlessly integrate into a shared environment.	Supporting tools
			"Business-IT alignment", "Business-IT capabilities"	EA assists organizations by aligning existing business processes, organizational structures, information systems, and technical infrastructure, which are also affected by Industry 4.0.	Alignment IT and business
			"Strategy layer", "Architecture Vision"	Aligning with company strategy is an integral part of implementing EA	Strategy and vision
(Aliee et al., 2019)	"The evolving Enterprise Architecture: A digital transformation perspective"	Both	"Strategy"	If there is no strategy to use IoT in an enterprise, the IoT will be a futile effort by the Enterprise. Enterprise Architecture is intended to support business strategies through the use of IT.	Strategy and vision
			"Anticipate future", "Agility"	Digital transformation leads to the ability to anticipate future decisions using multidimensional information obtained from physical or virtual objects.	Flexibility
			"Align IT with business"	The goal is to align IT with business to improve the performance of the enterprise. Aligning IT with the mission and goals of the business.	Alignment IT and business
			"Culture"	An enterprise needs to consider the workforce from a wide range of generations and cultures.	Culture and mindset
			"Fields of IT in Industry 4.0"	One of the main concepts of I4.0 is the digital transformation that covers various fields of IT like Big data, Cloud, IoT, VR, etc.	Industry 4.0 implementation
			"Costly"	The digital transformation is costly for an enterprise.	Budget

			"Change acceptance"	Enterprises should always be prepared to accept changes regarding digital transformations, as it is a differentiator for their business.	Process change management
			"Standards"	The use of standard communication protocols between the enterprise systems and devices is expected.	Standardization and protocols
			"Data management"	Efficient management of large volumes of data should be considered.	Data warehousing and quality
			"Interoperability"	Connecting all networks together and ensuring data interoperability. All departments need to be able to work together.	Communication
			"Innovations", "Improve learning"	Enterprise is expected to turn threats into opportunities, have innovations, adapt to conditions, and improve learning. The learning enterprise should be a constant principal.	Innovation and improvement
(Xu et al., 2018)	"Industry 4.0: state of the art and future trends"	Both	"Strategic goals"	In Industry 4.0, an organization's strategic goals need to be aligned within a company, between companies or across an entire supply chain.	Strategy and vision
			"Budget"	Industry 4.0 solutions require large budgets.	Budget
			"Communication", "Interaction"	Industry 4.0 creates a cyber-physical manufacturing environment that enables communication and interaction amongst all the players in the value-creation chain.	Communication
			"Industry 4.0, smart manufacturing"	Industry 4.0 offers new opportunities for manufacturing firms to analyze and use design, production, sourcing and inventory data to help them realize their modernization vision.	Industry 4.0 implementation
			"New and classical industrial production processes"	New ICT is capable of integrating both new and classical industrial production processes, where new production processes refer to the virtual environment, and the latter refers to the physical world.	Alignment IT and OT
			"Intra- and inter-organizational level models"	The transition of traditional industrial ecosystems to Industry 4.0 will not only require new ICT but also new business models at intra- and inter-organizational levels to be developed.	Communication
			"Changes in Enterprise Architecture"	In Industry 4.0, integration in all directions requires changes in Enterprise Architecture, ICT integration, and processes.	Enterprise Architecture implementation
			"Help organization with adaptation"	Due to the arrival of Industry 4.0 and the profound changes to complex industrial ecosystems, there is the need to embrace new architectures and new business processes that will help an industrial organization with the adaptation of existing enterprise architecture, ICT infrastructures, processes and relationships to support the transformation.	Process change management
			"Improving key requirements", "Evolution"	The EA change process is creating, improving, and communicating the key requirements, principles, and models that describe the enterprise's future state and enable its evolution.	Innovation and improvement
			"Flexible"	Integrating Enterprise Architecture and connecting current and new system processes leads to flexibility.	Flexibility

			"Standardisation"	Each process used in an Industry 4.0 system integrates existing and proven technologies with new technologies and applications to address manufacturing problems. As such, the introduction of a uniform industry standard is especially important.	Standardization and protocols
(Gogineni et al., 2020)	"Applying Contextualization for Data-Driven Transformation in Manufacturing"	Industry 4.0	"Contextualization"	Contextualization contributes to saving time and efforts involved in carrying out an activity and making decisions. A connection to Industry 4.0 as well as data allocation is an ongoing challenge, but necessary.	Contextualization
			"Context of origin"	Origin information, linked to questions such as 'Who organized the actions', 'what were the reasons or motives', 'who were the owners'.	Roles and responsibilities
			"New discipline"	New capabilities in designing, planning, and executing manufacturing with respect to the collection, identification, interpretation, and digital composition of the right or decisive data sets will form a new discipline in manufacturing. This discipline will need competence in manufacturing/engineering process know-how, data analytics, data contextualization, human-machine interaction, and IT knowledge.	Knowledge and skills
(Basl & Novakova, 2019)	"Analysis of selected ERP 4.0 features and proposal of an ERP 4.0 Maturity Model"	Both	"Information sharing"	Tracing of customers and their requirements via mobile applications leads to higher customization.	Customization
			"Communication"	Applications can help companies improve service quality, improve employee productivity and make communication easier and faster.	Communication
(Basl, 2018)	"Analysis of Industry 4.0 Readiness Indexes and Maturity Models and Proposal of the Dimension for Enterprise Information Systems"	Industry 4.0	"Data-driven"	Data-driven manufacturing is a cornerstone of Industry 4.0 and smart manufacturing.	Data-driven decision-making
			"Industry 4.0 readiness"	Attention has shifted towards the advantages of Industry 4.0, mainly towards readiness and development of Industry 4.0.	Industry 4.0 implementation
			"Strategy"	Defining strategy is crucial to implement Industry 4.0 technologies.	Strategy and vision
			"Leadership"	Management needs to push top-down innovations.	Management and leadership
			"Culture"	Company culture is very relevant in implementing a digital transformation.	Culture and mindset
			"Human resources"	Current employees are often influenced very heavily by digital transformations.	Knowledge and Skills
(Bi et al., 2014)	"Internet of Things for Enterprise Systems of Modern Manufacturing"	Both	"Acquiring data"	Acquiring and managing data of the current system state is necessary to guide further decision making. Moreover, sensors or devices for data acquisition are crucial to the success of new products.	Data acquisition
			"Scope"	Defining the scope and boundary of the design problems and its objectives is an activity relevant in every enterprise system	Strategy and vision

			"Relational models"	Establishing relational models among inputs, outputs, and system parameters is also an activity relevant in every enterprise system	Standardization and protocols
			"Making decisions"	Making decisions according to given design criteria and data is a key component of an enterprise system, and thus this serves as a decision-making system within an enterprise.	Data-driven decision-making
			"System adaptability", "Flexibility", "Dynamics"	Conventional enterprise models are static and lack the capability to accommodate changes. Agile manufacturing can be integrated with enterprise models to increase system adaptability and flexibility.	Flexibility
			"Information islands"	The problem of the isolation of information sub-systems has been observed by many researchers. The isolation not only happens at the top level of decision-making but also happens at device or sub-system levels where raw data of machine status are collected. Within a large-scale and complex system, information islands bring delays in information communication and sharing.	Communication
			"Core components and enabling technologies"	The characteristics and necessary elements of IoT include 1) the pervasive sensing of objects; 2) the hardware and software integration; and 3) a large number of nodes.	Industry 4.0 implementation
			"Massive data"	The large-scale deployment and semantic integration of massive data is a big challenge in combining IoT efforts in Enterprise systems	Data warehousing and quality
(Dallasega et al., 2020)	"Requirement analysis for the design of smart logistics in SMEs"	Industry 4.0	"Standardization"	Specific barriers to Industry 4.0 implementation are missing standardization and frameworks.	Standardization and protocols
			"Culture and people"	A company's culture needs to be supportive of new technologies to ensure the adoption of Industry 4.0 and to avoid missing acceptance.	Culture and mindset
			"Budget"	Budget is one of the requirements regarding the successful adoption of Industry 4.0 concepts and technologies.	Budget
			"Qualified workforce"	Qualified workforces for doing research and innovation actions in the adoption of Industry 4.0 is necessary. Here, the participants stated that employees should be specifically trained in software and data collection for the successful implementation of Industry 4.0.	Knowledge and Skills
			"Lean and agility"	The usage of advanced planning techniques that allow a production on-demand and delivery just-in-time. Workshop participants mentioned the requirement to ensure flexible supply chains. Moreover, the interconnection of customers with suppliers to avoid causes of missing parts/materials and to increase the reliability of supplies.	Customization
			"Information visualized"	Information should be provided and visualized everywhere and every time to reduce waiting times and unnecessary delays. The material flow should be visualized from upstream to downstream companies. This includes the visualization of tools and parts used throughout the supply chain processes	Contextualization

			"Automated communication"	Thereby, the requirements included the automated tracking of prices, the automation of processes (e.g., the generation of bill of materials), and the automated communication between multiple systems.	Communication
			"Top management"	Top management should be aware of and support Industry 4.0 to avoid missing acceptance throughout the company.	Management and leadership
(Bauer et al., 2015)	"Transforming to a hyper-connected society and economy - towards an Industry 4.0"	Both	"Leadership"	In the future, the goal should be to make employees and teams in CPS production systems into equal or, even better, leading decision-making authorities within the production process in line with the principles of Industry 4.0 and to organize the division of labor so that better decisions can be taken. This will open up new potential for employees by giving them a greater opportunity to regulate their own work but will also require more from them in terms of their own qualifications, particularly in the field of media and social skills	Management and leadership
			"Employees"	But not only in technology many things are changing, but humans and the society also transforms, too. To achieve a positive influence on key performance indicators, organizational approaches to enterprise architecture should not be restricted to purely technical aspects but should instead put the focus firmly on employees.	Culture and mindset
			"Flexibility"	In the future, flexibility will need to be oriented toward the long term, systematically organized, and utilized in a targeted manner in order to balance out the full range of fluctuation effects that occur in volatile markets. The use of cyber-physical systems with intelligently networked objects in manufacturing will enable a new quality of flexible working in the future which will constitute tasks distributed in multiple dimensions of time, space, and content	Flexibility
			"Skilled personnel"	Businesses will have to rethink their approach if they wish to have access to a sufficient number of qualified personnel in the future. In light of demographic change and the growing demand for qualified personnel, the employment of older workers continues to be an important goal.	Knowledge and Skills
(Chehri et al., 2021)	"Theory and practice of implementing a successful enterprise IoT strategy in the Industry 4.0 era"	Both	"Innovators"	Industry 4.0 leads to a stronger existing product by developing and innovating on this, and gaining new markets. Industry 4.0 engages businesses to innovate.	Innovation and improvement
			"Business units and operational teams"	However, designing a successful IoT strategy could be very challenging for an enterprise. Unlike other software initiatives, which IT owns and controls, IoT deployments span multiple business units and operational teams.	Roles and responsibilities
			"Strategy"	Without a strategy, an organization is unable to implement Industry 4.0 technologies.	Strategy and vision
			"Willing generation"	Part of the current payroll is neither prepared nor trained for this revolution. We would have to wait for at least one new generation more willing to adopt these new technologies	Culture and mindset

			"IT and OT teams"	Some of the factors that negatively impact IoT projects include lack of collaboration among IT teams and OT teams, confusing choice of technologies, lack of interoperability with existing business applications, and lack of alignment with overall business goals. Thus: Identify the hardware and devices participating in the connected solution	Alignment IT and OT
			"Standard", "Reference"	The development of a standard, a reference for companies. A common standard and standards would allow companies to support each other better and assert their competitive superiority if they initiate 4.0 standards.	Standardization and protocols
(Nardello et al., 2017)	The Industry 4.0 Journey: Start the Learning Journey with the Reference Architecture Model Industry 4.0	Both	"Reference models"	the authors demonstrated that reference models contribute to the information disseminations sub-process. The solutions allowed sharing of autonomously and human-generated information (e.g. respectively machine errors and equipment guidelines). Reference models contributed to organizational learning by collecting relevant knowledge about a specific context (e.g. manufacturing equipment) and providing it when need it. In addition, reference models facilitated the explanation of how the production line works.	Supporting tools
			"Standard"	The goal of this project is to enable information dissemination in the organization and therefore allow the organizational learning process to progress by applying a standard framework.	Standardization and protocols
			"Organizational learning"	At its basic level, organizational learning is "the process by which new knowledge or insights are developed by a firm". In this context relevant for working with RAMI4.0	Knowledge and Skills
(Nardello et al., 2020)	Incorporating process and data heterogeneity in enterprise architecture: Extended AMA4EA in an international manufacturing company	Both	"Purpose and scope"	An architect and a stakeholder define the desired EA model's purpose, scope and concepts. They decide the desired EA model's abstraction level—business, application, or technology (Lankhorst et al., 2017). The architect then chooses the desired EA model's type—e.g. business process model, product architecture model, or strategy model	Strategy and vision
			"Structural metadata"	They locate the relevant data in the ES and identify the data's structural metadata. The architect and DSM choose from the structural metadata the fields relevant to the desired EA model. In addition, they indicate the interfaces available for extracting data from the ES	Data warehousing and quality
			"Hierarchy"	The architect selects an abstraction hierarchy aligned with the desired EA model's purpose, scope, and concepts. If no suitable abstraction hierarchies exist, the SME and architect may search for one—e.g. industrial standards. If no satisfactory abstraction hierarchies are found, they develop a new abstraction hierarchy	Roles and responsibilities
			"Create the desired EA model"	End goal is to create the desired EA model and to progress using this in the organization.	Enterprise Architecture implementation

			"Standardisation"	Benefits are that there is a certain amount of process standardization across the enterprise as well as room for production site adaptation to not neglect local advantages	Standardization and protocols
(Mofolasayo et al., 2022)	How to adapt lean practices in SMEs to support Industry 4.0 in manufacturing	Industry 4.0	"Capital"	While large corporations have access to extensive capital markets and can capture economies of scale offered by leading-edge technologies of Industry 4.0, small and medium-sized enterprises (SMEs) with greater capital restraints face the challenge of justifying Industry 4.0 technologies and cannot risk being at the bleeding edge of technology.	Budget
(E. Gökalp & Martinez, 2021)	Digital transformation capability maturity model enabling the assessment of industrial manufacturers	Both	"Alignment IT strategy with DX strategy"	An IT strategy should be developed that is aligned with the organization's DX strategy for migration to the desired future environment.	Alignment IT and business
			"development, integration and maintenance of standardized EA"	The IT requirements for each DX project should be defined: the development, integration, and maintenance of a standardized enterprise architecture (EA), including hardware, software, data, and business process layers	Enterprise Architecture implementation
			"Collecting, storing, analyzing distributing data"	collecting, storing, analyzing, and distributing data; management of data analytics is fundamental for the digital transformation journey of organizations in EA.	Data warehousing and quality
			"Agile principles"	development of applications based on agile software development principles is fundamental for the digital transformation journey of organizations in EA	Flexibility
			"IT security management"	IT security management is fundamental for the digital transformation journey of organizations in EA	Security
(Goerzig & Bauernhansl, 2018)	Enterprise architectures for the digital transformation in small and medium-sized enterprises	Both	"Agile methods"	Another point of criticism is that EA offers an extensive and inflexible way of planning. But currently, agile methods change the way software is planned and developed.	Flexibility
(Nowakowski & Breu, 2018)	Enterprise Architecture planning for Industry 4.0	Both	"Business IT and OT"	An identified challenge is the communication between the business IT and the operational technology (OT) departments	Alignment IT and OT
			"Standardized process"	Additionally, we were able to observe the need for a standardized EA planning process for I4.0 transformations. This was also observed for the general task of EA planning. Here, most of the interviewees reported that they were struggling with the planning of their companies' EA.	Standardization and protocols
			"Tool support"	Hence, we learned that there exists neither a standardized EA planning process nor sufficient tool support to guide companies in their planning endeavors	Supporting tools
			Togaf implementation	we propose a planning process that will be implemented in the form of a TOGAF Architecture Development Method (ADM) extension. TOGAF ADM is the core of TOGAF and describes a method for developing and managing the lifecycle of an EA	Enterprise Architecture implementation

(Nowakowski, Farwick, et al., 2018)	Enterprise Architecture Planning in the Context of Industry 4.0 Transformations	Both	"Communication IT/OT, Production machines and applications similarity"	Core problem found in this study relating to the combination of Industry 4.0 and Enterprise Architecture	Alignment IT and OT
			"Interfaces and connections need for better visualizations"	Core problem found in this study relating to the combination of Industry 4.0 and Enterprise Architecture	Contextualization
			"Data needs to be up to date"	Core problem found in this study relating to the combination of Industry 4.0 and Enterprise Architecture	Data warehousing and quality
(Heiland, Hillmann, & Karcher, 2021)	Enterprise Architecture Model Transformation Engine	Both	"business it-alignment"	This enables the integration of services within the movement of Industry 4.0 in order to improve the quality and performance of the processes. Enterprise architecture models form the basis for this with a better business-IT alignment.	Alignment IT and business
			"Heterogeneity of languages and frameworks"	Conclusion of paper: Model transformation is a complex challenge due to the heterogeneity of languages and frameworks.	Standardization and protocols
(Piest, 2019)	A platform architecture for Industry 4.0 driven intelligence amplification in logistics	Both	"Strategic dimension"	Paper proposes four dimensions of architecture important to incorporate Industry 4.0: strategic dimension (who), active actor dimension (who), operation dimension (how) and object dimension (what)	Strategy and vision
			"Active actor dimension"		Roles and responsibilities
			"Operation dimension"		Alignment IT and OT
			"Object dimension"		Industry 4.0 implementation
			"Software tool support"	And these are accompanied by support tools	Supporting tools
			"Supporting criteria"	And these are accompanied by supporting criteria	Support processes
(Kornyshova & Barrios, 2019)	Industry 4.0 Impact Propagation on Enterprise Architecture Models	Both	"Addition on TOGAF"	Purpose of the paper is to design supporting tools for EA implementation in the field of Industry 4.0	Supporting tools
(Baptista & Barata, 2021)	Piloting Industry 4.0 in SMEs with RAMI4.0: an enterprise architecture approach	Both	"integration and communication"	The ongoing industrial revolution expands the company borders to allow horizontal, vertical, and end-to-end digital integration.	Communication
			"Support functions"	Additionally, there is a lack of expert support functions in SMEs. For example, financial management, IT, and supply chain management. The introduction of new technologies is always risky in SMEs, and some challenges concerning standards, business tools, security, and investment may exist	Support processes

			"Social"	Also the social aspect is important in piloting Industry 4.0 in an EA context	Culture and mindset
(Kempegowda & Chaczko, 2019)	Industry 4.0 complemented with EA approach: A proposal for digital transformation success	Both	"Cloud"	Enabled Organizations to rapidly provision infrastructure, enabled sufficient computing power to the business, that too based on the need basis. Infrastructure procurement and provisioning consideration are across the organization.	Cloud
			"Standards"	As Industry 4.0 is a digital ecosystem open standards are critical to its success. Following the EA approach, the standards are enforced across the core architecture of business, application, data, security, technology, and cross-cutting integration	Standardization and protocols
(Leyh et al., 2017)	SIMMI 4.0 – a maturity model for classifying the enterprise-wide IT and software landscape focusing on Industry	Industry 4.0	"Vertical integration"	This dimension focuses on the components of the lowest level of an enterprise, where different physical things ((semi-) products, machines, etc.) need to exchange information throughout the level itself and with the levels above. The most important criterion here is that this exchange is possible in both directions.	Data acquisition
			Horizontal integration	Industry 4.0 requires horizontal integration across the different value networks. Accordingly, an essential criterion has emerged from the requirements above. An automated and integrated information flow is necessary along the horizontal enterprise level as well as beyond the enterprise borders. Without this information flow, a business-wide value network is not realizable, meaning that the various enterprise systems of the different partners in the value networks require interoperability at the data level. Therefore, a continuous and consistent information flow is needed,	Communication
			Digital product development	Dimension – Digital product development: For the engineering's digital continuity it is especially important that each process step is represented digitally. For this purpose, at least one enterprise system should be integrated into each respective process step. In addition, the resulting data and information of each step must be forwarded to the next and previous step/enterprise system.	Innovation and improvement
			Technology criteria	This dimension focuses on assessing the extent to which technologies are used across all different fields of Industry 4.0. Based	Industry 4.0 implementation
(Dennis et al., 2017)	Asset Performance Management Maturity Model	Industry 4.0	Governance and standards	Governance in asset management deal with clear policies and guidelines to manage assets throughout their lifecycle from commissioning to retirement. With stricter regulations, an organization requires stringent governance structures. Governance does not deal with asset management per se, but it deals with the principles upon which asset management is executed. The maturity model approach will help determine whether or not proper governance mechanisms are in place for asset management.	Standardization and protocols
					Roles and responsibilities

			People and culture management	Asset performance are highly dependent on the skills of those working with assets and established processes. There is a strong need to manage the training, development, and work force in an asset-based organization. Not focusing on these elements can create a barrier to implementing any asset performance management initiative.	Culture and mindset Knowledge and skills Management and leadership
			Tools and technologies	Leveraging the right set of tools and technologies for asset management can significantly transform and optimize asset operations. However, organizations operating in silos will fail to extract the full benefits. The extent to which appropriate tools and technology are used in the organization will determine the maturity level. An organization at level 4 of the maturity curve will utilize technologies like augmented reality/virtual reality for training, big data for asset information management, drones for monitoring, and 3D printing for spare parts replenishment.	Supporting tools Industry 4.0 implementation
			Process management	It is necessary for organizations to develop and maintain standard management processes and guidelines to support their asset management systems.	Support processes
			Asset information management	For an organization to have effective asset performance management, they need to have accurate information regarding the assets on the plant floor. Lack of availability and access to information about the assets on the plant floor will impair the organization's ability to make the right decisions. The Asset Information Management dimension will indicate how effectively the organization manages its asset information. the information being assessed will also include asset strategy, financials, and information systems.	Data warehousing and quality
(Schumacher et al., 2016)	A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises	Industry 4.0	Strategy	Implementation I40 roadmap, Available resources for realization, Adaption of business models, ...	Strategy and vision
			Leadership	Willingness of leaders, Management competences and methods, Existence of central coordination for I40, ...	Management and leadership
			Customers	Utilization of customer data, Digitalization of sales/services, Costumer's Digital media competence, ...	Customization
			Operations	Decentralization of processes, Modelling, and simulation, Interdisciplinary, interdepartmental collaboration, ...	Communication
			Culture	Knowledge sharing, Open-innovation, and cross-company collaboration, Value of ICT in the company, ...	Culture and mindset

			People	ICT competences of employees, the openness of employees to new technology, the autonomy of employees, ...	Knowledge and skills
			Governance	Labour regulations for I40, Suitability of technological standards, Protection of intellectual property, ...	Roles and responsibilities
			Technology	Existence of modern ICT, Utilization of mobile devices, Utilization of machine-to-machine communication, ...	Industry 4.0 implementation
(Weber, Königsberger, Kassner, & Mitschang, 2017)	M2DDM (Maturity Model for Data-Driven Manufacturing) from	Industry 4.0	Data storage and acquisition	In order to derive knowledge from data, these data have to be collected and analyzed. Therefore companies retrofit legacy assets with computing, storage, and connectivity capabilities	Data warehousing and quality
					Data acquisition
			Digital twin, service orientation, data integration	Paper is very much focused on the technical side of implementing Industry 4.0 tech	I4.0 technologies
			Data-driven	Focus of paper is on data-driven manufacturing	Data-driven decision-making
(E. Gökalp et al., 2017)	Development of an Assessment Model for Industry 4.0: Industry 4.0-MM	Industry 4.0	Organizational alignment	It refers to the management of enterprises through Enterprise Architecture in terms of organizational structure, and strategy of the business. From the managerial point of view, the knowledge about the advantages of the smart manufacturing concept significantly affects the decision of IT investment and implementation	Alignment IT and business
			Process transformation	This aspect covers the transformation of the basic processes of each enterprise system which are Planning, Acquisition, Production, and Sale & Distribution. According to the business structure of the enterprise, once the transformation to Industry 4.0 begins, each process of the enterprise system should be mapped to the digital world. Furthermore, different value-added processes should be integrated across the enterprise architecture in a standardized manner	Process change management
			Data governance	This aspect investigates the capability level of the following: data collection, usage, data analytics and big data tools, and data-driven services. Gathering and complete assessment of data from various sources, including manufacturing infrastructure and systems as well as information systems, enable organizations to make real-time decisions regarding current or future operations	Data acquisition
					Data-driven decision-making

			Application management	With Industry 4.0, it is expected that revolutionary applications will come about principally as a result of combining applications with manufacturing and automation technologies. It is aimed to ensure an optimal and secure design and construction of information systems that best work for its business and users. Application capabilities provide an abstract perspective on the functional behavior required to support the business. Interfaces and information flow of applications should be structured, connected, standardized, controlled, and interoperable	Control
			Asset management	It covers IT systems of the organization, and technological readiness for Industry 4.0, usage of emerging business technologies like Cloud Computing based enterprise solutions, and security issues of smart technologies	Cloud Security
(Pessl et al., 2020)	Roadmap Industry 4.0 - implementation guideline for enterprises	Industry 4.0	Flexible working models	The possibility of real-time control of fully digitalized companies and the associated new areas of competence also require flexible organizational structures	Flexibility
			Information to employees	clear internal information through formal and informal contextualization is a key success factor	Contextualization
			Competences	Professional and learning competences are crucial for Industry 4.0	Knowledge and skills
			Acceptance of tech	Acceptance of new technologies and media is often difficult for organizations.	Culture and mindset
			Strategy	A corporate strategy for the entire Industry 4.0 implementation is required within this roadmap.	Strategy and vision
			Change management	The named organizational changes must go hand in hand with the entire change process. Unlike the anchoring of I4.0 in the company strategy, it is not possible to convert this without the appropriate adaptation of the working processes. Nevertheless, it is important to make the necessary preparations for the adaptation	Process change management
(Reinhard et al., 2016)	Industry 4.0: Building the digital enterprise, Global Industry 4.0 survey,	Industry 4.0	Security	With so much change in store, there's one area that companies can't afford to ignore: digital trust. Digital ecosystems can only function efficiently if all parties involved can trust in the security of their data and communication, as well as the protection of their intellectual property. Protecting your company and ensuring digital trust requires significant investment and clear guidelines for data integrity and security.	Security
			Capital and costs	Within the next five years, advanced implementation of Industry 4.0 will become a 'qualifier to compete' and is also likely to be seen by investors as a 'qualifier for funding'. Companies that have not kept up will not only find themselves struggling to maintain market share but are also likely to face higher capital funding costs.	Budget

			People	Develop strategies for attracting people with the right digital skills. Your success with Industry 4.0 will depend on your skills and knowledge. Your biggest constraints may well be your ability to recruit new employees or rain existing ones who can put digitization into place. You need to introduce new roles in your company, like data scientists, user interface designers, or digital innovation managers. And you'll probably need to update existing job profiles to take into account new digital skills.	Employees
			Agile IT architecture	Single data lake with external data integration functionalities and flexible organization. Partner service bus, secure data exchange	Flexibility
			Data & analytics	Central use of predictive analytics for real-time optimization and automated event handling with intelligent database and self-learning algorithm enabling impact analysis and decision support	Data warehousing and quality
			Horizontal and vertical integration	Fully digitized, integrated partner ecosystem with self-optimized, virtualized processes, focus on core competency; decentralized autonomy. Near real-time access to an extended set of operative information	Communication
(van Steenbergen et al., 2010)	The Dynamic Architecture Maturity Matrix: Instrument Analysis and Refinement	Enterprise Architecture	Development of architecture	The approach to architecture development, varying from isolated, autonomous projects to an interactive process of continuous facilitation.	Innovation and improvement
			Use of architecture	The way architecture is used: merely as a conduit for information, as a means of governing individual projects, or even as a tool for managing the entire organization.	Enterprise Architecture implementation
			Alignment with business	The extent to which the architectural processes and deliverables are in tune with what the business wants and is capable of	Alignment IT and business
			Alignment with Operations	The extent to which architecture is both used in and built on the operations and maintenance discipline.	Alignment IT and OT
			Roles and responsibilities	The distribution of responsibilities concerning both architecture processes and deliverables within the organization.	Roles and responsibilities
			Relationship to as-is	The extent to which the existing situation is taken into account by the architecture processes and deliverables.	Strategy and vision
			Coordination of developments	The extent to which architecture is used as a steering instrument to developments coordinate the content of the many developments that usually take place concurrently.	Communication
			Budget	The extent to which architectural activities are budgeted and planned	Budget
			Monitoring	The extent to which and the manner in which compliance of projects with the architecture is guaranteed	Control
			Architectural tools	The extent to which architects are supported by tools	Supporting tools
			Commitment and motivation	The extent to which commitment is attained from and shown by the motivation organization.	Culture and mindset
			Architectural training	The support of the architectural roles and the extent to which architects can educate themselves.	Knowledge and Skills

(MIT, 2014)	MIT Enterprise Architecture Guide	Enterprise Architecture	Security Services	Applications should ensure data and access security	Security
			Standards	Promoting consistency using standards is a key principle of EA	Standardization and protocols
			Data warehousing	Data warehousing is crucial for Enterprise Architecture, both in data storage and integration between different elements	Data warehousing and quality
			Alignment with operations	Alignment of IT systems with operation technology is a key goal of using the technologies mentioned in the paper	Alignment IT and OT
			Tooling	Main purpose of the guide is to help companies with what tooling to use in what situations	Supporting tools
			Metadata-driven	This guide is focused very much on the technical aspect of EA, including data and tooling and how to use data in your organization	Data-driven decision-making
(Proença & Borbinha, 2017)	MM based on TOGAF ADM	Enterprise Architecture	Communication and common language	Paper identifies these CSFs, critical success factors, for Enterprise Architecture. The explanation can be found in this paper. Factors are explained in a textual fashion as opposed to a list structure. Therefore not directly quoted here.	Communication
			Business-driven approach		Alignment IT and business
			Commitment and motivation		Management and leadership
			Development Methodology		Flexibility
			Tool support		Supporting tools
			EA Models and governance		Enterprise Architecture implementation
			Project and program management		Process change management
			Assessment and evaluation		Control
			Investment and acquisition		Budget
			Skilled team, training and education		Knowledge and Skills
			Organizational culture		Culture and mindset

(Bittler & Kreizman, 2007)	Gartner Enterprise Architecture	Enterprise Architecture	Economic climate	Every enterprise operates in the context of dynamic internal and external environmental conditions that will affect the enterprise's future state. Trends in these environmental conditions clearly influence business strategy, ensuring EAs, and resultant development, procurement, and operations. Environmental trends are often implied or are included tacitly with business strategy. However, these trends should be called out explicitly	Budget
			Customer demand		Customization
			Regulations		Regulations and other legalities
			People		Employees
			Technology		Enterprise Architecture implementation
			Context	When intention and action are not congruent, an "integrity gap" is formed, which generates a business context vacuum. The resulting "chaos" has a profound impact on the risk/reward behavior of employees, inhibits effective decision making, and erodes confidence and loyalty. If an enterprise is to be successfully bridging the business context vacuum referenced above, then a mechanism must be deployed to articulate the impact of strategy on the enterprise. We assert that this mechanism is EA.	Contextualization
(Ikegwu, Nweke, Anikwe, Alo, & Okonkwo, 2022)	Big data analytics for data-driven industry: a review of data sources, tools, challenges, solutions, and research directions	Industry 4.0	Data-driven manufacturing	Comprehensive review and systematic data-driven analysis, comparison, and rigorous evaluation of methods, data sources, applications, major challenges, and appropriate solutions	Data-driven decision-making
(Bousdekis et al., 2019)	Enterprise Integration and Interoperability for Big Data-Driven Processes in the Frame of Industry 4.0	Both	Integration and interoperability	The architecture shall support physical, application, and business integration. The architecture shall support technical, semantic, and organizational interoperability	Communication
			Sensor data acquisition	The acquired data feed into the stream processing functionalities, i.e., Descriptive, Predictive, and Prescriptive Analytics, which implement various data fusion, (deep) machine learning, and optimization algorithms, which are configurable according to the specific use case requirements and complexity.	Data acquisition
			Data-driven	requirements guide the design of the proposed architectural framework for enterprise integration and interoperability for big data-driven processes in the frame of Industry 4.0.	Data-driven decision-making

			Customer's demand	In this way, not only the decisions about the rolling replacement were taken dynamically, but also it adopted imperfect maintenance actions (e.g., lower the speed of the mill, increasing the soap oil to eliminate friction, optimal utilization of repaired rolls, etc.) that extend the lifetime of the equipment when downtime is not acceptable (e.g. when customers' demands need to be met).	Customization
(Sjödin, Parida, Leksell, & Petrovic, 2018)	A Maturity Model for Business Model Management in Industry 4.0	Industry 4.0	Continuous smart factory innovation	Create a culture of continuous smart factory innovation	Innovation and improvement
			Specialized roles and responsibilities	Create specialized roles and responsibilities geared toward predictable production.	Roles and responsibilities
			Educate	Educate people to develop the ability to exploit connected data systems. Revise production staff roles to proactively coordinate digital insights and knowledge sharing.	Knowledge and skills
			Culture	Create an inclusive culture for implementation by involving the workforce in vision development.	Culture and mindset
			Connect existing tech	Connect existing technological applications to create data flow.	Alignment IT and OT
			Data collection	Increase accuracy of data collection from technology. Create automated processes for data mining and sharing across functions.	Data acquisition
			Implement systems for ...	Create systems to monitor and visualize critical operational analytics. Integrate digital system insights from external partners to enable supply chain predictability. Implement systems for real-time performance analysis. Implement simulation systems to test, prototype, and optimize the digital factory.	Industry 4.0 implementation
			Visualization	Develop processes for integrating data visualization into decision-making. Create proactive processes for forecasting and planning future production.	Contextualization
			Data interpretation	Use insight analysis and data interpretation to streamline operational processes. Create processes for evaluating optimization opportunities.	Data-driven decision-making
			Agile processes	Introduce Agile processes to leverage rapid technological development. The traditional Stage-Gate model and similar techniques for developing and implementing process innovations cannot keep up with the pace of technological change. Agile implementation processes, incorporated into formal work approaches, provide autonomy and Flexibility in smart factory implementation	Flexibility

Table 17: Systematic literature review details per paper

C Interview 1 structure

Introduction
A short personal introduction to get to know the interviewee commences. Information about the company and the participant's specific role in the company is noted.

Introductory questions
First, the interviewee is asked whether the meeting can be recorded for note-taking purposes and if the interviewee consents to the data of the interview being used anonymously in the final report.

"To facilitate the note-taking, we would like to ask your consent to record our conversations today. This recording will be used to fill gaps in the interview notes, is only accessible to the researcher, and will subsequently be immediately removed.
Next to this, we would like to use the data from this interview, anonymously, in the final report. Do you give your consent for this?
This interview is planned to last one hour, during which we will have several questions that we would like to cover."

Next, interviewees are asked about their familiarity with Industry 4.0, Enterprise Architecture, and Maturity Models on a Likert-scale, as used by (Mukherjee et al., 1998). When necessary, additional information is provided.

"How familiar are you with the concepts of Industry 4.0, Enterprise Architecture, and Maturity Models? For this please indicate on the following Likert scales how familiar you are with each of these concepts. The scales range from 1 (strongly disagree) to 5 (strongly agree).

- *I am familiar with the concept of Industry 4.0*
- *I am familiar with the concept of Enterprise Architecture*
- *I am familiar with the concept of Maturity Models*

1: strongly disagree, 2: disagree, 3: neutral, 4: agree, 5: strongly agree"

Key questions
First, the interviewer explains how the interview will proceed, and how the interviewee is expected to validate the domain content and domain dependencies.

"Research hints that for a good implementation of Industry 4.0, it might be very convenient to combine this with Enterprise Architecture efforts. Industry 4.0 does not only affect technological aspects but also the surrounding IT infrastructure and subsequently the whole business and its employees. What is missing in research is some kind of growth or maturity model that can guide companies in when to take which steps or actions. So, what we will create is a maturity model for

Industry 4.0 in combination with Enterprise Architecture.

We will specifically be creating a so-called focus area-oriented maturity model, which defines a set of separate focus areas to reach certain maturity levels. This image shows this, where you can see that some areas are relevant in time-step 1, but some areas become relevant later when the areas in step 1 have been completed. By making the model in this way, we can help companies in showing what actions they have to take next to improve.

To validate the model, we will walk through the 20 focus areas that we have deducted from the literature, and for each focus area, I will ask you first if you feel this area should remain in the model, be changed, or be removed, based on the definition. If you feel it should be changed or removed, please provide the rationale for your decision.

Hereafter, I will also ask you to score each focus area on when it needs to be achieved to reach a certain level of maturity, in comparison to the other focus areas. Imagine you as a company trying to improve your maturity in this domain. When you do decide this, which of these areas will you begin with directing attention at? Then some areas will require attention after the initial areas. And finally, some areas require attention last. For each area, please provide your rationale on when that area requires attention, by explaining if it is either one of the first steps, something that comes after the first steps, or something that can only be done if the other steps are to some extent completed. I understand this feels quite abstract, but the main goal of this is to learn from your experience which areas should be taken care of before we can continue with different areas. To give an example of this, think of the following: if you as a company want to be mature and developed in data-driven decision-making, you first need to make sure that your data quality is good, that you measure what you think you measure, etc.

So, we first inquire about if you feel we have here the complete relevant set of areas, or that something is missing, and then roughly the order in which these areas require attention."

Then, for each focus area and corresponding definition, the following two questions are asked.

"Should this focus area remain in this maturity model, or should it be changed or removed?"

"Is this focus area initially relevant, intermediately relevant, or relevant in later stages, and why?"

Final questions

Finally, the completeness of the set of focus areas is checked, by asking if the interviewee feels all relevant areas are covered. This is asked after every main domain (organization, people, processes, and technology), as well as at the end.

After every domain: *"Do you feel these X focus areas cover all relevant elements for this domain?"*

At the end: *"Do you feel this set of focus areas covers the entire relevant spectrum for Industry 4.0 and Enterprise Architecture?"*

And finally, there is room for final remarks and/or comments.

"Do you have any final remarks or comments on the current set of focus areas, or related to this?"

Since most interviewees are speaking Dutch, this same information is summarized in Dutch in an excel file which will guide the interviewer during the interview. This excel file is also used during the interview to note the interviewee's responses.

D Interview 1 results

Detailed results per participant

Participant	A	B	C	D	E	F
Organization missing	Missing: organizational maturity, what is a technological advancement a company can even process.	-	Missing; how do I fill in my organization, do we have an innovation lab or something? Do we have an 'enabler'	-	-	You need to add something about 'where do you want to go as a company
People missing	Missing; forming and maintaining teams. Trust in each other is really important	-	-	-	-	-
Process missing	-	-	-	Missing; time-scale, project management	-	-
Technology missing	Missing; what tech do we have, what are new innovations, continuous lookout, external referencing, technology scouting.	-	-	Missing; assessment what you want	-	-
Overall missing	-	Security is an important topic to consider, not necessarily as a separate focus area, but definitely as a step to reach a certain level of maturity for some of the focus areas	-	-	-	Something to add might be 'industry best practices', which can help companies start quicker. You don't need to reinvent the wheel yourself.
Final remarks	Remarks; you need to combine tech that you already have because full-on new tech is often difficult and expensive. Combinations of already existing components can lead to new insights	-	-	Remark; tools often are unable to link together. Remark; for companies, it is often the question "what maturity do we even want", maybe you are content at some levels already. Remark; ambition dictates the level of maturity you want.	-	Make sure the model is understandable and more concrete.
Strategy and vision	I4.0 needs to be part of strategy	Important to distinguish where to go	Watch out the distinction between vision and strategy	-	-	Always necessary to have this clear

Alignment IT and business	Bus goal is what you want to achieve, IT should support this	IT is supporting	IT at the same table as management	Define clearly what IT is in this context	-	Has to happen, always need to keep business in mind
Budget	It's not about the money but about the integrity of the decision making	-	-	-	-	You need to convince the business that EA and i4.0 are necessary
Contextualization	How do we go from a corporate strategy to an executable plan	Good to include	Looks a bit like organizational change management	Very difficult	Full Product data management is end goal	Less relevant for lower levels
Integration and communication	Risk for complex projects	-	Stimulate from the beginning but must grow	Every layer makes this more difficult	Newsletters, status updates	Make sure you hit working level
Enterprise Architecture implementation	EA = enabling	-	Kind of want to use this for communication purposes	Definition can go either way	-	Step 1: Think about what type/kind of architecture you want
Knowledge and skills	Check feasibility of skills for every new project	-	Need people to pull the cart	Training is important	Train high-level people to explain this stuff	You need knowledge and skills but not everyone needs to know exactly what is going on
Culture and mindset	You need different ways to change the perspective of people	-	Show from the beginning what your intentions are	Influenced by personality types	You can choose to deliberately hire young people	One of the most important things, make sure people are involved
Management and leadership	Management needs to have ownership over the change, pull the cart	-	Start first, control and monitoring comes later	Becomes important later	People that pull the cart	Management always first, make sure they will lead and press this issue/innovation
Roles and responsibilities	Result of process redesign	Raci model possibly	Very important to have this down	-	Check what tasks can go to existing roles	You need ownership, you need governance
Innovation and improvement	Process change needs to happen in the entire architecture	PLM	Needs better definition	-	-	This is what your entire thing is about. Isn't this a final level of maturity for other areas?
Standardization and protocols	Standards are good but leave room for own core process	Nobody is special	Very important	One of the biggest challenges, cultural sensitivities	As much as possible	-
Data-driven decision-making	Must be based on KPIs	More of a result	-	You need reports for this so this comes later	More of an end goal than a focus area on its own	Differs a lot per company
Flexibility and customization	This is something you want indeed, how to get there? Put that in MM	-	Bit of a culture thing	Depends on company goals and needs	Very dependent on the company which gives them orders	Very difficult, you need to build your organization like this. Similarly with innovation, isn't this a final level of maturity?

Process change management	Clearly necessary	You do need other stuff to do this	-	There are different types of change management	Start with immediately	-
Data warehousing and quality	Very important, architectural requirement	Database must be good for I4.0	Assessment is required	Depends on how many people will use it	Not necessarily necessary to start	Remove legacy, single source of truth, and data correctness. Very hard though
Alignment IT and OT	-	Opex is goal	Important	Time scale and interfaces	-	Differs per company but is very relevant
Data acquisition	Always important	Might want to add a focus area broader than this concerned with the security and governance of data	Grows with maturity	You need to assess how much to automize and how much to do by hand	-	Starting with a focus on sensors is difficult, you need to start somewhere to see what happens also
Industry 4.0 Implementation	Always check if what we are doing now is optimal, or if innovation is required	-	Need foundation for this	-	-	Everything needs to be fixed to do this
Supporting tools	Evolve tooling over time	Part on other requirements	Always relevant	-	You need a lot of stuff to be covered before you can start with these technical implementations	Important for high level but for lower level not so relevant

Participant	G	H	I	J	K	L
Organization missing	-	-	Outward looking view, external view	Think about new business models, portfolio management, new customers	You need to add some form of assessment, where are we now. Also for IT. Also for culture. Assessment could be a separate part but better to have it under maturity steps. Think about if you want to add some form of 'control'. Also, think about 'change management' definitions.	Think about adding 'result' like features, do you make money from this? KPI's, etc.
People missing	-	-	-	Think about how you include change management	-	It's important to add a 'what's in it for me' for employees regarding digital transformation
Process missing	-	-	Maintenance is very important in IT, when a change happens, do we then know which other technological aspects are affected by this?	Proces model, process architecture needs to be added	Think about techniques surrounding these digital transformations, like kanban, agile, lean, etc.	You need to do yearly revisions on what you want/strive for. Focus, make sure you keep working on the project also after the initial hype. Stick to the plan.
Technology missing	Do you have the required means (technical), do you have an infrastructure to couple factories? Might be a maturity step within supporting tools. The minimal requirements to do all of this (assessment)	In tech think about more general topics like 'tech adoption'	Think about the link between production processes and control	Think about including 'interfacing'	-	Think about control/-management on a functional and application level.

Overall missing	Assessment of where you are as an organization. How do IT and business relate, do you know what is really happening? Insight is important. Maybe the first step of maturity should be 'insight into where are you right now'. (assessment)	Think about more high-level aspects, things that a company would want to achieve like sustainability or servitization. Some things in the model right now are more means than goals, like supporting tools or budget. Those are not things you want to achieve maturity in.	What is the added value, that is missing in the model (even though it's difficult)? Sensing technology needs to be added, possibly step under data acquisition or under i4.0 technology.	Think about where we mention EA, since it's clear in 'organization', but less so in the other 3 overarching domains	-	Contextualization and 'budget'/finance need sharper definitions
Final remarks	-	Think well about the granularity of focus areas	IT yourself or external?	-	-	-
Strategy and vision	Necessary	Goal must be clear	The 'why'	Full strategy not necessary in step 1	Repeat vision/strategy loop	You need initial plan, but entire company vision comes later
Alignment IT and business	-	-	Often forgotten	-	Check back with vision	Often mising
Budget	Why something is important should already be in strategy	-	ROI	EA and I4.0 is very expensive	Budget definition can be more broad	Budget needs to be available
Contextualization	Make sure you include employees	-	Initial situation	You need this to get commitment	Specify what I4.0 means for the company	-
Integration and communication	Isn't this change management, vague term	-	Initial situation	horizontal integration is important	Different from contextualization?	Think about external relations with customers or suppliers
Enterprise Architecture implementation	You need overview!	Logical	To what extent do you want EA?	-	More mature you are, the later this is updated	First steps can come quite fast, but the entire organization takes time. You don't need to wait with this, start with the initial plan and initial setup, and slowly build and incorporate the entire enterprise.
Knowledge and skills	impact analysis, what is required?	Add 'digital literacy'	Have skills or train	You need a base level of knowledge	You need to actively work on this, technical knowledge is often lacking	-
Culture and mindset	Do we even want this? Assessment	Very difficult	Unions	Through contextualization	Top-down	Intern versus commerce

Management and leadership	Top down, first step of everything	-	Guidance	Ownership	You need visible person who pulls the cart	These people push cart so more important than culture
Roles and responsibilities	Think about what roles are necessary	-	You need knowledge to do this	Some form of raci	-	-
Innovation and improvement	Important	-	Granularity	-	-	-
Standardization and protocols	very important	-	Starting with wrong standards is detrimental	add 'best practices'	Even though this is important to compare things, you should not overly standardize and lose your core business	Continuously check
Data-driven decision-making	One of the last things	-	Without data this is impossible	Need data for this	Start small	-
Flexibility and customization	Keep in mind what you actually want to achieve, do you want this, should you want this?	-	-	Very dependent on what your enterprise wants	Start with 1 area or project	Relevant for everybody
Process change management	Make sure its clear that this is not about people	-	Standard process required	-	Add way to check if previously introduced tech actually made money/was positively evaluated	-
Data warehousing and quality	-	-	-	-	-	Assess first
Alignment IT and OT	-	-	You need to know what applications make use of other applications	Assess if your tech is even capable of doing this	Assessment required	Assessment required
Data acquisition	-	Granularity	-	-	Define what you are measuring and how you will use it. Definitions.	Assessment required
Industry 4.0 Implementation	Depends on what you want as well	-	-	Think about 'capabilities to perform i4.0'	-	Assessment required
Supporting tools	-	-	Is this its own focus area?	-	Check tools for this and add under 'best practices'	Useless if done before alignment

Participant	M	N	O	P	Q	R
Organization missing	-	-	Roles, is under people tab	Name 'strategic objectives' under strategy and vision. Also, think about 'partnerships' under strategy and vision (but also at knowledge and skills)	-	Clearly mention structure
People missing	-	-	-	Call roles and responsibilities governance. Management & leadership should be a separate area, right now looks too much like strategy and vision.	Why not also use HRM data? Money streams, check-in data, contracts, and also for knowledge and skills. Why not also use this in I4.0?	Name incentives at management and leadership. There needs to be an incentive for i4.0 to work. Can be traditional incentives like money, but also status, promotion, etc. Incentives need to be explicit, otherwise, they will not work. If every incentive in the company is short-term, nobody will care about innovation. Incentives must fit with the goal you are trying to reach.
Process missing	-	-	-	-	-	Mention validation of solutions. A lot of creative brilliant ideas, but does it really tackle the problem? Post-implementation reviews
Technology missing	-	-	Security is missing and is really important, needs to be added	You do stuff like this in projects, not the entire organization at once. So think about incorporating this.	Sensor to data (kepware) often does not go well. There are suppliers for this. So we should add; how do we go from sensor to data, you need software for this.	-

Overall missing	-	-	Procurement maybe? Place under budget. Regulations? Place under standards. Version control? Think about this. Validation/quality, think about this.	Think about assessing business capabilities.	-	Validation, incentives (can also be that they can join in a participation council where they can jointly think about purpose)
Final remarks	Dya and its assessment are currently way too long. To make a more comprehensive model is required. The assessment is 160 questions, which is too much.	Gladly mail for second interview	-	Tip: fill in the maturity model for a dummy case (2nd round of interviews)	This is very useful, RAMI is way too difficult for SME	-
Strategy and vision	Think clearly of difference between strategy, vision, mission	-	-	Complete strategy not required in step 1	Business should be driving force	-
Alignment IT and business	What is maturity here?	-	-	Must be driven by business capabilities	Difficult in brown state	Build IT based on strategy
Budget	-	-	Depends on available budget	First always think of 'what' you want to do	Think about 'invisible' money like licensing and software	Is an enabler which makes a frame in which the project should fit
Contextualization	-	-	Maybe not the entire shopfloor needs to understand everything in great detail	-	Involve stakeholders, but not too early	-
Integration and communication	-	Cannot happen without strategy	More on corporate level than shopfloor	You need something to communicate	-	-
Enterprise Architecture implementation	Might also be part of alignment	-	This is required otherwise your company cannot function well	You need to know what you want from EA	What people need for digital transformation	-
Knowledge and skills	Might also be part of the alignment	Assessment required, continual process	Immediate training for everyone is stupid	Always get external knowledge first, and see what you have in-house. Later steps, think about partnerships external	Differences between people that make them, and that need to work with it	without culture this will not work

Culture and mindset	Mature management means enablement, clear vision, and leadership. Monitoring and control are more classical forms of leadership. Also affected by culture.	Must grow slowly	-	-	Old people really is a thing, experience vs IT affinity	-
Management and leadership	Leave room for creativity	Guide people from strategy	-	Ownership and inclusion	Experts need to pull the cart, and management should be involved. Make sure people see the advantage of digital transformation	If management is not on board and leadership does nothing it will not work
Roles and responsibilities	-	-	-	-	First step, know who does what. Second maturity step, who does control, definitions, etc	Everyone needs to be on board before you can do this
Innovation and improvement	-	Starts on a project basis!	-	-	R&D	-
Standardization and protocols	Important	Within vision you can decide to use RAMI, but for specifying their processes and organization knowledge is required	very important	Assessment first, what do we want?	You need this but not too fast or you lose creative process	-
Data-driven decision-making	Think about granularity	-	-	-	This needs a lot of time	-
Flexibility and customization	Learn from changes	-	Customization is not a goal of every organization	How flexible should your company want to be?	Very late	-
Process change management	-	Assessment required	very important	Essential	-	Very important for the implementation process. What do I need to take care of to make sure this change works? This assumes certain standards.
Data warehousing and quality	Possibly combine with acquisition	-	Required	-	Warehousing is a later step within this. Think about safety and about process vs product quality. Maybe add data governance as well	You can only do this when you know what you want to measure

Alignment IT and OT	-	-	Falls together quite a bit with the other alignment point	Because alignment IT OT should be in the use case	-	-
Data acquisition	Possibly combine with quality	-	-	First think of what we want, then think of this point	Gather as much as you can, no boundaries, get what you can get.	-
Industry 4.0 Implementation	-	-	I4.0 should not be a goal in itself	-	This is simpler in a new factory than within an existing organization. Start small, find people that want to work towards this and like this, and then things will start. Then also a link with management and stakeholders. You kind of need to start with something. Start small, things will grow.	-
Supporting tools	-	-	-	Very basic tooling can go a long way	Is this MES and/or PLM? Also, think about document control. Assess what systems you have, and put them into your EA. Software is always growing, so check what you can do with already existing software. It will always cost money, so make sure it does not sprawl uncontrollably.	-

Table 18: Interview 1 comments per participant

E Development Model V2

Initial dependencies results

This paragraph gives an overview of the derived dependencies results from the first round of interviews. Table 19 below shows for each focus area the numerical results for each participant, including the resulting average per focus area.

Focus areas	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Mean	SD	Round
Strategy	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	2	1,18	0,38	1
Alignment IT Bus	3	2	1	2	2	2	3	1	2	2	2	2	1	2	1	2	3	1,94	0,64	2
Budget	2	1	2		2	3	3	2	2	3	2		2	1	3	2	3	2,20	0,65	2
Contextualization	2	3	4	2	4	5	4	3		4			1	3	4	3	2	3,14	1,06	3
Communication	2	3	3	2	3	3	4	3		4			2	3	4		4	3,08	0,73	3
EA implementation	1	4	5	4	5	5	3	5		3	3		4	2	5	5	4	3,87	1,20	4
Knowledge	1	2	1	1	2	3	3	3	2		3		2	4	3		3	2,36	0,89	2
Culture	2	1	1	2	4	1	2	2	3	4	2		5	4	2		2	2,47	1,20	2
Management	2	1	2	3	1	1	1	1	2	2	1	1	2	2	3	2	1	1,65	0,68	2
Roles	3	4	3	4	3	2	4	4	4	5	2		3	3	4	2	4	3,38	0,86	3
Innovation		5			5	5	3	5		5	5			5		4	4	4,60	0,66	5
Standardization	2	2	4	2	2	3	2	1	2	4	1		3	1	3	2	5	2,44	1,12	2
Data-driven		5	5	4	5	5	5	4	5	4	2			3	1	5	5	4,14	1,25	4
Flexibility	5	5	2		5		5		3	5	5			3		5	4	4,27	1,05	4
Process change	2	3			1		3	3		5	1		4	1			5	2,80	1,47	3
Data quality	2	2	3	1	3	1	3	3		2	3		1	1	3	3	5	2,40	1,08	2
Alignment IT OT	3	3	2	2	3	2	2	3	1	3	3	2	3	2	2		3	2,44	0,61	2
Data acquisition	2	4		2	5	5	3	4	2	1	4		3	2	3	1	4	3,00	1,26	3
Industry 4.0	2	3	5			5	4	5	2		5		4	4	5	2	5	3,92	1,21	4
Supporting tools	2	5	2		4		4	1		4	4			3	2	2	4	3,08	1,19	3

Table 19: Dependency results per focus area (rows) per participant (columns)

Next, table 20 shows how the average values of the final (14) focus areas were derived from the initial (20) focus areas.

New focus areas:	Consisting of old:			Average value
Alignment	Strategy	Align IT buss	Alignt IT OT	1
Embedding	Context	Communication		3
Finance	Budget			2
Process management	Process management			3
Governance	Roles and resp.			3
Enterprise Architecture	EA impl			4
Change management	Innovation	Flexibility		4
Knowledge	Knowledge			2
Culture	Culture			2
Leadership	Management			2
Data governance	-			2
Data quality	Data qual	Data acq		3
Standards	Standards			2
Technology	I4.0 Impl			4

Table 20: Dependency changes to updated focus areas

F Validation round structure

This appendix details the textual information sent to the participants at the start of the validation round. Next to the textual information provided below, the second version of the model was sent, which can be found in Appendix N.

The goal of the maturity model is to guide companies in the digital transformation through Industry 4.0 through the use of Enterprise Architecture. Industry 4.0 projects and applications require the integration of technological implementations into the existing infrastructure of the company, which can be achieved by Enterprise Architecture.

The maturity model is set up similarly to the DYA Maturity Matrix with which you are all familiar and therefore includes focus areas for organizations to improve their maturity in. However, different from the DYAMM is that our model divides the model into four separate levels of maturity, which means a higher level of structure is present, but requirements of different maturity levels cannot overlap outside of their respective levels of maturity.

The attached file contains the complete maturity model, including firstly the definitions for each general level of maturity, derived from the ISO33020-standard. Next, a definition is given for each focus area individually. Lastly, a table details the definitions for each maturity level for each focus area separately.

Feedback can be given or changes can be made to all three parts as described above, including the naming of elements. You can review the document in whatever way you prefer, either through the 'review' function in Word, as a list of comments, or any other way you see fit.

G Validation round results per participant

General maturity	P1	P2	P3	P4	P5	P6	P7
Perform	-	Remove the first "process" in every definition	Change to: "Implemented processes achieve their purpose", Add: "therefore processes cannot be repeated with confidence for the same outcome", Remove: "The as-is situation is being assessed"	-	-	-	Add: "There is no learning cycle"
Manage	-	Remove the first "process" in every definition	Change to: "Processes are being implemented .."	Add: "Standardization has taken place and some level of intervention is visible."	-	-	Add: "Some learning cycles are in place"
Establish	-	Remove the first "process" in every definition	Change to: "Processes are being fully integrated using a defined procedure.. "	-	-	Be careful with vertical v horizontal, clearly define what is meant by what!	Add: "Learning is actively documented but improvements are not yet actively pursued".
Optimize	-	Remove the first "process" in every definition	Change to: "The procedure of implementing processes is now performed predictively and with a clear objective defined upfront.", Change to: "data are being collected", Change to: "The procedure to implement processes is continually improved through innovative approaches."	Change to: "There is not only a vertical integration but also a complete horizontal integration with the supply chain and its surrounding value network."	-	-	-

Alignment	Be very careful in defining IT and OT and the link between them in the areas below. Make sure you have clearly in mind what you mean by them.	Add a sentence at the top of the table which clarifies briefly how the model works. Something like: "Each capability level A) to D) represents a coherent stage where all focus areas are perfectly in balance regarding the maturity of an enterprise which successfully integrates Enterprise Architecture and Industry 4.0."	Change to: "are all in sync and coherently aligned"	-	-	-	-
Perform	-	-	Change to: "An understanding of Industry 4.0.."	-	-	-	-
Manage	-	-	-	-	-	-	-
Establish	-	-	Change to: "alignment is in place through", Change to: "IT and OT elements across the organization ("	-	-	-	-
Optimize	-	-	-	-	-	-	-
Embedding	-	-	-	-	Change to: "whole, and"	Change to: "transformation towards an I4.0 organization", Change to: "in place that informs all employees on the progress of the transformation"	-

Perform	Change to: "There is top down communication and embedding based on basic view, setting expectations of.."	-	-	-	Change to: "top-down"	Change to: "There is embedding by periodical top-down communication of the strategic I4.0 company goals, setting the expectations of individuals participating in the digital transformation."	-
Manage	-	-	-	-	-	Change to: "Embedding is realized by having appointed transformation stakeholders participating in smaller projects. These stakeholders include Industry 4.0 experts and Enterprise Architects."	-
Establish	-	-	-	-	-	-	-
Optimize	-	-	-	-	Change to: "top-down"	-	-
Finance	-	If you plan to do best practices, name more KPIs than just ROI	-	-	-	Change to: "place facilitating Industry 4.0 and Enterprise Architecture initiatives,", Remove: "concerned with available budget and financial KPIs" (keep it simple)	-
Perform	-	-	Change to: "Individual project budgets are defined for applications concerning Industry 4.0"	-	-	Change to: "Individual project budget is available for 'proof of concepts' projects to obtain knowledge of the possible applicability in the organization."	-

Manage	-	-	-	-	-	Change to: "is available for a portfolio of I4.0 projects."	-
Establish	-	-	-	-	-	-	-
Optimize	-	-	-	-	-	-	-
Process management	-	-	Change to: "and being managed"	-	-	-	-
Perform	-	-	-	-	-	-	-
Manage	-	-	-	Define this more clearly, can an architecture exist without business processes? And secondly, maintenance of what? Clarify!	-	-	-
Establish	-	-	-	-	Change to: "can be adjusted"	Version control of what? Process or architecture	-
Optimize	-	-	-	-	-	-	-
Governance	-	-	Change to: "which decision-making power, as well as roles", Change to: "clearly defined, implemented and actively executed within"	-	-	Change to: "concerning the transformation to Industry 4.0"	-
Perform	-	-	-	-	-	-	-
Manage	-	-	Change to: "required specific roles", Change to: "documented and actively executed in change guidance"	-	-	-	-
Establish	-	-	Change to: "structure is active in the organization, it is fully embedded and standardized where top-level.."	-	-	-	-
Optimize	-	-	-	-	-	-	-

Enterprise Architecture	-	-	Change to: "Architecture capability is active to define and guide the change of the structure and operations of the organization"	-	-	Add: "Towards Industry 4.0"	-
Perform	-	-	Change to: "recognized by appointing a project architect"	-	-	-	-
Manage	-	-	Change to: "Architecture are consistently used."	-	-	-	-
Establish	Reference architecture should be mentioned here	-	Change to: "being used"	-	Change to: "decision-making"	-	-
Optimize	-	-	Change to: "in the company's"	-	-	-	-
Change management	It is important here to define the time scope, project or tactic change or strategic management	-	Change to: "able to define and implement changes concerning the"	-	-	-	-
Perform	-	Change to: "project has been delivered"	Change to: "with individual participants and business .."	-	-	-	-
Manage	-	-	Change to: "the organization performs"	-	-	-	-
Establish	-	-	-	-	-	-	-
Optimize	-	-	Enhances?	-	Change to: "can"	-	-
Knowledge and skills	-	-	-	-	Change to: "knowledge is being managed"	-	-
Perform	-	-	-	-	-	-	-
Manage	-	-	Change to: "Need-based training consistently takes place.", Remove: "where ncessary"	-	-	-	-

Establish	-	-	Change to: "Budget for people development is available and actively being used for personal growth"	-	-	-	-
Optimize	-	-	-	-	-	-	-
Culture	Does the company shape the culture, or does the culture dictate what you will and can do?	-	-	-	-	-	-
Perform	-	-	Change to: "has taken place to answer to what extent our organization is able to pursue.."	-	-	-	-
Manage	-	-	Change the final sentence to: "Organizational measures for digital transformation are implemented in specific cases of cultural assessment."	-	-	-	-
Establish	-	-	-	-	-	-	-
Optimize	Change to: "Continuously being improved"	-	-	-	-	-	Change to: "organizations and actively shares knowledge."
Leadership	"Guide" instead of "able to guide"	-	Change to: "managers guide employees"	-	-	-	-
Perform	-	-	Change to: "and push the digital"	-	-	-	-
Manage	-	-	-	-	-	-	-
Establish	-	-	-	-	-	-	-
Optimize	-	-	Change to: "Managers are now change leaders"	Change last sentence to: "Managers pursue innovation"	-	-	-
Data governance	-	Ensure clear difference between data governance and data quality	-	-	-	-	-

Perform	-	-	-	-	-	-	Add: "and ad hoc executed."
Manage	-	-	-	-	-	-	-
Establish	-	-	-	-	-	-	-
Optimize	-	-	-	-	-	-	-
Data quality	-	Ensure clear difference between data governance and data quality	Change to: "manage its own data quality and the acquisition of external data"	-	-	Change to: "able to comply to the data"	-
Perform	-	-	Change to: "and external data acquisition"	-	-	-	-
Manage	Change to: "sensory technology"	-	-	-	-	-	-
Establish	-	-	Change to: "defined metrics and improvements are being followed up."	-	-	-	-
Optimize	-	-	-	-	-	-	-
Standards	-	-	Change to: "manages standards to guide implementations throughout the enterprise via standardized rules .."	-	-	-	-
Perform	-	-	-	-	-	Add: No choices are yet enforced	-
Manage	-	-	-	-	-	-	-
Establish	-	-	-	This is utopic, a company could also deliberately not follow standards	-	-	-
Optimize	-	-	-	-	Change to: "open-source"	-	-
Technology	More clearly define in the steps below what the tech capabilities are	-	-	-	-	-	-
Perform	-	-	-	-	Change to: "project based"	-	-

Manage	-	-	-	Add something about the ist, gap, soll. Something where excess tech is removed	-	-	-
Establish	-	-	-	-	-	-	-
Optimize	-	-	-	-	-	-	-

Table 21: Comments validation round per participant

H Focus group structure

Introduction

First, a short personal introduction of all members commences. Next, the setup of the focus group session is explained, as well as general information regarding the topic.

"The goal of today is to find dependencies between maturity levels of focus areas. The current model consists of fourteen focus areas that were found to be relevant for Industry 4.0 and Enterprise Architecture through literature and the first round of interviews. Every focus area can reach four maturity levels, for which all definitions can be found on the paper in front of you. This paper contains information on the focus areas and their respective maturity levels. Every maturity level of a focus area corresponds to a general overall maturity level, for which the definitions can also be found on the paper in front of you. These general maturity levels range from a 'performed' process, the lowest stage of maturity, to an eventual 'predicted and optimized' process, the highest level of maturity. The goal of this focus group session is to identify dependencies between maturity levels of focus areas by specifying, for every focus area, what other focus area maturity levels should be reached as prerequisites to that specific level. The whiteboard behind me shows the four general maturity columns, consisting of the 'performed', 'managed', 'established', and 'performed and optimized' stages. Each row corresponds to the fourteen distinguished focus areas. Are there currently any questions on the structure of this model?

** Focus group session 1: An example of a filled-in model can be found on the paper in front of you, which is based on the results of the first round of interviews. We will walk through the model in 12 rounds, first placing all dependencies for the general 'performed' maturity level, in the 'organization' domain. This means we start with the first seven focus areas and their corresponding lowest levels of maturity. Next, the dependencies for the 'people' domain will be identified, and finally those for the 'technology' domain. With every new iteration, we will look back at the previously identified dependencies, and discuss if changes need to be made. After the general 'perform' maturity level has been established, we will continue with the other three general levels of maturity until the entire model is completed. Remember, the goal is to find dependencies for when a certain focus area maturity level requires maturity in other areas. An example of this might be that a company needs a financial plan before a technical implementation can take place. Are there any questions at this point?*

** Focus group session 2: In this session, we will build on the work of the previous focus group session, which derived the dependencies as can be seen on the whiteboard behind me. The goal is to verify their work and to ensure consensus on the dependencies among all of you. We will walk through the model in 12 rounds, first discussing all dependencies for the general 'perform' maturity level, in the 'organization' domain. This means we start with the first seven focus areas and their corresponding first levels of maturity. Next, the dependencies for the 'people' domain will be discussed, and finally those for the 'technology' domain. With every new iteration, we will look back*

at the previously identified dependencies, and discuss if changes need to be made. After the general 'perform' maturity level has been established, we will continue with the other three general levels of maturity until the entire model is completed. Remember, the goal is to establish dependencies for when a certain focus area maturity level requires maturity in other areas. An example of this might be that a company needs a financial plan before a technical implementation can take place. Are there any questions at this point?

"To make sure this session follows a structured and unbiased approach, we will follow the procedure individually first, and then share it and discuss it with the group. Thus, each of you will separately think of the order between focus area maturity levels, before sharing it with the rest of the group and discussing it to reach a consensus. In front of you, you can find a paper that you can use to place your own Post-it notes to show dependencies between maturity levels. We will do this per domain, so first for the 'perform' level in the organization domain, then the 'perform' level in the people domain, and so on. Each time we will give you a few minutes to think of the ordering between the corresponding levels, and then discuss with the entire group to reach a consensus. We will then place this consensus on the whiteboard in the back of the room, and move on to the next round. In total, we will do this 12 times, three domains in four maturity levels. In every round, we ask you to not only think about the dependencies between the focus area maturity levels of the domain we are currently establishing, but to also evaluate this concerning the maturity levels already present on the whiteboard. For example, when we are establishing the dependencies in the 'people' domain, not only think about their internal dependencies but also keep in mind the maturity levels of the 'organization' domain which are already placed on the whiteboard. Is everything clear about the procedure for this focus group session?"

Key questions

When everything is clear for the participants, the twelve rounds commence in order from 'performed' to 'predicted and optimized', per domain separately.

"Please now read the information for the maturity levels pertaining to this round. For the first round, these would be the steps required to reach the 'perform' level, for the seven focus areas under the 'organization' domain. Then, place the Post-it notes on your desk on the grid paper in front of you. The goal here is to identify dependencies for when a certain focus area maturity level requires maturity in other areas. It is possible that two maturity levels fall in the same column, which would then mean these two levels are not dependent on each other to reach this stage of maturity. An example of this might be as follows:"

*** Show example of filled-in grid ***

Order:	First						Last
Alignment	X						
Integration		X					
Finance		X					
Process management				X			
Governance			X				
Enterprise Architecture							X
Change management					X		

Figure 16: Example of a filled-in grid

After all, participants have filled in their individual grids, the facilitator identifies the commonalities first and places these focus area maturity levels on the whiteboard when applicable. Next, all remaining focus area maturity levels are discussed one by one until a consensus is reached. This discussion is guided by the facilitator, in turn asking one of the participants to deliberate on the reasoning behind their identified dependencies. When a consensus is reached, applicable changes are made on the whiteboard.

To keep track of the changes after each of the twelve rounds, a picture of the whiteboard is taken containing the overall consensus. Through this, changes in dependencies in each round are documented.

After each of the 12 rounds, we look back at the previously placed letters and discuss if the order needs to be changed based on the newly added letters.

Final remarks

After all 56 maturity levels have been defined, the model is complete. The participants are asked separately if they are content with the consensus, or if there are still dependencies that need to be altered. Finally, participants are thanked for their input.

I Focus group results

All textual changes as a result of the focus group sessions can be found in the research design section of this document. This appendix shows the dependencies as derived after the first focus group session but before the second focus group session.

	Performed				Managed				Established				Optimized			
Alignment	X				X				X				X			
Embedding			X			X					X			X		
Finance				X			X					X			X	
Process management		X			X				X					X		
Governance			X			X			X				X			
Enterprise Architecture	X					X				X			X			
Change management			X					X				X			X	
Knowledge			X				X				X					X
Culture		X						X				X		X		
Leadership	X				X							X			X	
Data governance			X				X			X					X	
Data quality				X				X			X			X		
Standards		X					X					X				X
Technology			X		X							X		X		

Figure 17: Intermediate dependencies between focus areas

J Assessment round structure

This appendix covers the textual information participants received before filling in the maturity assessment for their company.

Goal: The goal of the EAI4.0 maturity model is to guide companies in the digital transformation through Industry 4.0 through the use of Enterprise Architecture. Industry 4.0 projects and applications require the integration of technological implementations into the existing infrastructure of the company, which can be achieved by Enterprise Architecture.

This questionnaire is used to assess a company's maturity in Industry 4.0 and Enterprise Architecture, through 115 yes/no questions. Each question is directly linked to a requirement and is therefore either achieved or not achieved. When you are in doubt for a certain question whether the company fully achieves the requirement, you should answer 'no'. In other words, only answer 'yes' if the answer is clearly positive.

After each question, you have the opportunity (not required) to let us know if you are uncertain about the answer that you provide, or if you want to add something. An example of this could be the following: when your organization does not exactly meet the requirement posed in the question but achieves its purpose in a slightly different way. Important: these open questions are not mandatory but are meant for the instances where you feel a little bit of extra information is required.

Definitions:

Industry 4.0: Industry 4.0 requires a digital transformation where companies integrate new technologies, such as IoT, cloud computing, and AI, into their production facilities and throughout their operations. Industry 4.0 focuses on connectivity between the entire factory, which, through advanced sensors and data analytics, allows for quicker and better decision-making. In an ideal state, production data is combined with operational data from ERP and customer service, but also data from the surrounding supply chain When Industry 4.0 technologies are correctly integrated, they can lead to highly positive operational excellence results.

Enterprise Architecture: By nature, Industry 4.0 technologies rely heavily on adjacent processes and technology and must therefore be integrated into the company's architecture. The EAI4.0 maturity model proposes the use of Enterprise Architecture to manage these technological implementations. Enterprise Architecture is defined as "the consistent set of rules and models that guide the design and implementation of processes, organizational structure, information flows, and the technical infrastructure within an organization". The use of Enterprise Architecture for Industry 4.0 ensures that the alignment and integration of new technologies align with the already existing infrastructure.

K Assessment round results

All individual assessment results of each organization are stored on a separate secured database for use in possible future research.

The assessment overview of an organization is automatically created through an Excel table in which the questionnaire results can be inserted. When the questionnaire results are converted to binary data (yes=1, no=2), this can be pasted into the file which will result in the table showing the dark green and light green colors making up the assessment. This Excel file is added as an addendum to this thesis for further use.

L Interview 2 structure

Introduction
A short personal introduction commences, after which the goal and structure of the interview are explained. Interviewees that did not participate in the first interview receive a short recap of the research process up until this point.

"To facilitate the note-taking, we would like to ask your consent to record our conversations today. This recording will be used to fill gaps in the interview notes and is only accessible to the researcher and will subsequently be immediately removed.
Next, we would like to use the data from this interview, anonymously, in the final report. Do you give your consent for this?
The interview is scheduled to last for one hour, during which we will have several questions that we would like to cover regarding the filled-in maturity assessment. Next, we have some questions regarding the utility of the model, and finally, we will ask you about digital transformation in your company in general."

For participants that did not partake in Interview 1:

"The maturity assessment and corresponding maturity model was created through a literature study, combined with interviews with experts in different areas of industry. Next, the model's dependencies between focus area maturity levels were derived through two focus-group sessions."

Maturity assessment
Before talking about the maturity assessment in detail, we ask the participants to what extent their organization utilizes Enterprise Architecture. Through this, we aim to infer the level of necessity of using an Enterprise Architecture approach for Industry 4.0 and thereby evaluate the robustness of the model in light of ways to structure the digital transformation. When a participant indicates that their organization does not work with an Enterprise Architecture approach, we question if there is a different approach used.

"Before we talk about your maturity assessment in detail, we would like to ask you to answer the following question: Does your organization utilize an Enterprise Architecture approach within the organization? If the answer is no, please elaborate if there is any other systematic approach utilized to structure the IT of the organization."

Next, we show the participants their maturity assessment based on the filled-in questionnaire. A short explanation follows which highlights how the assessment is to be read, and subsequently what steps we recommend them to take to improve their general level of maturity. Moreover, participants are urged to consider the level of maturity they have versus the level of maturity they aspire to reach. Not every organization will or has to want to reach the optimized level of maturity

in this domain, which impacts the next maturity levels to be achieved.

"The maturity assessment is to be read from left to right, ideally achieving all 'performed' levels of maturity for all focus areas before moving onto the 'managed' levels. In green, the model indicates the focus area maturity levels that your organization has achieved. In yellow, the model indicates the focus area maturity levels that your organization has achieved, but, for which the previous levels of maturity are not yet fully completed. The X's in the model highlight the dependencies between the maturity levels, which can be used by your organization as a roadmap for what maturity levels to achieve first. For each general maturity column first seek out which focus areas are in white, and are thus not yet achieved. Then, start with the left-most X in white, and follow this through until all X's in that general maturity column is achieved.
What is important to realize is that the 'optimized' level of maturity might not be the level your organization needs or wants to reach. Within your business model or within your strategy it might be very well possible that the 'managed' or 'established' stage of maturity is enough for the goals that you want to reach. Please keep this in mind both while reading the assessment, as well as in the future if you were to make a plan to improve your maturity through our maturity model.
According to the maturity assessment of your organization, the following focus areas should achieve a higher level of maturity to reach the next overall level of maturity: ... "

To evaluate the 'fidelity with practice' of the model, we ask the participants to discuss for each focus area if they feel the maturity assessment is in line with their view of the company's maturity in that area. Any comments participants might have about their organization's maturity assessment can be shared here. To evaluate the 'completeness' of the model regarding ways in which maturity levels can be reached, we ask participants about possible (best) practices used in reaching their achieved levels of maturity, to find out if there are (best) practices that are currently not present in the model.

"Next, for each focus area we would like to ask you to reflect on if you feel this assessment corresponds to your view of the company's maturity in that area. It might be the case that something we determined as a requirement for a specific maturity level, has not been a requirement in your organization while you did in fact progress through this level of maturity. These possible different approaches to progressing in maturity help us in generalizing the model and checking if our content is in line with a real-life situation. Moreover, we are curious to know if there are specific (best) practices that you deployed to reach the maturity levels you achieved. For each focus area:

- *To what extent do you feel this assessment is in line with your view of the company's maturity in this focus area? 1. Not at all, 2. Close, 3. Perfect.*
- *Are there any specific (best) practices that you utilized to reach the maturity levels that you did achieve?"*

Technology acceptance model questions

To evaluate the acceptance of the maturity model we use a Technology Acceptance Model questionnaire, as explained in section 5.

"Now that you have seen your organization's maturity assessment and corresponding improvement roadmap, we would like to ask you a couple of questions about how you experience the model. The goal of these questions is to infer how useful you perceive the model, how easy to use you perceive the model, and if you would intend to use the model.
Please rate these questions on the following 5-point Likert scale: 1=Extremely unlikely, 2=Unlikely, 3=Neutral, 4=Likely, 5=Extremely likely."

Construct	Nr.	Statement
Perceived usefulness	1	Using the model would facilitate me to reflect on our organization's current level of maturity regarding I4.0 and EA.
	2	Using the model would improve the way in which our organization operates with I4.0 and EA.
	3	Using the model would be an effective way to assess and improve maturity regarding I4.0 and EA.
	4	Using the model would make it easy to improve maturity regarding I4.0 and EA.
	5	Using the model would be a useful way to assess and improve maturity in I4.0 and EA.
Perceived ease of use	6	Learning how to read the model to evaluate and improve our organization's maturity regarding I4.0 and EA would be easy for me.
	7	I would find it easy to use the assessment questions to assess our organization's maturity.
	8	The assessment questions and model information would be clear and understandable to me.
	9	I would find it easy to use the model to improve our organization's maturity.
Intention to use	10	I would intend to use the model to improve our organization's maturity in Industry 4.0 and Enterprise Architecture

Table 22: TAM Questionnaire Interview round 2

General digital transformation KPIs

Finally, we ask participants to answer four questions on general digital transformation KPIs, as explained in section 5.

"For the last part of the interview, we would like to ask you to grade your company on the following four KPIs. Our goal is to find out if a company's level of maturity in our model correlates with a company's general digital transformation performance. Please indicate your company's performance on the following 5-point Likert scale: 1=Totally disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Totally agree.

- *KPI1: Our organization is generating profit through the deployment of digital technologies, either by reducing costs or improving revenue.*
- *KPI2: Our organization has digitalized products & services or processes related to these.*
- *KPI3: Our organization has digitalized customer & partner network interaction channels.*
- *KPI4: Our organization has digitalized general internal processes, not only concerned with Industry 4.0.*

This was the last element of the interview and thereby everything I wanted to ask you today. Are there any final comments that you still want to share?
Then I want to immensely thank you for participating in the interview(s)!"

M Interview 2 results

Textual results per participant in the second round of interviews.

Organization	A	B	C	D	E	F
Use of EA	Currently deep in ERP implementation, EA is the end goal	ERP first	Started with data architecture and ISA95 but in 'children's shoes'	Started with ISA95	Lot of older systems and externally governed, full EA is the goal	ERP & PLM currently being set up, some local architecture
Roadmap	The model lets me think about other elements, very positively. The fact that a plan needs to be present is very useful, as well as the roadmap. Highly recognize the roadmap	This model will really help due to the concrete examples. It's a very nice model which inspires us to think differently.	The pdf plus the assessment feels very useful. It is a good starting point for discussions within the company.	Large recognition and surprised how a seemingly random set of questions leads to such a connection to the real-world model. The concrete steps are really nice.	This 'fits like a bus', large recognition with our current situation.	We recognize ourselves in this a lot and we see possibilities to continue with this model by thinking about our current situation differently.
Alignment	-	-	-	I wonder if the CEO would fill in the same	-	-
Embedding	-	-	Dedicated people for embedding for steering groups, advisory groups, sponsors, etc.	-	For this industry supply chain embedding specifically is a core business, and therefore they have achieved requirements at the optimized level without requirements in lower levels.	-
Finance	-	We are doing project portfolio management for every project which includes financial structure and KPIs. So we do this anyway also not for I4.0.	-	Checking projects financially is way more of a boundary for SMEs, so that comes earlier than in established/optimized	-	-
Process management	This is way too mature for how far our organization is, especially when I think of process management regarding Industry 4.0. The link with I4.0 is missing in the first two levels.	-	Light green at the end needs to be sharpened	Some best practices are not always relevant for each type of organization.	Optimized sharper	-

Governance	-	Add that governance (M) is for the whole organization	-	When the company is less large a responsible manager is not always necessary or feasible, and instead this can be a role that falls under someone with another title.	-	-
Enterprise Architecture	-	Specify reference architecture, name RAMI	-	Sharpen optimized definition on supply chain incorporation	-	-
Change management	It is important to have a real 'role' for change manager	Start small but think big, always look for added value	-	-	-	-
Knowledge and skills	-	Gap analysis for 'known current situation', add to all assessments	-	-	-	-
Culture	-	Culture is difficult to grade, optimized needs to be more strict	Start of culture is too strong requirement wise. Moreover, incentive mechanism does not work in every company culture, this should be added.	Culture performed needs to be less strict. Moreover, some cultural aspects can be written down in a bit more detailed to explain what is meant.	Cultural assessment questions were difficult in yes/no format	-
Leadership	-	Vision, commitment and belief is required from top management	Optimized needs to be stronger	Optimized requirement should be stronger	-	-
Data governance	-	-	Optimized more strict	The optimized requirement should be stronger. Moreover, SMEs often purchase this externally because they have no other option. It can happen that an external company will not share data, check this beforehand.	-	-

Data quality	-	Visualize data quality, what is it and what is going wrong. You need dashboards to show mistakes. Concrete examples.	-	-	data warehousing is managed here as this is part of their core business	-
Standards	Some of the requirements in the optimized levels are not something we are aiming to achieve in the coming years	-	-	-	-	-
Technology	-	spelling mistake “i40.0”	-	For SME predictive maintenance might be an external purchase instead of inhouse. For the future technical capabilities, we have an idea but not a strict plan, so what should I have filled in?	-	-
Reflective	-	-	-	-	-	-
Improve performance	-	-	-	Good model but you need to have quite some knowledge and information to use it	-	-
Effective	-	-	-	Concreteness and practicality really help in making the model useful. A pragmatic approach with the roadmap is nice.	-	-
Make it easier to improve	Will this make it easier, with the best practices likely, but you still have to do it yourself which is difficult	-	Shows well where the issues are but a short paragraph to explain the best practices and the plan would be nice. Companies like copy-paste.	-	-	-
Useful	-	-	-	Usefulness depends on how much the user wants to improve	-	-
Learning how to read	-	-	-	Difficult model, is necessary, but tricky	Can be rather abstract	-

Easy to use assess	-	-	Structure the model a bit more	-	-	-
Clear and understandable	-	High level model content but detailed explanation in pdf and interview helps a lot	-	-	-	-
Easy to use improve	Due to best practices the model becomes easy to use to improve	-	-	You need the mindset for this	-	-
Intent to use	Would gladly use it due to concrete steps and storyline with a roadmap	Concrete actions really help, but, more of a storyline would be great with the advice, possibly specific for our industry	-	-	-	-

Organization	**G**	**H**	**I**	**J**	**K**	**L**
Use of EA	-	EA is in the DNA of the organization. Agile architecting, a continual stream of architecture and changes.	EA is a must for our organization, hiring architects as we speak	-	EA is a basic element throughout the organization. Team of lead architects that work together to cover the entire organization, OT to IT.	Our organization is very scattered, therefore we cannot function without EA. Different logical clusters with solution architects, combined with EA for the entire organization. Archimate library
Roadmap	Good model, fits our situation, clear story.	Seems like a useful model	Eye-opening model	-	Spot on, connects extremely well to our current situation. We'd want to continue working with this model. The model feels nicer to use than a Gartner assessment we used in the past, as this is way more applicable while Gartner is often abstract and not applicable (and way more expensive).	Difficult assessment as this company is a conglomerate of 100s of companies, nevertheless, high level of recognition.
Alignment	-	-	-	-	This is hard work. Every year a business plan, workshops, etc. Every year an alignment check between business wishes and plans, for IT, security, etc. A periodical review of business plans and alignment between business, IT, and OT. You must remain feeling with each other.	-
Embedding	-	-	-	-	-	-
Finance	-	Project portfolio management for every project	-	-	-	-

Process management	-	-	-	Optimized should be extended a bit	Specific process management end support department which helps other departments with visualizing their processes, managing them, controlling them, etc. Reactive (established) and proactive (optimized)	-
Governance	-	-	-	-	-	-
Enterprise Architecture	-	Often, organizations start with EA in rough times when profit is low. However, you should do it and focus on generalizing when things are going well, so the dip is less severe when things are going bad. This is a pendulum between specifying and generalizing.	-	-	-	-
Change management	-	-	-	-	Is a difficult focus area because it doesn't matter if you are white in performed if you are green in established right?	-
Knowledge and skills	-	-	-	Look out with assessments because in practice you often want to start quickly with learning, learning by doing, because you don't want to flatten innovation. Similar to boundaries like finance, don't let this inhibit innovation.	-	-
Culture	-	-	-	-	-	Involvement is key for culture

Leadership	-	-	-	-	In our high maturity it's less steering top-down and more because the people really want to.	Specific approach to get people to follow. Don't start when there is no roadmap and management is not on board. Similarly, don't leave when everything hasn't landed yet.
Data governance	-	-	-	-	-	Optimized needs to be more strict
Data quality	-	-	-	-	-	-
Standards	-	-	-	-	-	-
Technology	-	-	Add cyber-physical systems as a general best practice to explore at the established level and possibly add more examples of supporting tools.	-	-	-
Reflective	-	-	-	-	-	Let the model be filled in by multiple people, maybe see if you can make a shorter easier version for in-company
Improve performance	-	-	-	-	-	-
Effective	-	Long questionnaire, but I understand that this is necessary	-	A lot of questions but when I see the assessment I understand why	-	Lot of questions and difficult to generalize in our organization specifically
Make it easier to improve	-	Clear steps after the assessment are really nice, including the best practices	-	There will be differences between different types of companies, family-ran versus corporates.	-	-
Useful	-	Clear and concrete steps are very valuable to companies that do not have the time to explore such constructs.	-	-	-	-
Learning how to read	-	-	-	-	-	-

Easy to use assess	It's a long list, you might group the questions on topic. Moreover, a workshop format might work better instead of sending a questionnaire	-	-	-	-	-
Clear and understandable	-	-	The table with the definitions in a structured way is really helpful.	-	-	-
Easy to use improve	-	It's difficult to go from the assessment to the roadmap including the storyline on my own, I need an interviewer for this.	-	-	-	-
Intent to use	-	Good instrument	-	-	-	-

Table 23: Interview 2 comments per participant

Fidelity with practice results

Table 24 details the 'fidelity with practice' scores per focus area per participant, as used in section 5.

	A	B	C	D	E	F	G	H	I	J	K	L
Alignment	3	3	2	3	3	3	2	3	3	3	3	2
Embedding	3	3	2	3	2	3	3	3	3	2	3	3
Finance	3	3	3	2	3	2	3	3	3	3	2	3
Process management	1	3	3	3	3	2	2	3	2	2	3	3
Governance	3	2	3	3	3	3	3	3	3	3	3	3
Enterprise Architecture	3	3	3	2	3	3	3	2	3	3	3	2
Change management	2	3	2	3	3	3	3	3	3	2	2	3
Knowledge and skills	3	3	3	3	2	2	3	2	3	2	3	3
Culture	2	2	2	2	3	2	2	3	2	3	3	3
Leadership	3	3	2	3	3	3	3	2	2	3	3	3
Data governance	3	3	3	2	3	2	3	3	3	3	2	2
Data quality	3	3	3	2	2	3	3	3	3	3	3	3
Standards	3	3	2	3	2	3	3	3	2	3	2	3
Technology	3	3	3	3	3	3	3	3	3	3	2	3

Table 24: Fidelity with practice scores per participant

TAM results

Table 25 details the Technology Acceptance Model scores per construct per participant, as used in section 5.

	A	B	C	D	E	F	G	H	I	J	K	L	Mean	SD
Reflective	5	4	4	5	4	4	4	4	4	5	4	4	4,25	0,43
Improve performance	4	4	5	4	4	4	4	2	4	4	3	4	3,83	0,69
Effective	4	4	4	4	4	3	3	4	3	4	4	3	3,67	0,47
Make it easier to improve	4	4	3	5	4	4	3	5	5	2	5	3	3,92	0,95
Useful	5	3	4	5	4	4	4	4	4	5	4	4	4,17	0,55
Learning how to read	5	5	4	3	3	3	4	4	4	3	5	4	3,92	0,76
Easy to use assess	4	5	3	2	3	4	3	4	4	5	5	2	3,67	1,03
Clear and understandable	4	3	5	4	2	3	4	4	5	4	4	3	3,75	0,83
Easy to use improve	4	4	4	3	3	3	4	2	4	3	4	3	3,42	0,64
Intent to use	5	4	5	5	4	4	4	4	5	4	4	4	4,33	0,47

Table 25: TAM scores per participant

KPI results

Table 25 details the overall maturity score in the EAI4.0 Maturity Model on the first row, as well as the general digital transformation KPI scores per construct per participant, as used in section 5.

	A	B	C	D	E	F	G	H	I	J	K	L
Maturity score	22	38	50	44	9	7	55	109	63	33	75	40
KPI1	4	3	5	5	2	4	3	5	4	2	5	2
KPI2	4	4	4	4	1	3	4	5	5	4	5	4
KPI3	3	5	5	3	4	4	4	5	4	4	5	3
KPI4	4	4	4	3	2	3	4	5	4	3	4	2

Table 26: KPI scores per participant

PLS-SEM Analysis

Table 27 shows the skewness and kurtosis values for all variables used in the PLS-SEM analysis, of which the kurtosis value should be between -7 and 7, and the skewness value between -2 and 2, for the data to be considered normally distributed (Byrne, 2013).

Variable	Min	Max	SD	Kurtosis	Skewness
Maturity	7.0	109.0	27.28	1.10	0.80
KPI1	2.0	5.0	1.18	-1.55	-0.29
KPI2	1.0	5.0	1.04	4.79	-1.87
KPI3	3.0	5.0	0.76	-1.26	-0.16
KPI4	2.0	5.0	0.87	-0.33	-0.44

Table 27: Descriptive statistics and Kurtosis and Skewness values for variables used in the PLS-SEM analysis

N Model V2

	Maturity levels	Perform	Manage	Establish	Optimize
Focus areas	**Definitions**	The implemented process achieves its process purpose. Processes are performed in an ad-hoc fashion and are not standardized, controlled, or implemented in the organization. The as-is situation is being assessed.	The previously described Performed process is now implemented in a managed fashion (planned, monitored, and adjusted) and its documented information is appropriately defined, controlled, and maintained.	The previously described Managed process is now fully integrated using a defined process which is assured and improved. Standards and protocols are consistently followed, and processes are vertically integrated on a full organizational level.	The previously described Established process is now performed predictively. Quantitative management needs are identified, and measurement data are collected and analyzed to identify assignable causes of variation. Processes are continually improved through innovative approaches. Processes are horizontally integrated with the supply chain and value network.
Alignment	The extent to which business goals, IT, and OT are all coherently aligned with one another, and the extent to which Industry 4.0 is a part of the company's strategy.	A basic view of and interest in Industry 4.0 and Enterprise Architecture within the company is present, based on business goals. The current situation is known and a future plan has been drafted regarding the "why" and "what" of Industry 4.0 and Enterprise Architecture.	Alignment between strategy, business goals, OT, and IT is monitored and documented through the use of Enterprise Architecture. According to the alignment between the initial plan and the intended goals of the digital transformation, its development can be adjusted accordingly.	Full vertical alignment is achieved through a defined process within the Enterprise Architecture, which ensures alignment between strategy, business goals, IT, and OT (are we still on the right track?). KPIs are set up based on business goals.	Industry 4.0 and Enterprise Architecture are fully integrated into the company strategy, vision, and mission. The alignment process is continually improved through KPIs to respond to change through identified innovation. New Industry 4.0 projects are defined in an agile/flexible fashion. Research takes place with the aim of accelerating the execution of strategic goals through external partnerships.
Embedding	The extent to which the digital transformation is embedded in the organization as a whole and in the Enterprise Architecture, and the extent to which a process is in place to communicate it.	Top-down communication and embedding have started based on the basic view, to set expectations of individuals participating in the digital transformation.	An embedding and communication plan is defined and documented through regular meetings with stakeholders. Industry 4.0 practices are partly integrated into Enterprise Architecture.	A fully defined embedding and communication process is in place within the Enterprise Architecture, consisting of who and what needs to be updated and involved, which assures relevant decisions are communicated across the entire business. Contextualization and/or visualization take place to enhance communication and integration.	Horizontal embedding and communication take place also outside of company boundaries through the entire value network. Digital transformation and Enterprise Architecture as a vision are shared by employees and do not need a top-down push. Multiple groups of talented people are striving towards common goals, and opportunities for bottom-up pull are present.

Finance	The extent to which a financial management process is in place regarding Industry 4.0 and Enterprise Architecture, concerned with available budget and financial KPIs.	A budget is defined for individual projects or applications concerning Industry 4.0 and supporting Enterprise Architecture.	A central Industry 4.0 and Enterprise Architecture budget is defined. Financial information regarding the digital transformation is monitored and documented.	A financial management structure for Industry 4.0 and Enterprise Architecture is fully integrated and standardized. Industry 4.0 projects are measured with established financial KPIs like return on investment, to verify added value to the business.	Budgeting of projects is optimized through financial KPIs (data-driven) and projects are chosen and/or guided based on these KPIs. Post-implementation reviews take place on existing projects. The company looks externally for new customers or new markets to improve its financial situation.
Process management	The extent to which a process architecture or structure concerning Industry 4.0 and Enterprise Architecture is in place and managed.	A basic view of relevant (business) processes, both existing and required, concerning Industry 4.0 and Enterprise Architecture is present.	A process architecture is defined for Industry 4.0 and Enterprise Architecture. A maintenance process is defined to update the process architecture based on new technology implementations.	The process architecture is fully integrated and follows defined standards and protocols, and is able to be adjusted based on feedback. A process for version control is defined and in place.	Process architecture is horizontally integrated through the inclusion of the supply chain network. Process architecture is continually optimized through identified innovative approaches.
Governance	The extent to which roles and responsibilities concerning Industry 4.0 and Enterprise Architecture are defined and governed within the organizational structure.	A group of project experts is assigned to guide the digital transformation. A responsible manager and sponsor are defined for both Enterprise Architecture and Industry 4.0.	The required roles and responsibilities concerning Industry 4.0 and Enterprise Architecture are described and documented through a governance structure within the Enterprise Architecture.	The governance structure is fully standardized and embedded in the organization by capturing all relevant stakeholders and corresponding responsibilities. Top-level management has defined roles in the digital transformation.	The governance structure includes roles and responsibilities for horizontal integration with value network and innovation and is continually optimized through quantitative measures.
Enterprise Architecture	The extent to which an Enterprise Architecture approach is used to define the structure and operations of the organization.	Enterprise Architecture is recognized through the appointment of a project architect, responsible for the architecture of digital transformation projects.	An Enterprise Architecture structure is defined, which includes Industry 4.0 endeavors within the enterprise architecture. Required supporting tools for Enterprise Architecture are described.	The enterprise architecture is fully standardized and integrated into the organization, and is used in decision-making processes.	The enterprise architecture steers the (development of) the organization and is continually improved and updated to respond and adapt to changes stemming from innovations or changes in business goals. The full supply chain is incorporated into the company's enterprise architecture.
Change management	The extent to which level the organization is able to make changes regarding the digital transformation in the organization.	The organization innovates on a project-based level with individual business cases. The first Industry 4.0 project has been performed.	The organization is able to perform Industry 4.0 projects in a controlled and planned manner. Multiple Industry 4.0 projects are implemented, documented, and maintained.	A standardized change management process is present and embedded within the Enterprise Architecture, to change or transform existing processes throughout the entire organization. An innovation plan is defined for future projects.	The organization is able to disrupt and enhance existing processes to make data-driven optimizations.

Knowledge and skills	The extent to which the required skills for Industry 4.0 and Enterprise Architecture are present in the organization, and the extent to which knowledge as a whole is managed.	The current in-house knowledge is assessed, and a basic view of required knowledge is present. External knowledge is hired when necessary.	The enterprise has the required knowledge capabilities for the digital transformation. A knowledge management framework is defined and present in the Enterprise Architecture. Need-based training takes place where necessary.	A fully integrated knowledge management framework is present. An overview of future knowledge is present (what capabilities do we aim to have in the future). A budget for personal development is available.	Industry 4.0 and Enterprise Architecture knowledge is optimized by dedicated training based on future goals and quantitative measures. Periodic measurements of required knowledge take place. An innovation lab or external partnerships are deliberated to expand the knowledge base and implemented when deemed beneficial.
Culture	The extent to which the company culture is open to digital transformation, and the extent to which employees are actively involved in its improvement.	An assessment of the current culture in the organization has taken place: to what extent is our organization able to pursue industry 4.0, or, with what ease can technologies be adopted in our organization?	Measures are in place to alter culture regarding the digital transformation, based on the cultural assessment of the company. An incentive mechanism is created (monetary or non-monetary). A separate department or start-up for digital transformation is set up if cultural assessment dictates.	An organizational culture shift has taken place; ownership of technology is present. The company makes conscious decisions in deliberately hiring people that have an affinity with Industry 4.0 when applicable.	An innovative culture is present in the company, which is continuously improved. The company learns from other organizations to reach this level.
Leadership	The extent to which managers are able to guide employees through the digital transformation, and in which manner.	Responsible manager(s) has the willingness and skills to lead and pull the cart of the digital transformation.	Management is setting a planned vision and examples for employees and is able to clearly define to employees “what’s in it for me”. The management structure is controlled.	A management framework for the digital transformation is fully integrated and standardized in the Enterprise Architecture. A management development program is in place with the goal to improve management capabilities to lead the digital transformation.	Managers are now change managers instead of being required to forcefully include employees. Managers have the flexibility to innovate.
Data governance	The extent to which a data governance process is in place, concerned with data ownership, security, and policies.	Data ownership and data stewardship are defined.	A data governance structure is defined within the Enterprise Architecture, including policies on how data is dealt with. A data/technological security plan is defined.	Data governance structure is fully integrated and standardized in the Enterprise Architecture. Adjustments to data governance activities and structure can be made.	External governance structures and industry case studies are evaluated for best practices and lessons learned, providing ideas for improvements. Data governance processes are continually refined and improved.

Data quality	The extent to which the organization is able to deal with the data demands of Industry 4.0 and Enterprise Architecture and the extent to which the organization is able to manage data.	An assessment of current data quality and acquisition has taken place, showing which data (overviews) are currently present. A basic idea is present of what the data quality requirements are.	The required data quality and acquisition are defined through objectives, rules, and criteria. A data architecture, within the enterprise architecture, and corresponding data models are defined, and data warehousing and sensing technology are managed.	A data quality and acquisition process is integrated and standardized in the organization through the Enterprise Architecture. Periodic data quality assessments are conducted through defined metrics. Required data quality and acquisition goals are reevaluated and adjusted accordingly.	Industry 4.0 data is continuously used to optimize data quality. Analyses and visualizations are used to drive company improvement. Data quality program milestones and metrics are regularly reviewed by executives, and continuous improvements are implemented.
Standards	The extent to which the organization manages a standardization process that makes implementations throughout the enterprise follow standardized rules and protocols.	An assessment of current standards and protocols regarding Industry 4.0 and Enterprise Architecture has taken place.	Required standards and protocols are defined, keeping possible external regulations in mind. "What do we want to and should we want to standardize".	All new applications, systems, and procedures adhere to the defined standards and protocols.	Standards and protocols are evaluated through quantitative metrics and changes are made where necessary. External standards and open-source information are being evaluated for new opportunities.
Technology	The extent to which the organization has the technical capabilities in place to implement (Industry 4.0) technologies.	A basic view of current technological capabilities is present. Specific technological capabilities are acquired project-based.	(Required) technical capabilities are defined and documented through modeling of the desired IT solutions by the use of Enterprise Architecture. New technical capabilities are being acquired based on requirements in a planned fashion. The required supporting tools for Industry 4.0 is defined.	A plan for future technical capabilities is present, and a technical capabilities management framework is implemented in the Enterprise Architecture. Portfolio management and procurement processes related to Industry 4.0 technologies are established.	Technical capabilities are continuously improved. Company capabilities are extended by the addition of capabilities of other organizations in the value network in the Enterprise Architecture.

Table 28: Model V2: Definitions for Focus Areas (2nd column), definitions for general maturity levels (2nd row), and definitions for focus area maturity levels (remaining rows and columns)

O Model V3

	Maturity levels	Perform	Manage	Establish	Optimize
Focus areas	**Definitions**	Implemented processes achieve their purpose. Processes are performed in an ad-hoc fashion and are not standardized, controlled, or implemented in the organization, therefore processes cannot be repeated with confidence for the same outcome. There is no learning cycle.	Processes are being implemented in a managed fashion (planned, monitored, and adjusted), and its documented information is appropriately defined, controlled, and maintained. Standardization has taken place and some level of intervention is visible, some (unaware) learning cycles are in place.	Processes are being robustly implemented and integrated using a defined procedure that is assured. Standards and protocols are consistently followed and processes are vertically integrated on a full organizational level. Learnings are actively documented but improvements are not yet actively pursued.	The procedure of implementing processes is now performed predictively and with a clear objective defined upfront. Quantitative management needs are identified, and measurement data are collected and analyzed to identify assignable causes of variation. Processes are continually improved through innovative approaches. There is not only vertical integration but also complete horizontal integration with the supply chain and its surrounding value network.
Alignment	The extent to which business goals, IT, and OT are all in sync and coherently aligned with one another, and the extent to which Industry 4.0 is a part of the company's strategy.	An understanding of Industry 4.0 and Enterprise Architecture within the company is present, based on business goals. The current situation is known and a future plan has been drafted regarding the "why" and "what" of Industry 4.0 and Enterprise Architecture.	Alignment between strategy, business goals, OT, and IT is monitored and documented through the use of Enterprise Architecture. According to the alignment between the initial plan and the intended goals of the digital transformation, its development can be adjusted accordingly.	Full vertical alignment is in place through a defined process within the Enterprise Architecture, which ensures alignment between strategy, business goals, IT, and OT elements across the organization (are we still on the right track?). KPIs are set up based on business goals.	Industry 4.0 and Enterprise Architecture are fully integrated into the company strategy, vision, and mission. The alignment process is continually improved through KPIs to respond to change through identified innovation. New Industry 4.0 projects are defined in an agile/flexible fashion. Research takes place with the aim of accelerating the execution of strategic goals through external partnerships.
Embedding	The extent to which the digital transformation towards an Industry 4.0 organization is embedded in the organization as a whole, and in the Enterprise Architecture, and the extent to which a process is in place that informs all employees on the progress of the transformation.	There is embedding by periodical top-down communication of the strategic I4.0 company goals, setting the expectations of individuals participating in the digital transformation.	Embedding is realized by having appointed transformation stakeholders participating in smaller projects. Industry4.0 practices are partly integrated into Enterprise Architecture.	A fully defined embedding and communication process is in place within the Enterprise Architecture, consisting of who and what needs to be updated and involved, which assures relevant decisions are communicated across the entire business. Contextualization and/or visualization take place to enhance communication and integration.	Horizontal embedding and communication take place also outside of company boundaries through the entire value network. Digital transformation and Enterprise Architecture as a vision are shared by employees and do not need a top-down push. Multiple groups of talented people are striving towards common goals, opportunities are present for bottom-up pull.

Finance	The extent to which a financial management process is in place facilitating Industry 4.0 and Enterprise Architecture initiatives, concerned with available budget and financial KPIs.	Individual project budgets are defined for applications concerning Industry 4.0 and supporting Enterprise Architecture.	A central Industry 4.0 and Enterprise Architecture budget is available for a portfolio of I4.0 projects. Financial information regarding the digital transformation is monitored and documented.	A financial management structure for Industry 4.0 and Enterprise Architecture is fully integrated and standardized. Industry 4.0 projects are measured with established financial KPIs like return on investment, to verify added value to the business.	Budgeting of projects is optimized through financial KPIs (data-driven) and projects are chosen and/or guided based on these KPIs. Post-implementation reviews take place on existing projects. The company looks externally for new customers or new markets to improve its financial situation.
Process management	The extent to which a process architecture or structure concerning Industry 4.0 and Enterprise Architecture is in place and being managed.	A basic view of relevant (business) processes, both existing and required, concerning Industry 4.0 and Enterprise Architecture is present.	A process architecture is defined for Industry 4.0 and Enterprise Architecture. A maintenance process is defined to update the process architecture based on new technology implementations.	The process architecture is fully integrated and follows defined standards and protocols, and is able to be adjusted based on feedback. A process for version control of the architecture is defined and in place.	Process architecture is horizontally integrated through the inclusion of the supply chain network. Process architecture is continually optimized through identified innovative approaches.
Governance	The extent to which decision-making power as well as roles and responsibilities concerning (the transformation towards) Industry 4.0 and Enterprise Architecture are clearly defined, implemented, and actively executed within the organizational structure.	A group of project experts is assigned to guide the digital transformation. A responsible manager and sponsor are defined for both Enterprise Architecture and Industry 4.0.	The required specific roles and responsibilities concerning Industry 4.0 and Enterprise Architecture are described and documented and actively executed in change guidance through a governance structure within the Enterprise Architecture.	The governance structure is fully standardized and embedded in the organization by capturing all relevant stakeholders and corresponding responsibilities. Top-level management has defined roles in the digital transformation.	The governance structure includes roles and responsibilities for horizontal integration with value network and innovation and is continually optimized through quantitative measures.
Enterprise Architecture	The extent to which an Enterprise Architecture approach is used to define the structure and operations of the organization, and the extent to which EA guides the change towards Industry 4.0.	Enterprise Architecture is recognized by appointing a project architect, responsible for the architecture of digital transformation projects.	An Enterprise Architecture structure is defined, which includes Industry 4.0 endeavors within the enterprise architecture. Required supporting tools for Enterprise Architecture are consistently used.	The enterprise architecture is fully standardized and integrated into the organization, and is being used in decision-making processes. A reference architecture is defined and used.	The enterprise architecture steers the (development of) the organization, and is continually improved and updated to respond and adapt to changes stemming from innovations or changes in business goals. The full supply chain is incorporated into the company's enterprise architecture.

Change management	The extent to which level the organization is able to define and implement changes concerning the digital transformation in the organization.	The organization innovates on a project-based level with individual participants and business cases. The first Industry 4.0 project has been delivered.	The organization performs Industry 4.0 projects in a controlled and planned manner. Multiple Industry 4.0 projects are implemented, documented, and maintained.	A standardized change management process is present and embedded within the Enterprise Architecture, to change or transform existing processes throughout the entire organization. An innovation plan is defined for future projects.	The organization is able to disrupt and enhance existing processes to make data-driven optimizations.
Knowledge and skills	The extent to which the required skills for Industry 4.0 and Enterprise Architecture are present in the organization, and the extent to which knowledge as a whole is being managed.	The current in-house knowledge is assessed, and a basic view of required knowledge is present. External knowledge is hired when necessary.	The enterprise has the required knowledge capabilities for the digital transformation. A knowledge management framework is defined and present in the Enterprise Architecture. Need-based training consistently takes place.	A fully integrated knowledge management framework is present. An overview of future knowledge is present (what capabilities do we aim to have in the future). A budget for people development is available and actively being used for personal growth.	Industry 4.0 and Enterprise Architecture knowledge is optimized by dedicated training based on future goals and quantitative measures. Periodic measurements of required knowledge take place. An innovation lab or external partnerships are deliberated to expand the knowledge base and implemented when deemed beneficial.
Culture	The extent to which the company culture is open to digital transformation, and the extent to which employees are actively involved in its improvement.	An assessment of the current culture in the organization has taken place to answer to what extent our organization is able to pursue Industry 4.0, or, with what ease can technologies be adopted in our organization.	Measures are in place to alter culture regarding the digital transformation, based on the cultural assessment of the company. An incentive mechanism is created (monetary or non-monetary). Organizational measures for digital transformation are implemented in specific cases of cultural assessment.	An organizational culture shift has taken place; ownership of technology is present. The company makes conscious decisions in deliberately hiring people that have an affinity with Industry 4.0 when applicable.	An innovative culture is present in the company, which is continuously being improved. The company learns from other organizations to reach this level and actively shares knowledge.
Leadership	The extent to which managers guide employees through the digital transformation, and in which manner.	Responsible manager(s) has the willingness and skills to lead and push the digital transformation.	Management is setting a planned vision and examples for employees and is able to clearly define to employees “what’s in it for me”. The management structure is controlled.	A management framework for the digital transformation is fully integrated and standardized in the Enterprise Architecture. A management development program is in place with the goal to improve management capabilities to lead the digital transformation.	Managers are now change leaders instead of being required to forcefully include employees. Managers pursue innovation.

Data governance	The extent to which a data governance process is in place, concerned with data ownership, security, and policies.	Data ownership and data stewardship are defined and ad hoc executed.	A data governance structure is defined within the Enterprise Architecture, including policies on how data is dealt with. A data/technological security plan is defined.	Data governance structure is fully integrated and standardized in the Enterprise Architecture. Adjustments to data governance activities and structure can be made.	External governance structures and industry case studies are evaluated for best practices and lessons learned, providing ideas for improvements. Data governance processes are continually refined and improved.
Data quality	The extent to which the organization is able to comply with the data demands of Industry 4.0 and Enterprise Architecture, and the extent to which the organization is able to manage its own data quality and the acquisition of external data.	An assessment of current data quality and (external) data acquisition has taken place, showing which data (overviews) are currently present. A basic idea is present of what the data quality requirements are.	The required data quality and acquisition are defined through objectives, rules, and criteria. A data architecture, within the enterprise architecture, and corresponding data models are defined, and data warehousing and sensory technology are managed.	A data quality and acquisition process is integrated and standardized in the organization through the Enterprise Architecture. Periodic data quality assessments are conducted through defined metrics and improvements are being followed up. Required data quality and acquisition goals are reevaluated and adjusted accordingly.	Industry 4.0 data is continuously used to optimize data quality. Analyses and visualizations are used to drive company improvement. Data quality program milestones and metrics are regularly reviewed by executives, and continuous improvements are implemented.
Standards	The extent to which the organization manages standards to guide implementations throughout the enterprise via standardized rules and protocols.	An assessment of current standards and protocols regarding Industry 4.0 and Enterprise Architecture has taken place. No choices are yet enforced.	Required standards and protocols are defined, keeping possible external regulations in mind. “What do we want to and should we want to standardize”.	All new applications, systems, and procedures are checked to the defined standards and protocols, and adhere accordingly.	Standards and protocols are evaluated through quantitative metrics and changes are made where necessary. External standards and open-source information are being evaluated for new opportunities.
Technology	The extent to which the organization has the technical capabilities in place to implement (Industry 4.0) technologies.	A basic view of current technological capabilities is present. Specific technological capabilities are acquired project based.	(Required) technical capabilities are defined and documented, through modeling of the desired IT solutions by the use of Enterprise Architecture. When applicable redundant technology is removed. New technical capabilities are being acquired based on requirements in a planned fashion. The required supporting tools for Industry 4.0 is defined.	A plan for future technical capabilities is present, and a technical capabilities management framework is implemented in the Enterprise Architecture. Portfolio management and procurement processes related to Industry 4.0 technologies are established.	Technical capabilities are continuously improved. Company capabilities are extended by the addition of capabilities of other organizations in the value network in the Enterprise Architecture.

Table 29: Model V3: Definitions for Focus Areas (2nd column), definitions for general maturity levels (2nd row), and definitions for focus area maturity levels (remaining rows and columns)

P Model V4

	Maturity levels	Perform	Manage	Establish	Optimize
Focus areas	Definitions	Implemented processes achieve their purpose. Processes are performed in an ad-hoc fashion and are not standardized, controlled, or implemented in the organization, therefore processes cannot be repeated with confidence for the same outcome. There is no learning cycle.	Processes are being implemented in a managed fashion (planned, monitored, and adjusted) and its documented information is appropriately defined, controlled, and maintained. Standardization has taken place and some level of intervention is visible, some (unaware) learning cycles are in place.	Processes are being robustly implemented and integrated using a defined procedure that is assured. Standards and protocols are consistently followed and processes are vertically integrated on a full organizational level. Learnings are actively documented but improvements are not yet actively pursued.	The procedure of implementing processes is now performed predictively and with a clear objective defined upfront. Quantitative management needs are identified, and measurement data are collected and analyzed to identify assignable causes of variation. Processes are continually improved through innovative approaches. There is not only vertical integration but also complete horizontal integration with the supply chain and its surrounding value network.
Alignment	The extent to which business goals, IT, and OT are all in sync and coherently aligned with one another, and the extent to which Industry 4.0 is a part of the company's strategy.	An understanding of Industry 4.0 and Enterprise Architecture within the company is present, based on business goals. The current situation is known and a future plan has been drafted regarding the "why" and "what" of Industry 4.0 and Enterprise Architecture.	Alignment between strategy, business goals, OT, and IT is monitored and documented through the use of Enterprise Architecture. According to the alignment between the initial plan and the intended goals of the digital transformation, its development can be adjusted accordingly.	Full vertical alignment is in place through a defined process within the Enterprise Architecture, which ensures alignment between strategy, business goals, IT, and OT elements across the organization (are we still on the right track?). KPIs are set up based on business goals.	Industry 4.0 and Enterprise Architecture are fully integrated into the company strategy, vision, and mission. The alignment process is continually improved through KPIs to respond to change through identified innovation. New Industry 4.0 projects are defined in an agile/flexible fashion. Research takes place with the aim of accelerating the execution of strategic goals through external partnerships.
Embedding	The extent to which the digital transformation towards an Industry 4.0 organization is embedded in the organization as a whole, and in the Enterprise Architecture, and the extent to which a process is in place that informs all employees on the progress of the transformation.	There is embedding by periodical top-down communication of the strategic I4.0 company goals, setting the expectations of individuals participating in the digital transformation.	Embedding is realized by having appointed transformation stakeholders participating in smaller projects. Industry4.0 practices are partly integrated into Enterprise Architecture.	A fully defined embedding and communication process is in place within the Enterprise Architecture, consisting of who and what needs to be updated and involved, which assures relevant decisions are communicated across the entire business. Contextualization and/or visualization take place to enhance communication and integration.	Horizontal embedding and communication take place also outside of company boundaries through the entire value network. Digital transformation and Enterprise Architecture as a vision are shared by employees and do not need a top-down push. Multiple groups of talented people are striving towards common goals, and opportunities are present for bottom-up pull.

Finance	The extent to which a financial management process is in place facilitating Industry 4.0 and Enterprise Architecture initiatives, concerned with available budget and financial KPIs.	Individual project budgets are defined for applications concerning Industry 4.0 and supporting Enterprise Architecture.	A central Industry 4.0 and Enterprise Architecture budget is available for a portfolio of I4.0 projects. Financial information regarding the digital transformation is monitored and documented.	A financial management structure for Industry 4.0 and Enterprise Architecture is fully integrated and standardized. Industry 4.0 projects are measured with established financial KPIs like return on investment, to verify added value to the business.	Budgeting of projects is optimized through company-wide KPIs (data-driven) and projects are chosen and/or guided based on these KPIs. Post-implementation reviews take place on existing projects. The company looks externally for new customers or new markets to improve its financial situation.
Process management	The extent to which a process architecture or structure concerning Industry 4.0 and Enterprise Architecture is in place and being managed.	A basic view of relevant (business) processes, both existing and required, concerning Industry 4.0 and Enterprise Architecture is present.	A process architecture is defined for Industry 4.0 and Enterprise Architecture. A maintenance process is defined to update the process architecture based on new technology implementations.	The process architecture is fully integrated and follows defined standards and protocols, and is able to be adjusted based on feedback. A process for version control of the architecture is defined and in place.	Process architecture is horizontally integrated through the inclusion of the supply chain network, including inclusion in the Industry 4.0 framework. Process architecture is continually optimized through identified innovative approaches.
Governance	The extent to which decision-making power as well as roles and responsibilities concerning (the transformation towards) Industry 4.0 and Enterprise Architecture are clearly defined, implemented, and actively executed within the organizational structure.	A group of project experts is assigned to guide the digital transformation. A responsible manager and sponsor are defined for both Enterprise Architecture and Industry 4.0.	The required specific roles and responsibilities concerning Industry 4.0 and Enterprise Architecture are described and documented and actively executed in change guidance through a governance structure within the Enterprise Architecture.	The governance structure is fully standardized and embedded in the organization by capturing all relevant stakeholders and corresponding responsibilities. Top-level management has defined roles in the digital transformation.	The governance structure includes roles and responsibilities for horizontal integration with value network and innovation and is continually optimized through quantitative measures.
Enterprise Architecture	The extent to which an Enterprise Architecture approach is used to define the structure and operations of the organization, and the extent to which EA guides the change towards Industry 4.0.	Enterprise Architecture is recognized by appointing a project architect, responsible for the architecture of digital transformation projects.	An Enterprise Architecture structure is defined, which includes Industry 4.0 endeavors within the enterprise architecture. Required supporting tools for Enterprise Architecture are consistently used.	The enterprise architecture is fully standardized and integrated into the organization, and is being used in decision-making processes. A reference architecture is defined and used.	The enterprise architecture steers the (development of) the organization and is continually improved and updated to respond and adapt to changes stemming from innovations or changes in business goals. The full supply chain is incorporated into the company's enterprise architecture.

Change management	The extent to which level the organization is able to define and implement changes concerning the digital transformation in the organization.	The organization innovates on a project-based level with individual participants and business cases. The first Industry 4.0 project has been delivered.	The organization performs Industry 4.0 projects in a controlled and planned manner. Multiple Industry 4.0 projects are implemented, documented, and maintained.	A standardized change management process is present and embedded within the Enterprise Architecture, to change or transform existing processes throughout the entire organization. An innovation plan is defined for future projects.	The organization is able to disrupt and enhance existing processes to make data-driven optimizations. A plan is in place on how and in what steps the value network is to be integrated.
Knowledge and skills	The extent to which the required skills for Industry 4.0 and Enterprise Architecture are present in the organization, and the extent to which knowledge as a whole is being managed.	The current in-house knowledge is assessed, and a basic view of required knowledge is present. External knowledge is hired when necessary.	The enterprise has the required knowledge capabilities for the digital transformation. A knowledge management framework is defined and present in the Enterprise Architecture. Need-based training consistently takes place.	A fully integrated knowledge management framework is present. An overview of future knowledge is present (what capabilities do we aim to have in the future). A budget for people development is available and actively being used for personal growth.	Industry 4.0 and Enterprise Architecture knowledge is optimized by dedicated training based on future goals and quantitative measures. Periodic measurements of required knowledge take place. An innovation lab or external partnerships are deliberated to expand the knowledge base and implemented when deemed beneficial.
Culture	The extent to which the company culture is open to digital transformation, and the extent to which employees are actively involved in its improvement.	An assessment of the current culture in the organization has taken place to answer to what extent our organization is able to pursue Industry 4.0, or, with what ease can technologies be adopted in our organization.	Measures are in place to alter culture regarding the digital transformation, based on the cultural assessment of the company. An incentive mechanism is created (monetary or non-monetary). Organizational measures for digital transformation are implemented in specific cases of cultural assessment.	An organizational culture shift has taken place; ownership of technology is present. The company makes conscious decisions in deliberately hiring people that have an affinity with Industry 4.0 when applicable.	An innovative culture is present in the company, which is continuously being improved. The company learns from other organizations to reach this level and actively shares knowledge.
Leadership	The extent to which managers guide employees through the digital transformation, and in which manner.	Responsible manager(s) has the willingness and skills to lead and push the digital transformation.	Management is setting a planned vision and examples for employees and is able to clearly define to employees “what’s in it for me”. The management structure is controlled.	A management framework for the digital transformation is fully integrated and standardized in the Enterprise Architecture. A management development program is in place with the goal to improve management capabilities to lead the digital transformation.	Managers are now change leaders and pursue innovation.

Data governance	The extent to which a data governance process is in place, concerned with data ownership, security, and policies.	Data ownership and data stewardship are defined and ad hoc executed.	A data governance framework is defined within the Enterprise Architecture, including policies on how data is dealt with. A data/technological security plan is defined.	Data governance framework is fully integrated and standardized in the Enterprise Architecture. Adjustments to data governance activities and frameworks can be made.	External governance frameworks and industry case studies are evaluated for best practices and lessons learned, providing ideas for improvements. Data governance processes are continually refined and improved.
Data quality	The extent to which the organization is able to comply with the data demands of Industry 4.0 and Enterprise Architecture, and the extent to which the organization is able to manage its own data quality and the acquisition of external data.	An assessment of current data quality and (external) data acquisition has taken place, showing which data (overviews) are currently present. A basic idea is present of what the data quality requirements are.	The required data quality and acquisition are defined through objectives, rules, and criteria. A data architecture, within the enterprise architecture, and corresponding data models are defined, and data warehousing and sensory technology are managed.	A data quality and acquisition process is integrated and standardized in the organization through the Enterprise Architecture. Periodic data quality assessments are conducted through defined metrics and improvements are being followed up. Required data quality and acquisition goals are reevaluated and adjusted accordingly.	Industry 4.0 data is continuously used to optimize data quality. Analyses and visualizations are used to drive company improvement. Data quality program milestones and metrics are regularly reviewed, and continuous improvements are implemented.
Standards	The extent to which the organization manages standards to guide implementations throughout the enterprise via standardized rules and protocols.	An assessment of current standards and protocols regarding Industry 4.0 and Enterprise Architecture has taken place. No choices are yet enforced.	Required standards and protocols are defined, keeping possible external regulations in mind. “What do we want to and should we want to standardize”.	All relevant applications, systems, and procedures are checked to the defined standards and protocols, and adhere accordingly.	Standards and protocols are evaluated through quantitative metrics and changes are made where necessary. Emerging standards and means to standardize are being evaluated for new opportunities.
Technology	The extent to which the organization has the technical capabilities in place to implement (Industry 4.0) technologies.	A basic view of current technological capabilities is present. Specific technological capabilities are acquired project based.	(Required) technical capabilities are defined and documented, through modeling of the desired IT solutions by the use of Enterprise Architecture. Obsolete technology is identified. New technical capabilities are being acquired based on requirements in a planned fashion. The required supporting tools for Industry 4.0 are defined.	A plan for future technical capabilities is present, and a technical capabilities management framework is implemented in the Enterprise Architecture. When applicable obsolete technology is removed. Portfolio management and procurement processes related to Industry 4.0 technologies are established.	Technical capabilities are continuously improved. Company capabilities are extended by the addition of capabilities of other organizations in the value network in the Enterprise Architecture.

Table 30: Model V4: Definitions for Focus Areas (2nd column), definitions for general maturity levels (2nd row), and definitions for focus area maturity levels (remaining rows and columns)

Q Questionnaire questions and requirements

Focus area	Lvl	Num	Requirements	Questions
Alignment	P	1	Understanding of I4.0 & EA in business	Does your company have an understanding about how Industry 4.0 and Enterprise Architecture should look like in your company, based on business goals?
		2	Known current situation	Is the current status regarding Industry 4.0 and Enterprise Architecture within the company known?
		3	Future plan for I4.0 and EA	Has a plan been drafted regarding the 'why' and 'what' of Industry 4.0 and Enterprise Architecture?
	M	4	Alignment between goals and progress is documented	Is alignment between strategy, business goals, OT and IT monitored and documented?
		5	Development is adjusted based on goals	Is the development of the digital transformation able to be adjusted based on the alignment between the initial plan and its intended goals?
	E	6	Industry 4.0 is fully vertically aligned through EA	Is Industry 4.0 fully vertically aligned within the organization?
		7	KPIs are set up based on business goals	Are KPIs set up to measure the progress of the digital transformation based on defined business goals?
	O	8	I4.0 and EA fully integrated into vision, strategy, and mission	Are Industry 4.0 and Enterprise Architecture fully integrated into the company's vision, strategy, and mission?
		9	New Industry 4.0 projects are flexibly defined	Are new Industry 4.0 projects able to be flexibly defined and executed?
		10	Research to external partners takes place for execution of bus. goals	Does research take place for external partnerships with the aim of accelerating strategic goals concerning Industry 4.0?
Embedding	P	11	Periodical top-down communication	Does periodical top-down communication happen regarding Industry 4.0 projects?
		12	Individuals expectations are being managed	Are the expectations of individuals participating in Industry 4.0 projects managed?
	M	13	Transformation stakeholders appointed	Are transformation stakeholders appointed for the digital transformation?
		14	I4.0 partly integrated into EA	Are Industry 4.0 processes at least to some extent integrated into Enterprise Architecture?
	E	15	Fully defined embedding and communication process	Is a defined embedding and communication structure in place concerning who and what needs to be updated and involved regarding Industry 4.0 projects?
		16	Contextualization and visualization takes place	Are contextualization and visualization taking place regarding the digital transformation?
	O	17	Embedding with supply chain/value network	Are external supply chain/value network processes embedded in the company's own structure, and subsequently being used?
		18	I4.0 and EA are a shared vision among employees	Are Industry 4.0 and its advantages a shared vision among employees?
Finance	P	19	Individual project budgets for applications	Are individual project budgets in place and used for Industry 4.0 applications?
	M	20	Central I4.0 & EA budget	Is a central Industry 4.0 and Enterprise Architecture budget in place?
		21	Financial info is being monitored	Is financial information regarding the digital transformation monitored?
	E	22	Standardized financial management structure regarding I4.0 and EA	Is a financial management structure for Industry 4.0 and Enterprise Architecture in place?
		23	Financial KPIs used	Are Industry 4.0 projects measured with established KPIs like ROI?
	O	24	Post implementation reviews	Do post-implementation reviews take place on existing Industry 4.0 projects?
		25	External look	Is the company looking externally for new Industry 4.0 opportunities?

		26	KPI-based optimization of projects	Are Industry 4.0 projects chosen and guided based on companywide data-driven KPIs?
Process management	P	27	Basic view of the relevant process concerning I4.0 and EA	Is a basic view present of relevant processes concerning Industry 4.0 and Enterprise Architecture?
	M	28	Process architecture defined for I4.0 and EA	Is a process architecture for Industry 4.0 and Enterprise Architecture defined and in place?
		29	Maintenance process of architecture defined for new implementations	Is a maintenance process defined to update the process architecture based on new implementations?
	E	30	Integrated process architecture with standards	Is the process architecture fully integrated and standardized?
		31	Version control of I4.0 and EA process architecture defined	Is a process for version control of the architecture defined and in place?
	O	32	The supply chain network is involved in and contributes to the Industry 4.0 process architecture	Is the supply chain network involved in and contributing to the Industry 4.0 process architecture?
		33	Process architecture is continuously being optimized.	Is the process architecture continually being optimized?
Governance	P	34	Project experts for digital transformation assigned	Is a group of project experts assigned to guide the digital transformation?
		35	Responsible manager and sponsor defined	Are a responsible manager and sponsor assigned for Industry 4.0 and Enterprise Architecture?
	M	36	Roles and responsibilities for I4.0 and EA described and executed for the entire organization	Are relevant roles for Industry 4.0 and Enterprise Architecture described, documented, and executed for the entire organization?
	E	37	Standardized governance structure	Is a standardized governance structure embedded in the organization capturing all relevant stakeholders and corresponding responsibilities?
		38	Top level management defined roles in digital transformation	Does top level management have defined roles in the digital transformation?
	O	39	Value network is captured in governance structure	Is the value network captured in the company's governance structure for the digital transformation?
		40	Governance is optimized	Is the company's governance structure being optimized through quantitative measures? (Data is used to make decisions regarding roles and tasks)
Enterprise Architecture	P	41	Project architect is appointed	Is a project architect appointed, responsible for the architecture of digital transformation projects?
	M	42	EA structure is defined	Is an Enterprise Architecture structure defined, including Industry 4.0 endeavors?
		43	Supporting tools for EA are used	Are supporting tools for Enterprise Architecture used?
	E	44	Standardized EA within the organization, used in decision making	Is a standardized Enterprise Architecture practice integrated into the organization and used for decision making?
		45	Reference architecture used	Is a reference architecture for Industry 4.0 and Enterprise Architecture defined and used?
	O	46	EA is being improved and steers organization	Is the Enterprise Architecture continually being improved to match business goals?
		47	Full supply chain within EA and actively contributing to improvement.	Is the supply chain incorporated in the company's Enterprise Architecture and actively contributing to improvement?
Change management	P	48	Innovation on project level	Does Industry 4.0 innovation take place on a project level?
		49	First I4.0 project delivered	Is the first Industry 4.0 project delivered?

	M	50	Projects in a controlled manner	Are Industry 4.0 projects executed in a controlled and planned manner?
		51	Multiple projects implemented and maintained	Are multiple Industry 4.0 projects implemented and maintained?
	E	52	Standardized change management process within EA	Is a standardized change management process present to change or transform existing processes through the organization?
		53	Innovation plan for future projects	Is an innovation plan in place for future developments regarding Industry 4.0?
	O	54	Disrupt and enhance existing processes	Is the organization able to disrupt and enhance existing processes?
		55	A plan is in place on value network integration	Is a plan in place on how to integrate the Industry 4.0 efforts of the value network/-supply chain?
Knowledge	P	56	Assessment of in-house knowledge has taken place	Has an assessment taken place or is a basic view present on in-house knowledge regarding Industry 4.0 and Enterprise Architecture?
		57	External knowledge is being hired	Is a basic view present of required knowledge for Industry 4.0 and Enterprise Architecture in the organization?
		58	A basic view is present regarding required knowledge	Is external knowledge concerning the digital transformation being hired *in case knowledge is not sufficient*?
	M	59	Required knowledge capabilities for digital transformation are present	Are the required knowledge capabilities for the digital transformation present?
		60	Need-based training takes place	Does need-based training take place to improve the level of capabilities of employees regarding Industry 4.0?
		61	Knowledge management framework is defined and in EA	Is a knowledge management framework defined and present in the Enterprise Architecture?
	E	62	Knowledge management framework fully integrated into the organization.	Is the knowledge management framework fully integrated into the organization and used to steer training and capability acquirement?
		63	Budget for people development is available and being used	Is budget available for personal development regarding Industry 4.0?
		64	An overview of future knowledge is present	Is it clear what capabilities regarding Industry 4.0 and Enterprise Architecture are desired in the future?
	O	65	I4.0 and EA knowledge is being optimized	Are knowledge capabilities for I4.0 and EA being optimized through dedicated training based on future goals and quantitative measures?
		66	Periodic measurements of knowledge take place	Do periodic measurements of knowledge capabilities for I4.0 and EA take place?
		67	Innovation lab or external partnership is used	Are innovation labs or external partnerships used to expand the company's knowledge base regarding I4.0 and EA?
Culture	P	68	A cultural assessment has taken place	Has an assessment taken place or is a basic view present of the current culture in the company regarding Industry 4.0 (adoption)?
	M	69	Measures are in place to improve culture regarding the digital transformation	Are measures in place to alter culture regarding the digital transformation based on an assessment or view of current culture?
		70	Incentive mechanism is in place to incite DT involvement	Is an incentive mechanism in place to incite involvement in the digital transformation?
	E	71	Technology ownership is present regarding Industry 4.0 innovations	Is (a feeling of) technology ownership regarding Industry 4.0 innovations present in the company?
		72	Deliberately hiring people savvy with technology/Ii4.0	Is technology/Industry 4.0 affinity consciously taken into account when hiring people?
	O	73	An innovative culture is present in the company where employees are bottom-up contributing to innovation	Is an innovative and digital culture present in the company, where employees are actively bottom-up contributing to innovation?

		74	The company is actively gathering and sharing knowledge with other organizations	Is the company actively learning from other organizations to improve their culture, and is the company sharing knowledge with other organizations in their value network?
Leadership	P	75	Responsible manager has willingness and skills to lead digital transformation	Does the responsible manager(s) for the digital transformation have the willingness and skills to lead and push the digital transformation?
	M	76	Management is setting vision and examples	Is management setting a clear vision and examples to clearly define for employees what the digital transformation brings them?
		77	Management structure is controlled	Is a management structure in place concerning the digital transformation?
	E	78	Management framework is integrated and standardized in EA	Is the management framework for the digital transformation fully integrated and standardized in the Enterprise Architecture?
		79	Management development program is in place	Is a management development program in place to improve management capabilities to lead the digital transformation?
	O	80	Managers are change leaders for the digital transformation and pursue innovation without restrictions	Are managers change leaders able to pursue digital transformation innovation without restrictions?
Data governance	P	81	Data ownership and stewardship are defined	Are data ownership and data stewardship defined?
	M	82	Data governance framework is defined in EA	Is a data governance framework defined within the Enterprise Architecture
		83	Security plan is defined	Is a security plan defined and used?
	E	84	Data governance framework fully integrated and standardized in the organization.	Is the data governance framework fully integrated and standardized within the Enterprise Architecture and within the organization?
	O	85	External governance is evaluated for best practices that are being utilized when beneficial.	Are industry case studies being evaluated for best practices to improve data governance and subsequently being utilized when beneficial?
		86	Data governance processes are continually refined and improved	Are data governance processes continually refined and improved?
Data quality	P	87	Assessment of current data quality and acquisition has taken place	Has an assessment taken place or is a basic view present of current data quality and acquisition?
		88	Basic idea is present of what data quality requirements are	Is a basic view present of data quality and acquisition requirements?
	M	89	Required data quality and acquisition is defined and standardized	Are the required data quality and acquisition defined through objectives, rules, and criteria?
		90	Data architecture is present within EA	Is a data architecture present as part of the Enterprise Architecture?
		91	Data warehousing is managed	Is data warehousing available and being managed?
		92	Sensory technology is managed	Is sensory technology being managed?
	E	93	Data quality and acquisition process is integrated and standardized within the organization	Is the data quality and acquisition process integrated and standardized within the organization?
		94	Periodic data quality assessments are conducted and improved upon	Do periodic data quality assessments take place to improve the data quality?
		95	Data quality and acquisition goals are evaluated and adjusted accordingly	Are required data quality and acquisition being (re)evaluated and when necessary adjusted?
	O	96	Data quality is optimized through I4.0	Are Industry 4.0 technologies being used to enhance and use data in a meaningful way?

		97	Analyses and visualizations drive improvement company-wide	Are analyses and visualizations from Industry 4.0 applications used to drive company improvement?
		98	Data quality milestones are regularly reviewed	Are data quality program milestones and metrics regarding Industry 4.0 regularly reviewed?
Standards	P	99	Assessment of current standards and protocols have taken place	Has an assessment taken place or is a basic view present of current standards and protocols?
	M	100	Required standards and protocols are defined	Are required standards and protocols for Industry 4.0 and Enterprise Architecture defined?
	E	101	All relevant applications, systems, and procedures are checked and adhere accordingly	Do all relevant applications, systems, and procedures adhere to the defined standards accordingly?
	O	102	Standards and protocols are quantitatively evaluated and improved	Are standards and protocols concerned with Industry 4.0 and Enterprise Architecture quantitatively evaluated and improved?
		103	Emerging standards are being evaluated for new opportunities	Are emerging standards concerned with Industry 4.0 and Enterprise Architecture being evaluated for new opportunities?
Technology	P	104	A basic view of current technological capabilities is present	Is a basic view present of current technological capabilities?
		105	Specific tech capabilities are being acquired project-based	Are specific technological capabilities being acquired project-based?
	M	106	(Required) tech capabilities are defined and documented through EA	Are required technological capabilities defined and described through the Enterprise Architecture?
		107	Supporting tools for i40.0 are defined	Are supporting tools for Industry 4.0 defined?
		108	Obsolete technology is identified	Is obsolete technology identified?
		109	New tech capabilities are being acquired based on requirements in planned fashion	Are new technological capabilities being acquired based on the earlier established requirements?
	E	110	Plan for future tech capabilities is present	Is a plan for future technological capabilities present?
		111	Technical capabilities management framework is integrated into EA	Is a technical capabilities management framework integrated into the Enterprise Architecture?
		112	Obsolete tech is being removed	Is obsolete technology being removed?
		113	Portfolio management and procurement related to I4.0 is established	Is portfolio management and procurement related to Industry 4.0 established?
	O	114	Tech capabilities are continuously being improved	Are technological capabilities concerned with Industry 4.0 and Enterprise Architecture continuously being improved?
		115	Capabilities are extended through capabilities of value network	Are the company's technological capabilities concerned with Industry 4.0 and Enterprise Architecture being extended through the addition of the value network?

Table 31: Model V5 requirements and corresponding questions per focus area

R Interviews presentation visuals

This appendix shows the visuals used during the first and second interviews.

Figure 18 details the manner in which participants were guided through the focus areas and prompted to answer on the validity and priority of the focus areas.

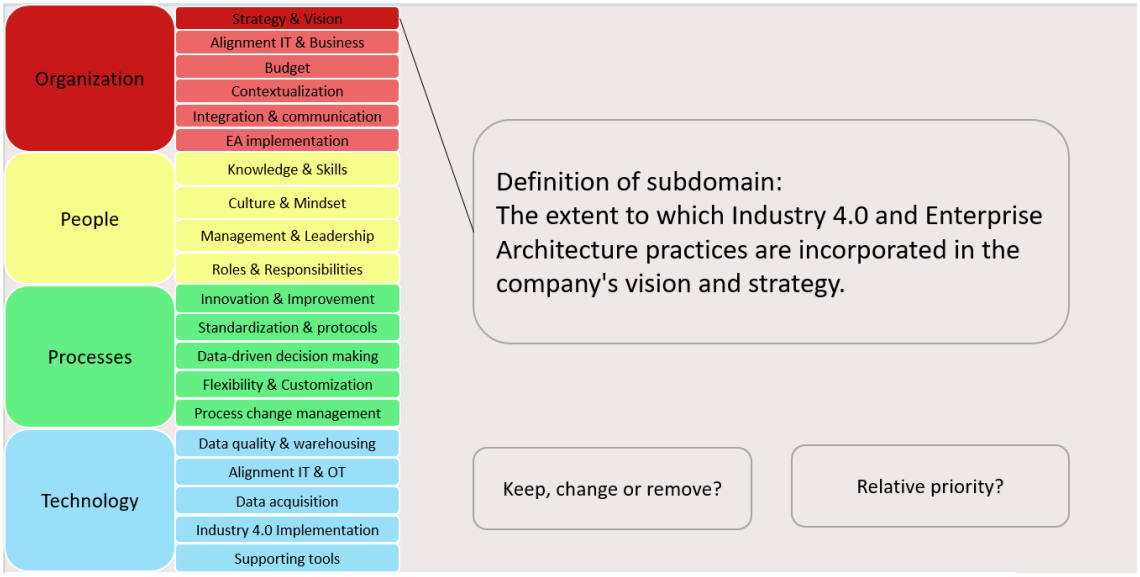

Figure 18: Interview 1 presentation layout

Figure 19 details the manner in which participants have presented the roadmap as a result of their organization's maturity assessment.

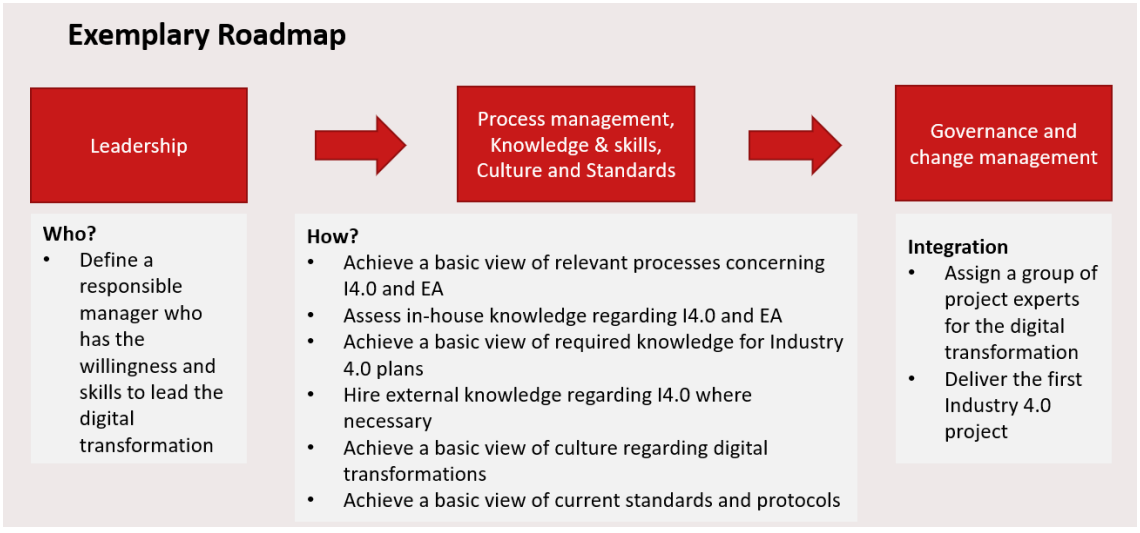

Figure 19: Interview 2 roadmap layout