An Enterprise Architecture Planning Process for Industry 4.0 Transformations

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Keywords: Enterprise Architecture Management, Enterprise Architecture Planning, Industry 4.0, Industrial Internet of Things, Transformation, Modeling, Process, Metamodel.

Abstract: Industry 4.0 changes the manufacturing industry significantly. In order to stay competitive, companies need to develop new business capabilities and business models that are enabled by Industry 4.0 concepts. However, companies are currently struggling with expensive and risky IT transformation projects that are needed to implement such concepts. We observed a lack of research on the planning and modeling part of IT transformations towards Industry 4.0. Therefore, we conducted a series of expert interviews on the topic of enterprise architecture in the context of modeling and planning Industry 4.0 transformations. As a result, we were able to develop a metamodel that can be used as target model for planning endeavors and a planning process that helps as guideline for such planning projects.

1 INTRODUCTION

Industry 4.0 (I4.0) is substantially influencing the manufacturing industry (Stock and Seliger, 2016). Companies need to adapt their business processes and business models in order to be able to stay competitive (Kaidalova et al., 2017).

Among the goals of the digital transformation is to optimize processes over the whole value chain. To achieve this, horizontal and vertical integration are essential. Hence, the concept of interoperability is of crucial importance, as it enables humans and organizations to connect and communicate via IoT and Cyber Physical Systems (CPS) (Xu et al., 2018). In order to gain benefit, corporations either have to introduce new connected IT systems (e.g. CPS), or legacy machines need to be upgraded so that they are able to communicate with other systems. This leads to new challenges due to the pervasiveness in all types of supply chains and organizations, which results in a new level of IT complexity that demands for a holistic management approach of the business, the IT, and the production IT (Nowakowski et al., 2018).

Enterprise architecture (EA) gives a consolidated and broad view of an entire company (Aier and Gleichauf, 2010) and is used to capture the essentials of business, IT, and its evolution (Lankhorst, 2013).

Enterprise architecture management (EAM) is an IT management discipline that uses the consolidated view of the EA to optimize IT support for business execution and reducing IT costs.

According to TOGAF (The Open Group, 2011), *EA planning* is one of the core processes of EAM and it aims at planning IT transformations that are aligned with the overall strategy of an organization. Such transformation projects are usually conducted in multiple phases and aim at meeting the emerging and current requirements of the business (Luftman et al., 1993; Nowakowski et al., 2017). EA planning is executed by modeling different scenarios (*to-be* architectures) that represent the future steps in the transformation project, which transforms the current architecture (*as-is*) into a specified target architecture. Afterwards, the planned steps are documented, executed, and evaluated. The planning phase is of crucial importance to ensure that digital transformations are successful.

In our research, we consider an EA planning methodology for digital transformations. Our past research on the topic of EA planning in the context of I4.0 transformations (Nowakowski et al., 2018) indicated that there is a need for a structured planning

Nowakowski, E., Farwick, M., Trojer, T., Häusler, M., Kessler, J. and Breu, R.
An Enterprise Architecture Planning Process for Industry 4.0 Transformations.
DOI: 10.5220/0007680005720579
In *Proceedings of the 21st International Conference on Enterprise Information Systems (ICEIS 2019)*, pages 572-579
ISBN: 978-989-758-372-8

process and a metamodel for I4.0. These two artifacts are able to guide companies in their planning endeavors. The I4.0 metamodel proposes a target data model for the transformation project and the process helps to realize it by using an agile approach. Both of these artifacts were developed and evaluated based on an interview series with industry experts and are presented in the paper at hand.

The remainder of this paper is structured as follows: Section 2 describes our research method and research questions. Furthermore, in Section 3 relevant related work is presented. In Section 4, we describe our interview results consisting of the proposed I4.0 metamodel and the I4.0 planning process in detail. Section 5 contains the discussion and future work. Finally, Section 6 concludes our paper.

2 RESEARCH METHOD

The research presented in this paper is based on Hevner's three-cycle approach for design science research (DSR) that consists of a relevance, a design, and a rigor cycle (Hevner, 2007). The goal of DSR is to create IT artifacts that are able to solve organizational problems and to evaluate them rigorously (Hevner et al., 2004). Figure 1 depicts how we applied the DSR approach.

The design cycle builds the core of the DSR approach. In this cycle, we developed a metamodel and a planning process for I4.0 transformation planning. The requirements for the artifacts and the acceptance criteria for their evaluation come from the relevance cycle. Considering the rigor cycle, the DSR artifacts are influenced by the results of the conducted literature review.

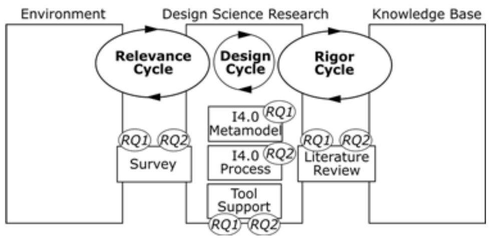

Figure 1: DSR applied to our research project (based on (Hevner, 2007)).

For analyzing the relevance of our research, we conducted an interview series consisting of nine experts in the field. From these interviews, we aimed to establish a deeper understanding of how I4.0 planning is conducted. Additionally, we discussed relevant metamodel elements and the connections between them, and evaluated the developed metamodel.

The following two research questions (RQ) build the core of this paper:

- RQ1: What kind of information should be part of the documentation model so that EA planning in the context of I4.0 can be conducted?
- RQ2: Which steps are needed to conduct I4.0 transformation planning and how should the process be structured?

3 RELATED WORK

In this section, related work for I4.0 metamodels, frameworks, and transformation processes that are conducted with the help of EA is presented.

Molano et al. (2018) developed a metamodel for the integration of the Internet of Things (IoT), social networks, the cloud and I4.0. However, their metamodel is mainly focused on communication flows from the various sensors and actuators to a specific IoT device.

Furthermore, Bücker et al. (2016) created a framework, which is based on I4.0 design principles and an approach to structure an organization. For achieving this, they developed a metamodel of the proposed I4.0 transformation process, which focuses on change management of the organizational aspects.

Goerzig and Bauernhansl (2018) developed a method which makes use of agile EA for digital transformations. Their approach is based on Scrum (Schwaber, 2004), hence, the EA evolution is done iteratively with the help of sprints and via user stories and a backlog.

Additionally, reference architectures for smart industry, such as the "Industrial Value Chain Reference Architecture-Next" (IVRA Next) (Industrial Value Chain Initiative, 2018), the "Industrial Internet Reference Architecture" (IIRA) (Industrial Internet Consortium, 2017), and the "Reference Architecture Model Industrie 4.0" (RAMI 4.0) (Bitkom et al., 2016) were developed. Furthermore, there are efforts to align the proposed architectures of RAMI 4.0 and the IIRA (Plattform Industrie 4.0 and Industrial Internet Consortium, 2018).

Considering EAM, the most commonly used framework is TOGAF (The Open Group, 2011) with its architecture development method (ADM), which is a generic method intended to be used by a wide variety of different enterprises (The Open Group, 2011). Furthermore, the modeling language

ArchiMate (The Open Group, 2016) is considered as standard. ArchiMate introduced a physical layer in version 3.0 (The Open Group, 2016) that was inspired by the I4.0 development. Franck et al. (2017) found shortcomings of ArchiMate 3.0 while they worked on an EA solution for I4.0 and developed new concepts and modeling patterns to compensate for them. Furthermore, Rogers (2016) conducted research on I4.0 simulation-based information assets that is based on TOGAF.

Zimmermann et al. focus on the transformation of EA for the IoT, architectural decision making for digital transformations, and the evolution of EAs (Zimmermann et al., 2016, 2015b, 2015a). However, the authors mainly discuss the improvement of decision-making and do not elaborate on techniques that help practitioners to model and plan target architectures in the context of IoT or I4.0.

Finally, Kaidalova et al. (2017) discuss the challenges in integrating operational technology (OT) into EA, where OT consists of the IT systems and production machines that are located on the shop-floor of a company. The researchers concluded that traditional EA layers (business, application, and technology) are suitable but not optimal for structuring OT. They propose that refinement layers are needed, e.g. by identifying a “mixed zone” between OT and business IT that has a different structure and granularity (Kaidalova et al., 2017).

4 INTERVIEW RESULTS

With the help of the interviews we aimed to gain information about the process how I4.0 transformation projects are conducted and about the required artifacts and resources. Furthermore, we investigated on which abstraction level the planning needs to be done and what is documented during this process.

For this purpose, we interviewed professionals in the field of EAM who are working in the industry and have experience with digital transformation projects. The interviews were conducted in the timespan between October and November 2018. We were able to interview nine interviewees from four different industry sectors in Germany, Austria, and Switzerland (see Table 1).

The interviewees were identified via Linked-In and XING – a business social network for German-speaking countries. Here, it was specifically searched for enterprise architects in industrial companies. We contacted 42 potential interview partners from which ten responded (~24%). Six of these and three of our former interview partners, from which two are consultants with I4.0 experience, agreed to participate. Hence, we conducted our interview series with nine participants in total that are all employed in different companies. Additionally, we were able to use a part of the interview results from our previous research (Nowakowski et al., 2018).

Table 1 gives an overview of the interviewees’ position in the company, the location, as well as the industry sector. The role of the participants is added to the abbreviation (see last row in Table 1).

Table 1: Interviewee overview.

Participant and Role	Country	Industry sector
PE1	Austria	Manufacturing
PE2	Germany	Manufacturing
PE3	Germany	Manufacturing
PE4	Germany	Manufacturing
PE5	Germany	Manufacturing
PE6	Germany	Chemical
PE7	Germany	Pharma
PC8	Germany	Consulting
PC9	Switzerland	Consulting
E = enterprise architect, C = consultant		

The interviews were conducted in a semi-structured way, were based on a fixed set of open questions, and took in average about 45 min. Furthermore, they were recorded for later analysis.

The interviews were transcribed and coded according to the procedure described by Mayring (2014). For this purpose, a completely *data-driven* coding frame in combination with *successive summarizing*, as proposed by Flick (2014), was used. The coding frame is the basis of the analysis methodology and consists of main and subcategories. Main categories are aspects for which more information are needed and subcategories specify what is said in respect to the main categories (Flick, 2014). With the help of successive summarizing, relevant passages of the interviews were paraphrased and the superfluous aspects were deleted. After that, the categories and subcategories were built by summarizing similar paraphrases. The next step was to check if there exist similar subcategories and to collapse them. Two rounds of coding were conducted based on the coding frame. This was done by one coder at different points in time and the results were compared in order to ensure coding consistency. As proposed by Flick (2014), the transcripts were segmented in a way that each unit fits exactly one category or subcategory of the coding frame to ensure that each time the codes were applied to identical parts of the transcripts. For checking if our coding frame needs to be adapted, we applied this procedure to a subset of our transcripts before it was used for the analysis of all transcripts. Finally, as suggested by Flick (2014), the final coding of all transcripts and the preparation of the coding results for answering the research questions was conducted.

From the interviews, we were able to extract the proposed I4.0 target metamodel, and the planning process for I4.0 transformations, which are described in detail in the following subsections.

4.1 Metamodel for I4.0

Based on the interview results we were able to enhance the proposed four-layer model from our previous work (Nowakowski et al., 2018), which builds the basis for our I4.0 target metamodel. The layered model, shown in Figure 2, adapts the classical three-layer approach of EAM (business layer, application layer, and technology layer) (The Open Group, 2011) and adds two new layers. The operational layer tackles the growing similarities of production machines and applications, as they now have the same security, update, and release management requirements. Hence, it is not possible to distinguish between technology and application layer anymore. Additionally, these automation assets now need to be part of the EA, while in the past OT and business IT were strictly separated from each other (Nowakowski et al., 2018). These assets are located in the operational layer and are connected to the business, application, and technology layers. Furthermore, the external interface layer is used for the horizontal integration of the business partners (e.g. suppliers) and customers, as they are now directly involved with the production processes.

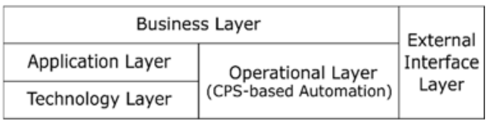

Figure 2: Five-layer approach for EAM.

The proposed metamodel, shown in Figure 3, depicts a target EA model with incorporated I4.0 concepts. In the following paragraphs, the metamodel layers and elements are described in detail.

External Interface Layer. As depicted in Figure 2, the external interface layer connects to the business and to the operational layer. It normally consists of partner systems and the customer. These two information sources are important to achieve horizontal integration, which is one key aspect of I4.0 (Xu et al., 2018). The production system is connected via an interface to the partner systems to be able to e.g. order parts automatically. On the other hand, the customer is directly involved in the production process and is therefore able to order highly customized products. The external interface layer is not included in the metamodel because it is not directly part of the EA. However, the business capability to manage this information needs to exist (PC9).

Standard EA Layers. The *business layer* consists of *business capabilities*, *business processes*, and the specific *product* that is produced. Here, the new aspect is the connection to the operational layer. The *application layer* consists of the *applications*, the *interfaces* and *data objects* that are transferred with the help of these interfaces. In the case of I4.0, the interface is also connected to the operational layer, which makes it e.g. possible to analyze machine data. The *technology layer* consists of *technology assets* like servers and storage devices. According to the interviewees, these assets are needed in order to be able to conduct impact analysis and are modeled on a course-grained level. Additionally, as many companies are currently migrating their assets to the cloud, detailed technology modeling is not important anymore (PE3).

Operational Layer. The difference to established EAM metamodels is that the business layer, the application layer, and the technology layer are now connected to the operational layer, which makes it possible that e.g. production machines and sensors can be associated to a business capability. Furthermore, it is possible to drill down directly to the machines and sensors, which is according to the interviewees necessary in order to be able to plan I4.0 transformations. According to PC8 and PC9, it is crucial to know the interdependencies between OT and business IT in order to be able to see how well it is integrated.

As can be seen in Figure 3, the operational layer consists of *production processes*, *I4.0 components* and *sensors*. All of these elements can be connected to *business capabilities* that are needed for the execution of I4.0 business models. The I4.0 components, as well as the products, may have sensors attached. This enables monitoring and analyzing production machines that are relevant for executing the production processes. Sensor data can be transferred via an *interface* and be analyzed with the help of an *application* to e.g. conduct predictive maintenance. Additionally, customers now have direct influence on the production process. Hence, it is necessary that the highly customized products can be individually produced by the factory. For this purpose, the I4.0 components need to be able to communicate with each other. Additionally, the sensors on the product enable the introduction of new services. With the help of detailed analysis of the sensor data and the actual usage of the product, it is possible to create new business models. Furthermore, it is important to know in which factory the *I4.0 components* are located; therefore, the components are linked to the *location*.

According to RAMI4.0 (Bitkom et al., 2016), an I4.0 component comprises one or more objects and an administration shell that consists of the functions of the technical functionality and the data for virtual representation.

The production processes are modeled separately from the business processes. According to the interviewees the two kind of processes differ significantly. Production processes are modeled in the OT department and are solely concerned with the production.

Enterprise architects mostly work with aggregated data and in some situations want to be able to drill down to a sensor type. Hence, in the proposed metamodel the I4.0 components and the sensors are only modeled with the type information attached. Therefore, it is possible to distinguish between different types of sensors and machines without needing to know about the specific instances. This makes a drill down and impact analysis still possible. Additionally, the I4.0 component can be used as an interface to the operational department. In this case, the operational department models the low level OT architecture and is able to connect it to the EA via the operational layer, which enables to create holistic plans. This is especially important for digital transformation projects, as mentioned by PE1. Though, choosing the right scope and level of granularity for the planning is challenging.

With the help of ArchiMates' physical layer, the OT can be modeled in detail. However, the interviewees required an abstract view on the production machines and other I4.0 components that is based on type information. Hence, in our metamodel only abstract concepts are modeled.

4.2 Transformation Planning for I4.0

In this subsection, the proposed planning process (see Figure 4) is described in detail. The process was developed on the basis of our interview results and existing planning methods for EAM.

According to our interviewees, a digital transformation has to be conducted in an agile way because waterfall methods are too rigid for this kind of project. We analyzed the results of our interviews and extracted the relevant planning steps that our interview partners mentioned and developed an agile I4.0 transformation planning process. This process is based on Goerzig and Bauernhansl (2018), which makes use of the agile Scrum method (Schwaber, 2004). The process consists of several steps and is iterative. Goerzig and Bauernhansl (2018) divided their approach into two cycles, a micro and a macro cycle. The macro cycle defines the architecture of the

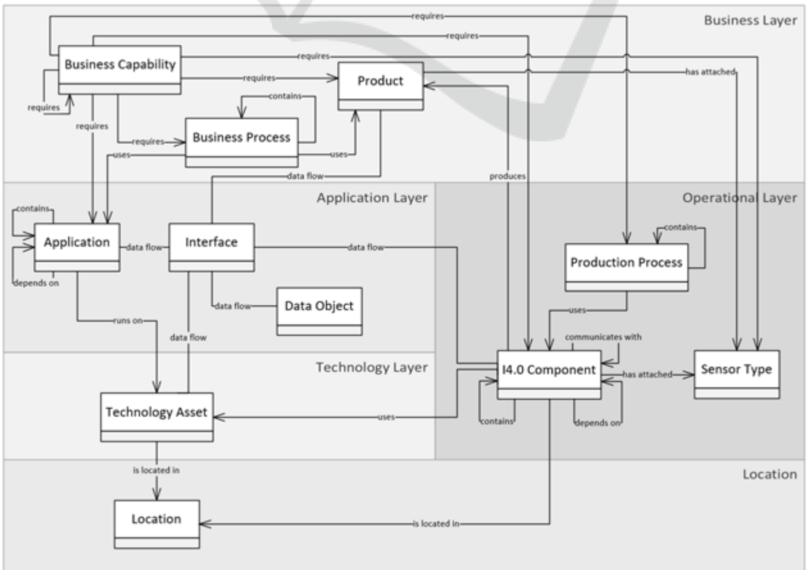

Figure 3: EA metamodel considering Industry 4.0 concepts.

entire company and the micro cycle is used for the implementation and testing of single functions. For our approach, we use a specification, a project and an implementation cycle. In the specification cycle, the whole architecture specification happens, while in the project cycle, the business stories are implemented and tested. Business stories are similar to user stories in the Scrum context and describe a business goal. Finally, the implementation cycle is needed for implementing the resulting IT projects.

We used the digital business strategy as initial point of the approach, which contains basic decisions concerning scale, speed, and scope of the digital technology application in the enterprise (Goerzig and Bauernhansl, 2018). In our definition, it consists of scope, scale, and speed of the I4.0 transformation.

Matt et al. (2015) concluded that it is necessary to derive the transformation strategy out of the digital business strategy. The transformation strategy consists of organizational and technological principles for the implementation of the transformation (Goerzig and Bauernhansl, 2018). Furthermore, the strategy influences the model of the target architecture.

According to the interviewees, the first step in the specification cycle is to derive the business model from the digital business strategy. The business model contains information like customer segments, revenue stream, and value propositions (Goerzig and Bauernhansl, 2018).

The next step is to derive the needed business capabilities from the new business model (PE2, PE3, and PE4). After that, the capabilities need to be analyzed and compared with the currently available capabilities to identify gaps. This analysis is mostly done with the help of capability maps.

After the capability gaps are found, the required business processes are derived from the new capability. Again, the set of new business processes is compared to the currently available processes and the gaps are documented. This is done with the help of business process landscapes or maps.

With the knowledge gained from the steps before, a target EA architecture can be developed. This architecture needs to close the found gaps in order to be able to introduce the new business model. Additionally, the target model is influenced by the transformation strategy, which dictates the technological and organizational principles of the transformation. Furthermore, the application and the technology landscape need to be analyzed to make sure that the new business processes are appropriately supported. This is usually done with the help of landscape visualizations, which show the technologies or applications and their interdependencies. If there are gaps to the current architecture, they are documented again. According to the interviewees, for the planning of the target architecture multiple scenarios are developed, which are compared and the one that fits best is chosen to be implemented. The fit criteria depend on the transformation strategy. As last step, the gaps to the as-is architecture are formulated into business stories, which describe the users, the desired functionality, and the benefit and are put in the architecture backlog. Afterwards, the business stories are prioritized and ready to be implemented.

When the best fitting target architecture is chosen, the first iteration of the specification cycle is finished and the project cycle begins with choosing the prioritized business stories from the backlog. The amount of the chosen business stories depends on the aimed speed of change of the company, which is defined in the transformation strategy.

The next step is to implement the business story with the highest priority. For this purpose, the gaps that were found in the specification cycle are analyzed again and closed according to the specified target architecture.

After that, it is checked if the architecture is now capable of depicting the new business story and if all identified gaps are closed. To evaluate the newly implemented business capability a proof of concept (PoC) with a pilot customer can be used. The newly needed IT artifacts are developed in the implementation cycle and tested again.

In the review, the final step in the project cycle, the state of the business story is either marked as done, adaptations need to be implemented, or the overall impact on the architecture needs to be analyzed again. If it is marked as done, the teams start with the next business story. Otherwise, if there are still adaptations required, the project cycle starts again. Finally, if the changes generate findings that have an impact on the whole architecture, the specification cycle has to start again (Goerzig and Bauernhansl, 2018).

According to Goerzig and Bauernhansl (2018), the architecture after the first iteration of the specification cycle is still very rough and more details are added with every run. Additionally, the specification cycle should always give enough space for decisions in the project and implementation cycle.

However, the business critical core processes should still be planned with the help of a waterfall method (PE4 and PE5). Additionally, PE5 mentioned that they are using agile methods for planning the architecture and the introduction of new capabilities

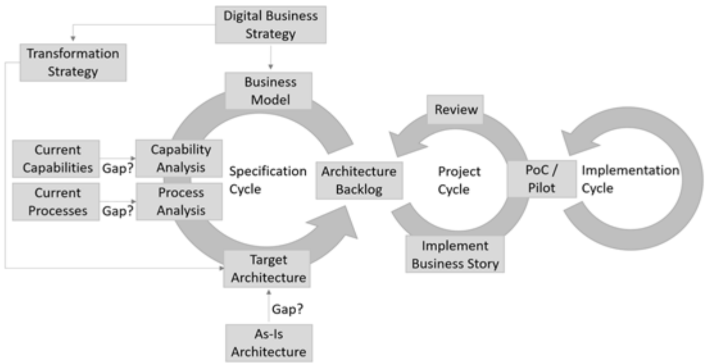

Figure 4: Agile EA planning for Industry 4.0 transformations (based on (Goerzig and Bauernhansl, 2018)).

until the PoC phase. Afterwards, for the business wide release they are planning based on waterfall methods.

5 FUTURE WORK

Our future work will consider further evaluation of the proposed artifacts. Hence, we plan to conduct a new interview series in which the interviewees will use the planning process and the metamodel for modeling a small example transformation. For this purpose, a tool will be used that is outcome of our previous research on automated EA documentation (Trojer et al., 2015). Additionally, confirmatory interviews are planned to evaluate if the developed artifacts are useful in their current state. Furthermore, we will evaluate the metamodel and the planning process with the help of a case study to ensure their applicability and a better alignment between the two artifacts.

The planning process needs further investigation, as details like team size and holistic EA planning via agile methods in general are still open research questions that are subject of current research on this topic.

Finally, the proposed research artifacts can be used to extend the TOGAF ADM and therefore to introduce a holistic planning guideline for digital transformations into the framework.

6 CONCLUSION

This paper presented an EA planning approach for digital transformations that consists of a planning process and a metamodel that serves as a target data model. Both of these DSR artifacts were developed based on the results of a series of expert interviews.

Furthermore, the interview results showed that OT needs to be part of the EA in order to be able to plan such transformations. This was materialized by introducing a new operational layer to the standard three-layer approach of EAM. This layer consists of I4.0 components, the production processes and sensors, where the I4.0 components are connected via an interface to the application layer. The I4.0 components and the sensor may not be modeled in detail, but on an abstract basis only considering their types. The operational layer can also be used as a modeling interface to the detailed OT models and therefore connects both worlds.

The proposed planning process is an agile approach that is based on the Scrum method. The process makes a detailed planning of the EA in several iterations possible. This is needed for the introduction of I4.0 concepts, as it is faster to conduct than planning based on a waterfall method.

ACKNOWLEDGEMENTS

This research was partially funded by the research project “txtureSA” (FWF-Project P 29022).

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