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Enterprise architectures for the digital transformation in small and medium-sized enterprises

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Abstract

The transformation towards smart connected factories causes enormous changes in mechanical engineering industry starting from the development of cyber-physical production systems up to their application in production. Enterprise architectures already offer suitable methods to support the alignment of the internal IT landscape. New demands like customer involvement, iterative development and increased business-orientation arising with these digitized products require new approaches and methods. This paper presents the foundation and the first steps aiming at the development of a method for the holistic planning of the digital transformation in small and medium-sized mechanical engineering enterprises.

1. Introduction

Currently, customers increasingly strive for maximization of personalized value. This becomes particularly obvious in the demand for individualized products and the increasing influence of customers on the development and the production processes [1]. Factories can only meet this challenge by the application of digital technologies. In Germany, the term Industrie 4.0 represents the aspired target state. Through improvements in information, communication and automation technology live information is available over life cycles of products, processes and factories. Production systems, products and humans are closely networked. Moreover, the resulting big data is used for holistic optimization. [2, 3, 4] This special situation gives rise to opportunities and risks for mechanical engineering enterprises. Based on customer data there are numerous new possibilities for product and process improvements including the optimization of the machining process or spare part forecasting services. At the same time, they are confronted with new demands. Customers not just want to buy a physical machine but service systems, consisting of hard- and software, that offer additional value in their unique context [1, 4, 5]. Examples are context-based

features and information for machine operators that support manufacturing to adapt rapidly changing customer needs. To realize such use cases a close collaboration of manufacturers and mechanical engineering enterprise is required. Through this development, IT is not any longer just a technological tool to improve the efficiency of internal processes. By becoming an essential part of the value creation it grows up to a new source of competitive advantage and thus takes a transformative role [5]. The required extension of products by digital components to the point of cyber-physical systems and their integration into service systems leads enterprises in mechanical engineering into a fundamental change process – the digital transformation. Besides mechanics and electronics they now need to develop digital capabilities and implement them into fast-changing, cross-company processes and structures. Especially for small and medium-sized enterprises (SMEs) this is an enormous challenge [6].

With the help of business model appraoches, many enterprises already started to design digital value creation concepts. But these means are very limited when it comes to deriving and implementing processes and IT services. In contrast to existing IT-based products, the new service logic requires a holistic process view. To take full advantage of the

digital opportunities adequate models, methods and tools are needed [4, 7]. With enterprise architectures (EA) information systems literature already offers a well-proven solution for this challenge [8, 9]. The aim of this paper is to examine if this approach is appropriate for digital transformation in SMEs of mechanical engineering. Therefore, digital transformation and EA are defined. Afterwards, strengths and weaknesses of EA in the context of digital transformation in SMEs are analyzed. In addition, this paper presents the first steps for the development of a method for the holistic planning of the digital transformation in small and medium-sized mechanical engineering enterprises.

2. Digital Transformation in Small and Medium-sized Enterprises

The following section outlines the state of the art in the field of digital transformation in SMEs. First, a closer look at the definition of digital transformation is required. In change management, the term transformation is used to describe the extent of strategic change. Whereas in a realignment there is just a slight change in the way an enterprise operates, in a transformation it changes its paradigms of doing things. [10] As shown in figure 1 in enterprise transformation literature the term is defined as a fundamental change during which enterprises reinvent themselves. This contains a change of the context in which the enterprise is active. The context includes the way of operation and the previous sources of success. Moreover, the enterprise substantially alters its relationships with its key constituencies like customers, suppliers or employees. The initial point of transformation is a radical change in the economic or market context. This can lead either to an experienced or an expected value deficiency and thereby influence the speed of change. [11, 12] On this basis it can be distinguished between an evolutionary transformation in incremental steps and a revolutionary transformation by a big bang. The speed of change depends in most cases on whether the enterprise is forced to or changes proactively. [10] Result of a transformation is a conscious and sustainable change in business performance [11]. It may lead to new value propositions as products and services, different ways of interaction with the customer in terms of delivery and provision of offers and new organizational forms to provide these offers to the customer [12].
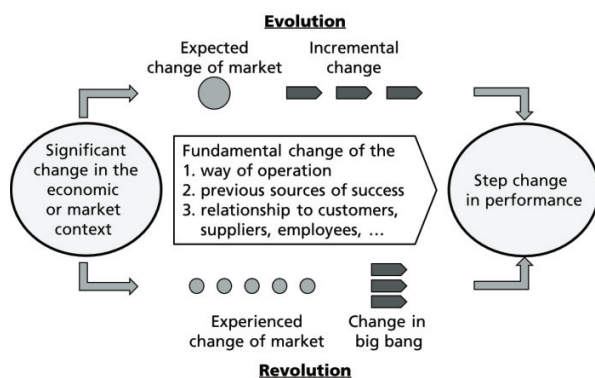

Fig. 1. Process of enterprise transformation.

The term digital covers gathering, storing, processing, providing and using information electronically with the help of information technology (IT). Through ever lower costs and the increasing pervasion of IT nowadays large information volumes can be shared worldwide at minimum costs. [3, 5, 13] The internet of things brings this development to the next level. By sensing and analyzing the context of the customer, this approach enable enterprises to get a deep insight into the customer motivations and create by this personalized customer value. [3, 5] One of the consequences is an enhancement of the relationship between provider and customer. Through the close networking of customers and providers digitization blurs the differences between them and enables cooperative value generation, also referred to as co-creation. Products evolve into services which are aiming at maximum value for both. [5, 14] Simultaneously digital technologies enable a fundamental reshaping of business towards cross-functional, modular and distributed processes [14]. This development increases business agility and empowers enterprises to act in turbulent environments like ecosystems. Ecosystems are self-containing and self-adjusting systems of loosely coupled actors that jointly create value. The basis of their relationship are institutional logics from which a set of rules and principles is derived. The importance of traditional, linear value chains decreases. [5, 15] A basic instrument to leverage the advantages of ecosystems are platforms. These modular structures facilitate the interaction between the actors. Platforms support the installation of rules for exchange and modular architectures. [5, 14] In summary, digital technologies become essential part of the value creation. For mechanical engineering enterprises as well as for new market actors this development offers chances to create new competitive advantages. Moreover digitization offers a possibility to fulfill the existing customer demands for a highly flexible supply of individual products. By reason of these significant changes the digitization can be seen as the initial point for a new wave of transformations.

At the moment, there is no common definition for the digital transformation. The following literature sources give a hint on the current discussion. Schallmo points out the networking of the value chain for improved decision-making. He defines digital transformation as the connection of actors over the value chain and the application of new technologies. In his view digital transformation demands capabilities for the gathering, the exchange, processing and analysis of data. The aim is to support decision processes and to initiate activities. Digital transformation influences enterprises, business models, processes, relationships and products to improve the performance and scale of the enterprise. [16] According to Matt et al. digital transformation involves the application of digital technologies with the aim of a change of key business operations, products, processes, organizational structures and management concepts. The authors describe manifold benefits like increased sales and productivity as well as innovations in value creation and customer interaction. [7] Nandico describes digital transformation as a change of an enterprise with the aim to provide new or enhanced products, services or both to the customer. A key enabler for this new offering or enhancement is the application of information technology. Thereby, enterprises try to create new business models, customer experience or operating models. [8] Whereas Matt et al. see the impact of digital transformation rather broad,

Nandico concentrates on service innovation.

In this paper, digital transformation is defined as a fundamental change process in enterprises initiated by new competitive advantages through the evolution of IT into an essential part of the value creation. To unlock these new potentials enterprises evolve their products into services and start to operate together with their customers in co-creation aiming at value maximization. Important enabler are context-sensitive systems that help to adapt the services to the individual and situational requirements of customers. In order to be capable of offering these digitized services enterprises have to think in modular, cross-functional and distributed business processes that allow them the integration into ecosystems. Result of the change is the ability to create personalized customer value at costs of mass production. Figure 2 summarizes the definition based on figure 1.

Hereby, several requirements for planning and development tools arise. Since it aims for the realization of innovative forms of value creation, an approach should be able to integrate ecosystems and platforms. Secondly, in order to create customer-oriented and context-based solutions, the approach should allow the analysis and documentation of the close interaction with the customer and a quick adaption of the necessary processes to changing market contexts. Because a digital transformation is a fundamental change process an approach should help enterprises to create a clear transformation strategy and to provide a clear vision of the future state to get the commitment of all stakeholders.

SMEs have special characteristics that influence the process of digital transformation and thus lead to requirements concerning the supporting tools. SMEs are very limited in their resources. On the one hand, their employees mostly do not have the required skills. Furthermore, they are tied to day-to-day business and are therefore not available for the development of new solutions. On the other hand, SMEs have only limited financial resources. Thus they cannot afford expensive external support. For digital transformation methods, this means that they should have very little demands for IT-capabilities and be very time-efficient. Moreover, it should be possible to apply them with a minimum of external support. Because of the financial shortage, SMEs are dependent on the success of the realized projects. Therefore, the expected returns of every project must exceed their costs and risks. A method for digital transformation should offer a good cost-benefit ratio. Since in SMEs the important decision are made by the CEO, he should be involved in the decision-making process. Another demand of SMEs is a clear description of how the results shall be realized. [6]

Enterprises in mechanical engineering are characterized by the development and system integration of long-lasting capital goods which are sold in a business-to-business relationship. The enterprises have a strong focus on product and technology innovation. [15] Currently, software services play a tangential role. They are mostly used to raise margins or to offer additional value to the customer. Software development and networking of machines are still a challenge for the branch. Thus, tools for digital transformation in mechanical engineering enterprises should be easy to use and understand in order to involve all relevant stakeholders. Additionally, they need to draw a clear picture of the transformation process and the expected results.
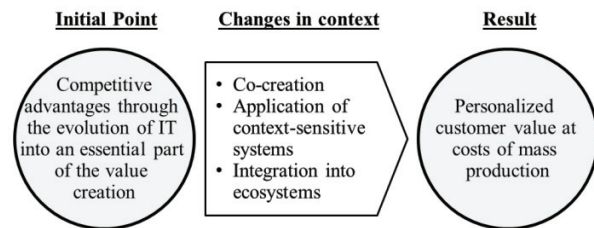

Fig. 2. Elements of digital transformation.

3. Embedding Enterprise Architectures in the Digital Transformation

The initial point of digital transformation is a digital business strategy. This is an organizational strategy that aims to create differential value by applying digital resources in formulation and execution. It goes far beyond traditional IT strategy which considers IT as a tool for improvement of business processes. It contains scope, scale and speed of digital business strategy as well as sources of business value creation and capture. [14] Since the digital transformation is a complex process for implementation, more details are required. That is why a business model is derived from the digital business strategy. In the past businesses operated in a relatively stable environment with limited operative possibilities. For business managers, it was possible to derive processes directly from strategy. With increasing digitization the situation becomes more complex. The application of IT-based processes not only expanded the possibilities of doing things, the things themselves also got more complex. [17] That is why new methods, models and tools are needed which help to put the strategy into action. Matt et al. propose the development of a digital transformation strategy. It contains essential decisions on technology, structure, financials and value creation. [7] This approach helps to detail important issues of digital business strategy but is still on an abstract level. With business models, there is an approach that helps enterprises to make strategy more explicit. [17] A business model describes how organizations create value. It contains activities and resources that create customer value and, therefore, lead to revenues. [18] Business models are made for the elaboration of value generation, but they are not suitable for planning the implementatio of processes and services. [17] Thus, another approach is needed to design and implement processes and synchronize IT activities. In information systems research many authors claim the application of EA for implementation of business transformation. [9] The question is if they are also useful for digital transformation.

EA can be comprised as a complete description of an enterprise. It describes the essential business artifacts and their relationship. Therefore, EA contains a set of principles, methods and models that help enterprises to design and realize its organizational structure as well as the fitting business processes, information systems and infrastructure. [19, 20, 21] The central aim of EA is creating transparency by documenting the actual situation. Thus, it aims at giving an enterprise the control over its complexity, processes and information systems. Additional aims are data demand and interface analysis. Secondly, by providing an overview of the essentials of the enterprise, EA helps to control and conserve its most stable parts. As a third task, EA supports enterprises

to transfer strategy to daily processes. The fourth aim for EA is that it can be understood by all involved stakeholders. A fifth aim is that EA supports holistic optimization and identification of simplification. [19, 20]

Besides this very general characterization of EA and its tasks, there are many different definitions and EA frameworks with different scopes and focuses. Important distinguishing features are the supported enterprise layers. There are five possible layers. In the strategic layer, an EA defines for example products, interaction with suppliers and customers. In the organizational layer, the architect elaborates business processes, information flows and roles. The integration layer considers applications, services and interfaces. Whereas the software layer defines data structures and software components, the IT infrastructure layer works out hardware and network components as well as software platforms. Most EA approaches focus on organizational, integration and software layer. First well-known approaches were the Zachman framework and ARIS. Today, TOGAF is the most common framework. [20]

4. Criticism on Enterprise Architectures as an Instrument for Digital Transformation

At first sight, EA could be a great support for digital transformation in SMEs of mechanical engineering. But currently, this approach is not very common in business transformation. In the literature, the development of the application of EA for business transformation is discussed only in a few publications. Especially in SMEs it is unknown and not used. Although there are enterprises which already align strategy and processes, they do not use EA. [6, 22] There are several possible reasons for this situation.

An important aim of EA is to bring people of different fields together and to create solutions that are understood by all of them. Though this is a very important concern in major changes, in practice there is a wide gap between business transformation and EA. Because of their origin in different disciplines, each approach uses different languages, description techniques and tools. Business transformation has a stronger focus on processes. Although EA has the word enterprise in its name it is strongly rooted in IT. Strategy and processes are only considered marginally and with an IT-focus. Thus, the application of EA is mostly limited to IT departments. Publications argue that EA is thus to abstract. That is why there is often a lack of management support. [19, 22]

In SMEs EA frameworks are not understood. TOGAF, for example, creates a complete view of an enterprise. But the approach is also very difficult to implement. It needs an extensive training and certification for use. EA frameworks are extensive and complex and difficult to handle. Although this challenge is widely known there are only a few approaches in literature to cope with this. Even the official TOGAF documentation points out that a reduction of the framework is recommended. But there is no information given which parts should be eliminated for the application in SMEs. Despite this situation, the application of EA in SMEs is barely noticed in research. [6, 20]

Besides these hurdles in business transformation, new challenges arise with digital transformation. Due to digitization, a short time-to-market and the inclusion of customers into the development processes of the fast-changing service systems become highly important. EA, in contrast, follows the traditional waterfall approach of developing detailed and completed architectures and implement them afterwards. In this view, information systems are quite stable. During this process, there is no space for quick adaptions and iterative development. The focus on detailed planning leads to a conflict with newer agile approaches. [8] These approaches base upon an incremental development and a high involvement of customers. This leads to less effort, increased velocity and an excellent customer satisfaction. [23] Additionally to the changes in the development approach also the system boundaries of EA are realigned. With digital transformation, there is a fundamental change in business processes and organizational structures. This entails a strong business orientation and creates a demand for deep integration of digital strategies and business models. Currently, there is a rather neglected integration and a concentration on the integration of applications and infrastructure. Through the use of standardized platforms, these challenges recede into background. At the same time, the borders between market actors get fuzzy or in some aspects even disappear. Digitized products gather customer data and adapt to the context. To cope with this situation IT frameworks need to think in a service-oriented way and unlock the potentials of ecosystems and platforms. Only in this way it is possible to create individual, customer-oriented solutions. Up to now, EA frameworks are not capable of this. [8, 22] EA is used to plan and maintain the current state of stable internal information systems. There are only limited ways for doing things. In the future, there will be a large demand for the agile development of target states. Moreover, the transformation process itself becomes more important, especially when it comes to the development of smart products, processes and services. This all creates new tasks for EA in the life cycles of applications. [20, 22] Table 1 compares the features of EA with the most important challenges of digital transformation.

In summary, EA is a very strong approach for development, maintenance and documentation of information systems. It offers a wide variety of tools and models and has proven its effectiveness in many projects. But while topics like digital transformation are hyped, EA becomes less important. The main objection is that EA is too complex and deeply rooted in IT. That is why this approach is not understood by business and also not by SMEs of mechanical engineering. But especially major change processes need a clear that is understood by all. 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. Through the digital transformation, new hurdles like a stronger customer integration and ecosystems arise. Needed are approaches that look closer at customer needs and offer an iterative development. Therefore, lightweight planning tools with a strong business focus, which can be understood by each stakeholder, have to be developed.

Table 1. Features of enterprise architectures compared to the new challenges of digital transformation.

	Enterprise architecture	Digital transformation
Driver	IT-focus	Business-focus
Target groups	IT-architects, IT-experts	Management, specialized staff, IT-architects, …
Subject	Stable information systems	Fast changing service systems
Development approach	Waterfall approach	Agile approaches
Focused vertical hierarchy levels	Organizational layer, integration layer, software layer, infrastructure layer	Strategic layer business model layer organizational layer integration layer
Value stream	Information systems for stable value chains and customer needs	Ecosystems and context-sensitive value creation
Life cycle phases	Development, maintenance, documentation	Agile development, usage, maintenance documentation

5. Approach for Digital Transformation in Small and Medium-sized Enterprises

The previous analysis shows that EA offers a high potential for the implementation of digital transformation. But concurrently there are also weaknesses in existing approaches. Especially an involvement of business could not be achieved. Moreover, there are new challenges for EA. With the development of the last years, an agile development of business gets more importance. Additionally, the ecosystems and smart products become part of the architecture. In this paper, we present the first steps for a new EA approach for digital transformation in SMEs. As previously analyzed, an approach for realization of digital transformation has to be much more agile and therefore nearer to the customer. That is why agile development methods are the basis of the developed approach.

As shown in figure 3, the approach is divided into a macro and a micro cycle. The macro cycle defines the architecture of the entire SME. In the micro cycle single functions are implemented and tested. Besides the incrementally developed macro and micro cycle there are two quite stable fields which help to conserve the digital strategy of an enterprise. The digital business strategy is the initial point of the approach. It contains basic decisions concerning speed, scale and scope of the digital technology application in the enterprise. As described by Matt et al. it is essential to derive a transformation strategy out of the digital business strategy. Here, technological and organizational principles for the implementation are defined. In contrast to Matt et al., in this approach value creation and financial aspects are not considered as stable enough and are, therefore, defined in the business model.

The first step of the macro cycle is to derive the business model from the digital business strategy. As described earlier, the business model contains information like value proposition, customer segments or revenue streams. The second step is to elaborate an ideal architecture. The aim of this step is to detail the business model in a very rough way. The ideal architecture contains descriptions of the main processes, main IT services and information that is needed for realization. An important feature is that there are no restrictions. The target of the ideal architecture is to give the architect room for new ideas without considering legacy systems or strategic restrictions. Afterwards, the real architecture is derived from the ideal architecture. In this step, the transformation strategy and the current architecture are considered. Since the fundamental change during a digital transformation should be realized incrementally, there are always legacy systems and interfaces that have to be taken into account. Nevertheless, the architect should not continue to use legacy systems at any price. The architecture backlog follows similar ideas as the product backlog in the scrum approach. Based on the differences between current and real architecture, user stories are defined in the architecture backlog. These user stories are capsuled service systems with defined interfaces. A defined set of user stories can run through the micro cycle independently from other user stories. They describe the users, the desired functionality and the benefit. There are no details about used software or hardware. The aim of this is to create free space for the development team. Within the backlog, user stories are prioritized. Moreover, it is defined which user stories are built by the enterprise and which are provided by partners within the ecosystem. Services that are part of the core competence or are not available on the market are developed single-handedly.

After running through the macro cycle the micro cycle can be started for the first time. This cycle begins with choosing the prioritized user stories from the backlog. The amount depends on the speed of change an enterprise aims for. Next step is the built or the service selection phase. During the built phase, the developers implement the user stories in a sprint. But in most cases the selection of services off the shelf is the better choice. Especially when a service is not part of the core competence and is already available on the used platform, an internal development should be avoided. After implementation or purchase, each user story is tested. Testing can be realized either together with a test customer or in a testbed as provided by different organizations (e.g. research institutes, universities …). In Germany, the I4KMU project offers SMEs help when it comes to testing of I4.0-relevant technologies. They are supported to find a fitting test environment. [24] Next step is the review. There are three possible decisions. The first possibility is that the user story is marked as done. Then the teams start with the next user story. The second possibility is that adaptions are required and the micro cycle has to start again. The third possibility is that there are findings that have an impact on the whole architecture. Then the macro cycle starts again. With the first pass of the macro cycle, the architecture is still very rough. With every pass, there are more details. The macro cycle should always give enough space for decisions in the micro cycle.
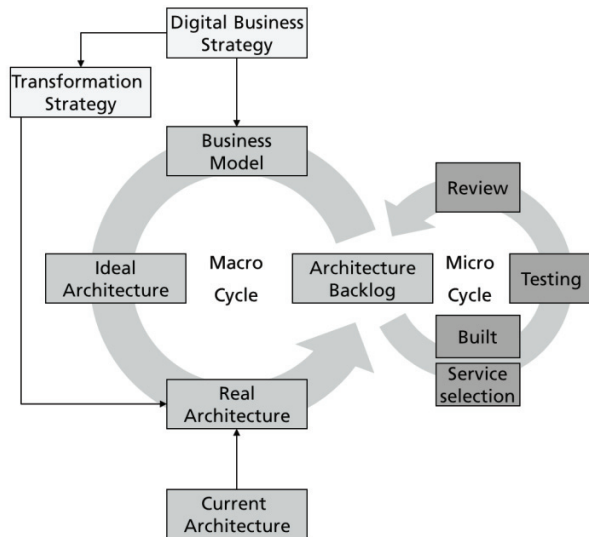
Fig. 3. Agile enterprise architecture for digital transformation.

6. Conclusion and Outlook

In this paper, we analyzed the content of the digital transformation. Furthermore, we took a closer look at possible methods and tools for the implementation of product ideas with a special focus on process implementation. Thereby we found that currently used approaches are not sufficient for SMEs in mechanical engineering. Main challenges are the high complexity of the approaches and the infeasibility for the fast development of new solutions. That is why we presented a new lightweight, agile approach.

Next steps planned for the development of this approach are the detailed definition of the single steps and their integration with each other and with the digital business and digital transformation strategy. Here, one challenge is to identify and test a suitable SME-oriented notation for modeling the business processes, services landscape and ecosystems. Another task is to optimize the cycles and test their comprehensibility in SMEs. It is planned to validate this in several projects with SMEs of mechanical engineering.

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