Multiple Perspectives of Digital Enterprise Architecture

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Abstract: Enterprises are transforming their strategy, culture, processes, and their information systems to enlarge their Digitalization efforts or to approach for digital leadership. The Digital Transformation profoundly disrupts existing enterprises and economies. In current times, a lot of new business opportunities appeared using the potential of the Internet and related digital technologies: The Internet of Things, Services Computing, Cloud Computing, Artificial Intelligence, Big Data with Analytics, Mobile Systems, Collaboration Networks, and Cyber-Physical Systems. Digitization fosters the development of IT environments with many rather small and distributed structures, like the Internet of Things, Microservices, or other micro-granular elements. Architecting micro-granular structures have a substantial impact on architecting digital services and products. The change from a closed-world modeling perspective to more flexible Open World of living software and system architectures defines the context for flexible and evolutionary software approaches, which are essential to enable the Digital Transformation. In this paper, we are revealing multiple perspectives of digital enterprise architecture and decisions to effectively support value and service-oriented software systems for intelligent digital services and products.

1 INTRODUCTION

Data, information, and knowledge are fundamental core concepts of our everyday activities. They are driving the Digital Transformation of today's global society (McAfee, et al., 2017). Influenced by the Digital Transformation, many companies are currently changing their strategy (Bones, et al., 2019), culture, processes and information systems to expand their digital scope of action. New services and intelligent networked digital products extend physical components by adding information, application and connectivity services over the Internet.

Digitization (Schmidt et al., 2016) defines the process of Digital Transformation enabled by important technological megatrends: Internet of Things, Cloud, Edge and Fog Computing, Services Computing, Artificial Intelligence, Big Data, Analytics, Deep Learning, Mobile Systems, and Social Networks. Digitized services and products amplify underlying values and capabilities, which offer exponentially expanding opportunities. Digitization enables human beings and autonomous objects to collaborate beyond their local context by using digital technologies. The exchange of information allows better decisions of humans, as well as promote automatic decisions by intelligent systems.

The integration of many micro-granular systems and services has a substantial impact on architecting digital services and products. Unfortunately, the current state of research and practice of enterprise architecture in the integration of a multitude of microgranular systems and services in the context of the Digital Transformation and evolution of architectures lacks an essential understanding of the diverse modeling perspectives of digital enterprise architecture.

Our goal is to extend previous quite static approaches to enterprise architecture (Lankhorst, 2017) to fit for flexible and adaptive Digitization of new products and services. When architecting digital products and services, having their origin in open micro-granular architectures, we introduce suitable mechanisms for co-creative architectural engineering by combining a value perspective with a service perspective.

Our current research paper is part of on-going research on fundamental digital architecture methods and models. We are investigating the following primary research question:

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How can an enterprise architecture and decision management for digital products support Open World integration across a significant number of microgranular digital systems and services through a holistic value and service perspective?

We will proceed as follows. First, we will set the architectural context for our Digital Transformation approach giving a pervasive view of a value-oriented relationship-mapping from the digital strategy to digital architecture. This digital enterprise architecture defines a core model for service-oriented digital products with a service-dominant logic. Then we present an original digital architecture reference model as an architectural framework, which defines ten integral architectural dimensions of a holistic classification model. Based on the target of digital architecture we are focusing on architecting micro-granular systems and services with the Internet of Things and Microservices, and present an architectural composition model for a bottom-up integration of micro-granular digital products and services into a digital enterprise architecture. Then we provide insides to our methods and mechanisms for architectural decision management for multi-perspective digital architectures. Finally, we conclude our research findings and mention our future work.

2 DIGITAL PRODUCTS

The Digital Transformation is the current dominant type of business transformation having IT both as a technology enabler and as a strategic driver. Digitized services and associated products (Brynjolfsson et al., 2014) are software-intensive (Schmidt et al., 2016) and therefore malleable and usually service-oriented (El-Sheikh, et al., 2016). Digital products can increase their capabilities by accessing Cloud-Services and change their current behavior (Zimmermann, et al., 2018).

Digitization fosters the development of IT systems with many, globally available, and diverse, rather small and distributed structures (Zimmermann, et al., 2018), like the Internet of Things (Uckelmann et al., 2011), (Walker, 2014), (Fremantle, 2015) or Microservices (Newman, 2015). A lot of software developing enterprises have switched to integrate Microservice architectures to handle the increased velocity (Balakrushnan et al., 2016). Therefore, applications built this way consist of several fine-grained services that are independently scalable and deployable.

In the beginning, Digitalization was considered a primarily technical term (Weill et al., 2015). Thus, many technologies are preconditions of Digitalization (McAfee, et al., 2017): Cloud Computing, Big Data often combined with advanced Analytics, Social Software, and the Internet of Things (Patel, et al., 2015). New technologies like Artificial Intelligence (Poole, et al., 2018) with Deep Learning (Goodfellow, et al., 2016) supports our Digitalization efforts. They allow intelligently automated activities that are traditionally exclusive to human beings.

Digitized products and services (Schmidt et al., 2016) support the co-creation of value together with the customer and other stakeholders in different ways. First, there is permanent feedback to the provider of the product. The internet connection of the digitized product allows collecting data permanently on the usage of the product by the customer. Second, the data provided by a large number of digital products can offer new insights, which are not possible with data from a single device. Current research argues that digital products and services are offering disruptive opportunities (McQuivey, 2013) for new business solutions, having new smart connected functionalities.

The business and technological impact of Digitization (Schmidt et al., 2016) has multiple aspects, which directly affect digital architectures of service-dominant digital products. Unfortunately, current modeling approach for designing proper digital service and product models suffers from using uncorrelated and diverse modeling approaches and structures, with issues in integral value-orientation of necessary composed services and systems.

High-quality digital models should follow a definite value and service perspective. However, today, we currently have no sound value relationship from digital strategies to the resulting digital business modeling, and subsequently to a value-oriented enterprise architecture, which today often has seldom properly aligned service and product model representations. The present contribution shows a newly introduced integral value-oriented model composition approach by linking digital strategies with digital business models for digital services and close aligned products through an extended multi-perspective digital enterprise architecture model.

Value is commonly associated with the worth of a digital service or product (Osterwalder et al., 2010), (Vargo et al., 2017) and aggregates potentially required attributes for a successful customer experience, such as meaning, desirability and usefulness. The concept of value is essential in designing adequate digital services with their associated digital products, and to align their digital business models with value-oriented enterprise architectures. From a financial perspective, the value of the integrated resources and the price defines the main parts of the monetary worth.

A current conceptualization of value as a service-based view is offered by (Vargo et al., 2017) and (Meertens et al., 2012) considering a conceptual framework of service-dominant (S-D) logic (Vargo et al., 2008), (Vargo et al., 2016) and its service-ecosystem perspective. The distinction between the concepts of value-in-use and value-in-exchange dates back to the antiquity and continue to influence our today's value view. Since the work of Adam Smith and the development of economic science the value-in-exchange as a measure for a price a person is willing to pay for a service or a product moved to the forefront. Smith recognized the value-in-use as the real value and value-in-exchange as the nominal value. The digital marketing discipline nowadays shifted to a simple use of the value perspective (Vargo et al., 2017) considering customer experience and customer satisfaction as critical value-related concepts.

Characteristics of value modeling for a service ecosystem were elaborated by (Vargo et al., 2017). Value has important characteristics: value is phenomenological, co-created, multidimensional, and emergent. Value is phenomenological means that value is perceived experimentally and differently by various stakeholders in the changing context within a service ecosystem. Value is co-created through the integration and exchange of resources between multiple stakeholders and related organizations. Value is also multidimensional, which means that value is aggregated up of individual, social, technological and cultural components. Value results as the new value from specific manifestations of relationships between resources and resource combinations. Therefore, the resulting real value cannot be determined ex-ante. Value propositions are value promises for a typical, but not precisely known customer at design time and should be realized later when using these digital services and associated products.

Our current paper sketches our view of an integrated value perspective combined with a service perspective, as in Figure 1. Today, we are experiencing a starting set of first digital strategy frameworks, like in (Bones et al., 2019), in loosely association with traditional strategy frameworks.

Our starting point is a model of the digital strategy, which provides direction and sets the base and a value-oriented framing for the digital business definition models, with the business model canvas (Osterwalder et al., 2010), and the value proposition canvas (Osterwalder et al., 2014). Having the base models for a value-oriented digital business, we map these base service and product models to a digital business operating model. An operating model (Ross, et al., 2006) strategically defines the necessary level of business process integration and standardization for delivering services and products to customers.

From the value perspective of the business model canvas (Osterwalder et al., 2010) results in suitable mappings to enterprise architecture value models (Meertens et al., 2012) with ArchiMate (Open Group, 2016). Finally, we are setting the frame for the precise definition of digital services and associated products by modeling digital services and product compositions, following semantically related composite patterns (Gamma et al., 1995).

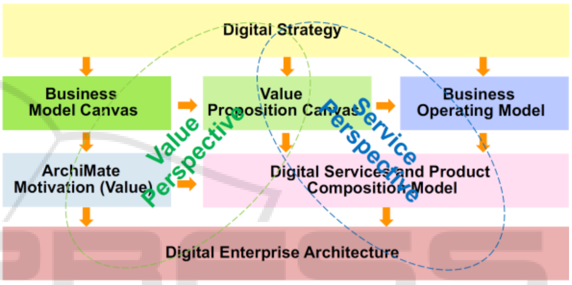

Figure 1: Integrating Value and Service Perspectives.

Our thesis is that Digitization embraces both a product and a value-creation perspective. Classical industrial products are static. We can only change them to a limited extent, if at all. On the contrary, digitized products are dynamic. They contain both hardware, software and (Cloud-)services. Digital products are upgradeable via network connections. Also, their functionality can be extended or adapted using external services. Therefore, the feature of digital products is dynamic and adjustable to changing requirements and hitherto unknown customer needs. In particular, it is possible to create digitized products and services step-by-step or provide temporarily unlockable functionalities. So, customers whose requirements are changing can add and modify service functionality without hardware modification.

3 DIGITAL ARCHITECTURE

Digitalization promotes massively distributed systems, which are IT systems with many rather small and distributed structures, like the Internet of Things or Microservices. Additionally, we have to support Digitalization by a dense and diverse amount of different service types, like Microservices, REST services, and put them in a close relationship with distributed systems and the Internet of Things. The change from a Closed-World modeling perspective to more flexible Open World composition and evolution of system architectures (Zimmermann et al., 2018) defines the changing context for adaptable systems, which are essential to enable the Digital Transformation. Digitalization has a substantial impact on architecting digital services and products. The implication of architecting micro-granular systems and services considering an Open World approach fundamentally changes modeling contexts, which are classical and well defined by quite static closed-world and all-times consistent and less sophisticated models.

Digital Transformation, Digitization (Schmidt et al., 2016) and digital disruption (McQuivey, 2013) create many events that may impact enterprises and organizations. Resilient enterprise architecture management plays an essential role in fostering strategies and capabilities for resiliency by providing methods and tools for designing enterprises architectures which are flexible for change. It may address enterprises but also selected parts of enterprise architecture such as services and processes. Resilient Services are services that provide additional meta-services in addition to their core functionality to cope with disruptive events. E.g., airlines reschedule passengers of delayed flights. Resilient Processes provide event handlers to deal with external events and are thus capable of leading back the control flow on the desired track even in the case of adverse events. Their decision points use data from a multitude of internal and external sources allowing them to detect and react to changes in the environment.

Resiliency is the capability of enterprises and their information systems (Betts et al., 2013) to cope with fast and real-time changing events. Resiliency is the ability of an IT system to provide, maintain and improve disturbed services even when changes occur. Resiliency is a challenging capability which combines a multitude of different perspectives on different abstraction levels such as organizational resiliency, information system resiliency, cyber resiliency, network and technology resiliency, as well as organizational resiliency.

Resiliency (Romanovsky et al., 2017) refers to an entity's ability to deliver the intended outcome despite adverse cyber events continuously. This ability includes response and recovery and developing resilient-by-design systems. Resiliency requires constructive and organizational approaches with a strong focus on a managed environment for enterprise architectures of information systems and services.

Enterprise Architecture (EA) (Lankhorst, 2017) is since years a well-motivated discipline of enterprise and IT governance. Since more than one decade Enterprise Architecture is a discipline with a scientific background and useful decision supporting functions and models for forward-thinking enterprises and organizations. Enterprise Architecture aims to model, align and understand significant interactions between business and IT to set a prerequisite for a well-adjusted and strategically oriented decision-making framework for both digital business and digital technologies.

Enterprise Architecture Management (Lankhorst, 2017), as today defined by several standards like (Open Group, 2018) and (Open Group, 2016) uses a quite large set of different views and perspectives for managing current IT. An effective architecture management approach for digital enterprises should additionally support the Digitization of products and services and be both holistic and easily adaptable (Zimmermann et al., 2018). Furthermore, a digital architecture sets the base for Digital Transformation driving new digital business models and technologies with a large number of micro-structured Digitization systems having their local micro-granular architectures like IoT (Patel et al., 2015), mobile devices, or with Microservices (Newman, 2015).

A Digital Enterprise Architecture (DEA) extends the research base in (Zimmermann et al., 2018) and provides today in our current research ten integral architectural domains for a holistic classification model (Figure 2).

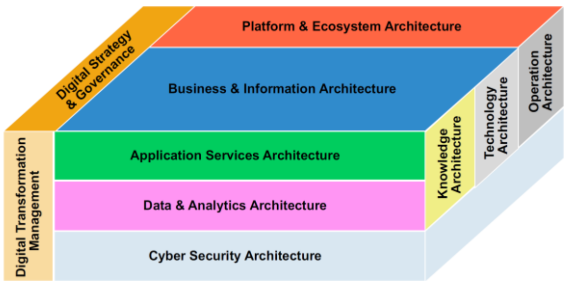

Figure 2: Digital Enterprise Architecture Reference Cube.

DEA covers also micro-granular architectures for different digital services and products. DEA abstracts from a concrete business scenario or technologies, because it is applicable for concrete architectural instantiations to support Digital

Transformation (Brynjolfsson et al., 2014), (Schmidt et al., 2016) independent of different domains.

DEA supports by a holistic view metamodel-based extraction and bottom-up integration methods and techniques by integrating micro-granular viewpoints, models, standards, frameworks and tools into a consistent digital enterprise architecture model. DEA frames these multiple elements of a digital architecture into basic configurations of a digital architecture by providing an ordered base of architectural artifacts for associated multi-perspective decision processes.

Architecture governance, as in (Weill et al., 2004), defines the base for well-aligned management practices through specifying management activities: plan, define, enable, measure, and control. Digital governance (McAfee et al., 2017) should additionally set the frame for digital strategies, digital innovation management, and Design Thinking methodologies. The second aim of governance is to set rules for value-oriented architectural compliance based on internal and external standards, as well as regulations and laws. Architecture governance for Digital Transformation changes some of the fundamental laws of traditional governance models to be able to manage and openly integrate plenty of diverse micro-granular structures, like the Internet of Things or Microservices.

4 MODELING ARCHITECTURAL COMPOSITIONS

Digitalization promotes massively distributed systems, which many rather small and distributed structures, like the Internet of Things, mobile systems, cyber-physical systems. Additionally, we are enabling Digitalization by a dense and diverse amount of different service types, as Microservices, REST services and put them in a close relationship with distributed systems, like the Internet of Things. Furthermore, the Internet of Things is an essential foundation of Industry 4.0 (Schmidt et al., 2015) and flexible digital enterprise architectures. The change from a closed-world modeling perspective to more flexible Open World composition and evolution of system architectures defines the changing context for adaptable systems, which are essential to enable the Digital Transformation. The implication of architecting micro-granular systems and services considering an Open World approach fundamentally changes modeling contexts, which are classical and well defined by quite static closed-world and all-times consistent and less sophisticated models.

Adaptability for architecting open micro-granular systems like the Internet of Things or Microservices is mostly concerned with heterogeneity, distribution, and volatility. It is a considerable challenge to continuously integrate numerous dynamically growing open architectural models and metamodels from different sources into a consistent digital architecture. To address this problem, we are currently formalizing small-decentralized mini-metamodels, models, and data of architectural microstructures, like Microservices and IoT into DEA-Mini-Models (Digital Enterprise Architecture Mini Model).

In general, such DEA-Mini-Models (Bogner et al., 2016) consists of partial DEA-Data, partial DEA-Models, and partial EA-Metamodel. Microservices are associated with DEA-Mini-Models and objects from the Internet of Things (Zimmermann et al., 2015). The structures of EA-Mini-Descriptions (Figure 3) are extensions of the Meta Object Facility standard (OMG, 2011), Object Management Group.

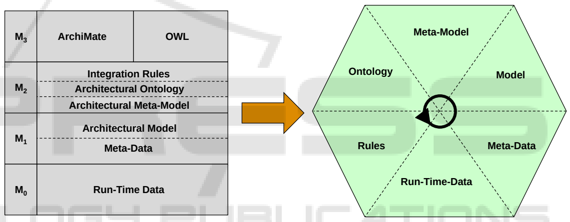

Figure 3: EA-Mini-Description.

We have extended the base model layer M1 to be able to host metadata additionally. Additionally, we have associated the original metamodel from layer M2 with our architectural ontology with integration rules. In this way, we provide a close associated semantic-oriented representation of the metamodel to be able to support automatic inferences for detecting model similarities, like model matches and model mappings during runtime.

Regarding the structure of EA-Mini-Descriptions, the highest layer M3 (Bogner et al., 2016) represents an abstract language concept used in the lower M2 layer. M3 is the meta-meta-model layer. The following layer M2 is the metamodel integration layer. The layer defines the language entities for M1, e.g., models from UML or ArchiMate (Open Group, 2016). These models are a structured representation of the lowest layer M0 (OMG, 2011).

Volatile technologies, requirements, and markets typically drive the evolution of business and IT services. Adaptation is a crucial success factor for the survival of digital enterprise architectures (Zimmermann et al., 2015), platforms, and application environments. The evidence from (Weill et al., 2015) introduces the idea of digital *ecosystems*. Ecosystems links with main strategic drivers for system development and system evolution. Reacting rapidly to new technology and market contexts improve the fitness of such adaptive ecosystems.

During the integration of DEA-Mini-Models as micro-granular architectural cells (Figure 4) for each relevant object, e.g., Internet of Things object or Microservice, the step-wise composed time-stamp dependent architectural metamodel becomes adaptable (Bogner et al., 2016) and (Zimmermann et al., 2015).

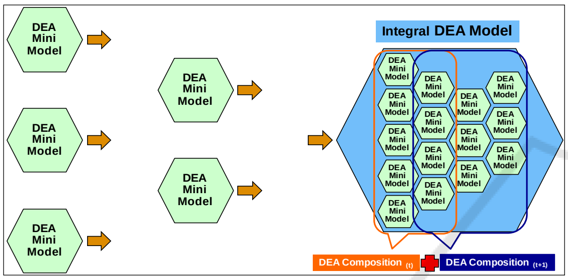

Figure 4: Architecture Composition.

Being a bit closer to the architecture and design of systems, (Trojer et al., 2015) coined the Living Models paradigm that is concerned with the model based creation and management of dynamically evolving systems. Adaptive Object Modelling and its patterns and usage provide useful techniques to react to changing user requirements, even during the runtime of a system. Moreover, we have to consider model conflict resolution approaches to support electronic documentation of digital architectures and to summarize integration foundations for federated architectural model management.

In the case of new integration patterns, we have to consider additional manual support. Currently, the challenge of our research is to federate these DEA-Mini-Models to an integral and dynamically growing DEA model and information base by promoting a mixed automatic as well as a collaborative decision process.

We are currently extending model federation and transformation approaches (Trojer et al., 2015) by introducing semantic-supported architectural representations, from partial and federated ontologies and associate mapping rules with unique inference mechanisms.

Fast changing technologies and markets usually drive the evolution of ecosystems. Therefore, we have extracted the idea of digital ecosystems from (Tiwana, 2013) and linked this with main strategic drivers for system development and their evolution. Adaptation drives the survival of digital architectures, platforms, and application ecosystems.

5 DECISION MANAGEMENT

Our current research links decision objects and processes to multi-perspective architectural models and data. We are extending the more fundamentally approach of decision dashboards for Enterprise Architecture (Lankhorst, 2017), (Zimmermann et al., 2018) and integrate this idea with an original Architecture Management Cockpit (Figure 5) (Jugel et al., 2014), (Jugel et al., 2015) for the context of decision-oriented digital architecture management for a vast amount of micro-granular architectural models from the Open World.

Figure 5: Architecture Management Cockpit (Jugel et al., 2014).

The Architecture Management Cockpit enables analytics as well as optimizations using different multi-perspective interrelated viewpoints on the system under consideration (Jugel, 2018). Multiple perspectives of architectural models and data result from a magnitude of architectural objects, linking dimension categories of digital enterprise architecture. Additionally, we have to consider analytics and decision viewpoints for the structural core information of enterprise architecture.

The ISO Standard 42010 (Emery et al., 2009) defines, how the architecture of a system relies on architecture descriptions. Jugel (Jugel et al., 2015) has developed a unique annotation mechanism adding additional needed knowledge via an architectural model to an architecture description. The fundamental work of (Jugel et al., 2014) reveals a viewpoint concept by dividing it into an Atomic Viewpoint and a Viewpoint Composition.

Therefore, coherent viewpoints can be applied simultaneously in an architecture cockpit to support stakeholders in decision-making (Jugel et al., 2015). Figure 5 gives an overview of the decision metamodel, as our extension of (Plataniotis et al., 2014), showing the conceptual model of main decisional objects and their relationships.

According the architecture management cockpit (Jugel et al., 2014), each possible stakeholder can utilize a viewpoint that shows the relevant information. These viewpoints are connected in a dynamically way to each other so that the impact of a change performed in one view can be visualized in different views as well. Following (Jugel et al., 2015) and (Jugel, 2008), we have integrated the concept of *Decision Process*, as a logical sequence of activities to solve one or more identified architectural decision, see also (Plataniotis et al., 2014), problems (Figure 6).

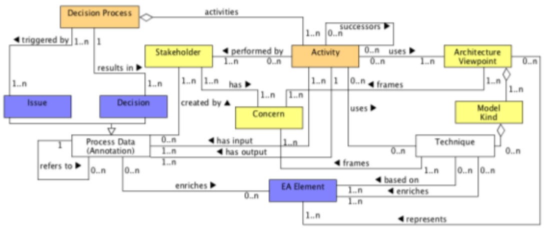

Figure 6: Architecture Decision Metamodel.

The concept *Activity* represents individual activities of process activities. Since these process activities performed with human participation, at least one *Stakeholder* connects to an *Activity*, who executes the respective action. The *Stakeholder* concept results from ISO Standard 42010 (Emery et al., 2009).

Architecture Viewpoints are used to visually represent parts of the enterprise architecture in a stakeholder-oriented way, while *Techniques* contain detailed recommendations of actions or algorithms for automated execution of specific tasks.

6 CONCLUSION

First, we have set the context for Digital Transformation for our research question. We integrate first two important base perspectives, the value perspective, and the service perspective, for a holistic architectural design of digital products, following fundamental premises of the service-dominant logic.

The main results of our current paper affect a new defined digital enterprise reference architecture by setting a flexible framework with ten structural domains providing additional integral perspectives for Digitalization. To be able to support the dynamics of Digitalization with resilient systems and service compositions we have leveraged an adaptive digital enterprise architecture for Open World integrations of globally accessed micro-granular systems and services, like the Internet of Things and Microservices, with their local architectural models.

We have also included methods and mechanisms for decision management of digital enterprise architecture with related intelligent systems and digital services. Furthermore, we have demonstrated and mention the feasibility of our research and the enterprise architecture cockpit through projects and validations with partners from science and practice.

Some limitations still exist in our work. There is a need to extend analytics-based decisions support with mechanisms from AI explanation mechanisms and context-data driven architectural decision-making. Limitations are, while integrating Internet of Things architecture in the field of multi-level evaluations of our approach, as well as in domain-specific adoptions.

Future research addresses mechanisms for flexible and adaptable integration of digital enterprise architectures. Similarly, it may be of interest to extend human-controlled interaction and visualizations by integrating automated decision making by AI-based systems like ontologies with semantic integration rules, and structural data and model analytics with Deep Learning mechanisms as well as mathematical comparisons (similarity, Euclidean distance) and Data Science methods.

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